Food Sec. (2010) 2:215–231
DOI 10.1007/s12571-010-0072-5

ORIGINAL PAPER

The importance of plant health to food security

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Received: 29 June 2010 / Accepted: 2 July 2010 / Published online: 22 July 2010

Abstract Rapid food price rises have highlighted serious concerns about food security globally and have had a huge impact on achieving Millennium Development Goal 1. Since 2007, an estimated 100 million more people have fallen into absolute poverty. Most live in developing countries where low incomes (less than $1 per day) make it difficult to access food. Access to sufficient food for dietary needs and food preferences defines food security. However, whilst price rises have brought food security into sharp focus, underlying problems need to be addressed. Over the last three to four decades, there has been chronic under-investment in agriculture at all levels. Development aid to agriculture has declined and often in-country policies do not support the sector. Low crop yields are common in many developing countries and improved productivity is vital to reducing rural poverty and increasing food security. Whilst the causes of low productivity are complex, one major contributory factor is crop losses due to plant health problems. Often accurate information on the extent of these losses is missing but estimates of 30–40% loss annually from "field to fork" are common. Any future solution regarding improved global food security must address these losses and that means improving plant health. Two trans-boundary diseases, wheat stem rust race Ug99 and Coffee Wilt Disease of *Coffea* are highlighted. CABI has a number of plant health initiatives and one radical approach (Global Plant Clinic) involves partnership with in-country services to deliver plant health advice to farmers at the point of demand. Such innovations are entirely consistent with a proposed new "Green Revolution" which would need to be "knowledge intensive".

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Keywords Millennium Development Goal · Food security · Plant health · Crop productivity · Ug99 · Coffee Wilt Disease · Global Plant Clinic · COPE

Introduction

The doubling of cereal and livestock production in the last half of the 20th century should have resulted in a global food supply that was adequate for all and yet currently nearly a billion people are hungry i.e. they do not have access to food (FAO 2008a, b). It is access to food—not just physical food production but guaranteed sufficient income to procure food to meet the needs of rural and urban households that is emphasised in the FAO definition of food security as derived from the World Food summits in 1996 and 2002. FAO's definition states

> Food security exists when all people at all times have access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life.

Paradoxically, it is often producers of food, notably smallholders, that are most at risk from food insecurity! Even in good years (2000–2001) fewer than 25% of Malawi farmers achieved self sufficiency in maize (Devereux 2009). Access to food can be obtained by production, by exchange (trade or barter) or by transfers such as food aid (Sen 1981). Adequacy of food supply and stability of supply (without shortages) as well as food safety and quality are also key tenets of food security. Often for the rural poor, guaranteed sufficient income means production of both staple crops for their own subsistence and for sale when there is a surplus but also many will grow cash crops for selling either in local, regional or international markets.

Increasing their income by production, diversification or value addition will not only allow them to meet their basic needs but will also make them less vulnerable to harvest failures and shortages of staple crops. In many cases, the extra income earned from cash crops will improve their living standards by allowing them access to education and health facilities.

However, having access to enough income to obtain sufficient food is often very difficult when incomes can be very low (below $1 per day) as occurs in many developing countries. With an estimated 1 billion people currently going hungry and a projected 9 billion total population by the middle of this century, feeding the world is a challenge; a challenge that will require the application of the current best scientific techniques as well as the development of new and innovative approaches. Certainly "business as usual" where we over-produce and waste much in the developed world while others go hungry is not acceptable and this is set against a background of projected declining oil reserves and the threat of climatic change. A warming of 0.2°C is projected for the next two decades and a rise of 0.6–4.0°C by the end of the century (IPCC 2007a). The long term effects on productivity are complicated. Increased yields are likely in higher latitudes (initially) while projections for some developing countries suggest lower yields (Cline 2007) and yet it is in some of these developing countries that productivity needs to be raised to feed both their current populations and any projected increases. Even without the complication of climatic change, raising productivity within many developing countries, notably in Sub Saharan Africa, is a critical concern and how to do this has inspired debate and argument and will continue to do so. Low crop yields are common in many developing countries and improved productivity is vital to reducing rural poverty and increasing food security. The causes of low productivity are complex but for the purposes of this paper I would like to raise the often neglected issue of the importance of plant health in productivity and hence in food security.

One major aspect of plant health concerns crop losses due to pest (*sensu lato*) constraints. Estimates of losses of 30–40% of crop production annually are common in the scientific literature. Any future solution regarding improved global food security must address these losses and that means improving plant health. We must lose less of what we are currently producing. Yet crop losses remain poorly recognised as an important driver in matters of food security and often plant health issues receive little attention; considerably more concern and attention is given to human and animal health. Nevertheless, plant diseases have had enormous impact on livelihoods throughout human history.

The Irish Potato Famine has many modern parallels and is an excellent example of the effect of a plant disease on food security and changing demographics (see later). There are several current examples too. One example of a plant disease that could have severe impacts on global food production, livelihoods and changes in demographics in the 21st century is Ug99, a virulent strain of black stem rust *(Puccinia graminis tritici)* that has spread from Africa into the Middle East and is threatening the wheat fields of South Asia and the high yielding wheat varieties developed under the Green Revolution. Another example, of such a trans-boundary pest is a disease of an important African cash crop—coffee. Coffee Wilt Disease, caused by the fungus *Fusarium xylarioides*, has already severely affected producer livelihoods in Central and Eastern Africa, has cost an estimated $1 billion (Flood 2009) and continues to spread. Yet few people outside affected countries (even adjacent countries) have heard of it.

What links 19th century Ireland with modern Sub–Saharan Africa or other developing countries is poverty. The challenge of reducing global poverty and hunger in the 21st century is the call to deliver on targets that we set ourselves at the start of the new Millennium—the Millennium Development Goals (MDGs).

Progress and challenges to delivering the Millennium Development Goals (MDGs)

Ten years ago, in 2000, we, the international community, committed ourselves to eight Millennium Development Goals (MDGs) to be met by 2015. The MDGs were adopted by 190 countries as a framework for development activities. The MDGs are not only development goals, they encompass fundamental human values concerning freedom from hunger, the right to have access to basic education and healthcare. Much progress has been made. The Millennium Development Report for 2008 summarised this progress at the mid-point (7 years after the initial commitment) and was able to report some significant achievements. It cited improvements in basic education with at least 90% primary school enrolment in all but two regions; improvements in human health (deaths from measles fell from over 750,000 in 2000 to less then 250,000 in 2006 and 80% of children in developing countries now receive a vaccine). The number of deaths from AIDS fell from 2.2 million in 2005 to 2.0 million in 2007, and the number of people newly infected declined from 3.0 million in 2001 to 2.7 million in 2007. Some 1.6 billion people have gained access to safe drinking water since 1990. However, the report was not complacent, despite such progress; much more is needed to be done to achieve the original targets. More than 500,000 prospective mothers in developing countries die annually in childbirth or of complications during pregnancy. Of the 113 countries that failed to achieve gender parity in both primary and secondary school enrolment by the target date of 2005, only 18 are likely to achieve the goal by 2015.

One key area for concern highlighted in the report was achieving MDG1 which calls for *the eradication of extreme hunger and poverty and a 50% reduction in poverty and hunger by 2015*. Extreme poverty was defined as living on less than $1 per day. The MDG Report (2008) stated that whilst the downward trend in poverty globally had continued through 2007 and the stated goal of a 50% reduction of people in the developing world living on less than $1 a day remained within reach, much of this achievement would be due to extraordinary economic success in most of Asia. Little progress was being made in reducing extreme poverty in Sub-Saharan Africa and, in fact, a rise in the number of people living on less then $1 per day was projected. The report concluded that one reason for this was food prices which had been rising steadily since 2002 but had risen steeply from 2007 (Lustig 2009). The MDG Report (2008) warned that the steep increases in food prices would have direct and adverse effect on the poor with an estimated further 100 million people falling into absolute poverty. Essentially, any progress in reducing the numbers of hungry people in the world and improving food security was being eroded by the worldwide increase in food prices.

Similarly, the FAO estimated the number of hungry people at 923 million in 2007, an increase of more than 80 million since 1990–1992 (FAO 2008a, b). On average, world prices for rice, wheat and maize increased by 50%, 49% and 43% respectively but in some countries the price rises were much greater. In Thailand, estimates suggest that a cumulative change of ca. 140% from April 2007 to April 2008 occurred (FAO 2008a). Stocks of basic foodstuffs were reported to be depleted in many countries and food riots occurred. FAO (2008a) concluded that high food prices had had a particularly devastating effect on the poorest in both urban and rural areas, among the landless and in female-headed households. Therefore, in order to reduce the number of hungry people by 500 million in the next 5 years, a concerted global effort with concrete actions will be needed. For the first time since the FAO started monitoring trends in under-nourishment, the number of chronically hungry people was higher in the most recent period relative to the base period (FAO 2008a).

The MDG Report (2009) continued to report problems with achieving targets, particularly for MDG1, stating that although only limited data were available to reveal the full impact of the recent economic downturn, the data pointed to areas where progress towards the eight goals has slowed or reversed. Major advances, made from 1990 to 2005, in the eradication of extreme poverty were stalled. During that period the number of people living on less than $1 a day had decreased from 1.8 billion to 1.4 billion but in 2009, an estimated 55 million to 90 million more people were living in extreme poverty than anticipated before the financial crisis. The UK All Party Parliamentary Group Report (APPG 2010) has continued to report that we are unlikely to reach our targets by 2015, two of the reasons being declining incomes of the poorest and increasing food prices. One billion people in the developing world spend over 70% of their income on food compared to just 15% of the average budget in the UK (APPG 2010). Any increase in grain prices and other food prices therefore has a disproportionate effect on the poor.

Consequently, major barriers remain in achieving the MDG1 target for 2015, and poverty and hunger remain a global challenge especially in the light of continuing population growth. One of the key questions for food security is that the challenge of agricultural productivity in developing countries, especially in Sub-Saharan Africa (SSA) and in parts of South Asia. Nevertheless it is worth remembering that food production has tripled in 40 years. Without agricultural research, including crop protection technologies which have increased food production and generated employment income over the past 40 years, poverty would have been far worse (Lenné 2000). For example, in India, government investment in agricultural research in the1970s, plus efforts by producers to raise yields, resulted in a decline in poverty between 1973 and 1993 from 55% to 33%. However, following such investment in agriculture, there have been several decades of chronic underinvestment at all levels (Ejeta 2009). Surprisingly, spending on agriculture is actually lowest in agriculturally based countries while their share of agriculture in GDP is the highest (World Bank 2008). Aid to agriculture actually decreased by 58% in real terms between 1980 and 2005 even though total development assistance increased significantly. The share of Overseas Development Aid (ODA) to agriculture fell from 17% in 1980 to 4% in 2006. In addition, in-country support to agriculture has declined with national governments investing in manufacturing and other sources of revenue (Bentley et al. 2009) rather than in the agricultural sector.

The food security crisis has now reawakened national governments and international decision makers to the fact that agriculture needs support (APPG 2010). The lack of investment in agriculture over the past 3 to 4 decades needs to be reversed and it is this lack of investment that has significantly contributed to concerns about food security. Inevitably, support to agriculture in each country including the livelihoods of the workers who depend on that sector is the responsibility of the country concerned. Policies should reflect this, and should be seen in the larger context of improving market access for producers in developing countries as part of a freer and fairer trade system but further innovations in agricultural research are now needed to rise to the challenges of the new Millennium and one of these challenges is raising productivity.

Increased crop productivity is essential for long term food security

It is the interaction between continuing chronic low productivity, lack of support to agriculture since the 1980s, and the frequent and unpredictable production problems such as erratic climatic events, that expose agriculturally-dependent rural families in developing countries to recurrent livelihood and food security crises. Climate change is likely to make the situation even worse with changing or reduced precipitation likely to result in lower production and unpredictable harvests. The extent of this change in any given region and over any given time period and the impact on the world's agriculture is perhaps only starting to be realised.

Past increases in agricultural production have occurred as a result of both extensification (altering natural ecosystems to grow food) and intensification (producing more food per unit area on land already used for agriculture) see Gregory and Ingram (2000). Krattiger (1998) cited in Lenné (2000) indicated that without improved agricultural technologies (intensification) another 350 million ha would have had to be cropped to produce enough food globally (an area the size of India). In China alone, cultivated cereal area would have had to be increased threefold so farming would have expanded to the extent that many natural ecosystems would have been destroyed. In the future, further suitable land for agriculture may be limited so we will need to increase productivity even further, particularly in Sub-Saharan Africa and some parts of Asia where population growth is predicted to be higher. Currently, yields in these regions lag behind those in many developed countries. However, the large gaps between current yields and what can be economically achieved with better support services, especially in high-potential areas, provide optimism that rapid growth in productivity can be achieved. Closing the "yield gap" and sustainable intensification of agriculture is discussed further in Godfray et al. (2010).

Many complex factors impact on productivity at the farm level and are often interlinked. They include such factors as low soil fertility, lack of fertilizers, soil degradation, drought, insufficient knowledge of water management, lack of knowledge of good agricultural practice, lack of infrastructure, poor credit access for producers, and lack of access to improved crop varieties and better seeds. Not least of these factors is water availability and there are increasing concerns on the overuse of irrigation due to poor understanding of water management. The APPG (2010) highlighted that scarcity of fresh water will be an increasing barrier to achieving global food security and raised concerns about the unsustainable use of water; for example, whilst the Green Revolution doubled crop production, this was accompanied by a trebling of water consumption. The "triply Green Revolution" which is defined as green for production increase, green for being based on "green water" (rainfed) and green as being environmentally sound (Falkenmark et al. 2009) might offer a way forward in this respect. The use of improved germplasm will also play a role in raising productivity, not least as germplasm with improved pest and disease resistance will be a significant factor in reducing losses.

Pre- and post-harvest crop losses

Given the seriousness of the impact from pest and disease constraints and their effect on productivity, one would imagine that information on crop losses is readily available but actually, information on losses is often scarce. "No one knows exactly how much food is lost on farms due to diseases and pests, whether measured in thousands of tons, or billions of dollars" (Pinstrup-Anderson 2000). Much of our information on losses is derived from estimates or projections based on limited data that has not been systematically collected. Such estimates should be treated with caution, but do allow a perspective on the sort of losses being faced. Oerke et al. (1994) reported crop losses ranging from 25 to over 50% depending on the crop. They estimated pre-harvest losses due to pests to be 42% of the potential value of the output; 15% loss was considered to be due to insects whilst weeds and pathogens accounted for 13% loss each. A further 10% loss was estimated at post-harvest. Strange and Scott (2005) estimated that ca.10% of the world's harvest is lost to disease alone, while Bentley et al. (2009) estimated the world could be losing as much as a third of the potential harvest to plant health problems. Some information is available for specific crops. For example, 30–40% of potential global production of cocoa is reportedly lost annually to a few diseases and pests, but very little actual quantitative data exist. Locally, the impact of pests and diseases of cocoa can be even more severe with producers losing their entire crop and hence, their income (Flood and Murphy 2004). Similarly, little information exists on post-harvest losses. This is due partly to losses varying greatly between crops and by country and climatic region, and to the absence of a universally applied method for measuring losses (Mazaud 1997). Estimates are controversial and range from 10 to 40% (FAO 1997). More recently, annual losses of ca 9% in barley, 11% in rice and 19% in maize have been estimated (Source: Post-harvest Losses Information System 2008). Post harvest contamination by fungi is particularly concerning given the production of toxins which can remain in food even when the micro-organism responsible has been killed. Overall, if we consider pre-harvest and post-harvest losses, then an estimated 25–55% (average 30%) of all available food is wasted "from field to fork" (Smil 2000).

Oerke and Dehne (2004) analysed production data from 1996 to 1998 for eight crops, namely wheat, maize, rice, cotton soybean, barley, potatoes and sugar beet. The data for area harvested, yields per unit area and total production were based on FAO data from 17 regions of the world. Two loss rates were differentiated, namely loss potential from pests (*sensu lato*) without any management and actual losses occurring despite management practices designed to prevent them. Oerke and Dehne (2004) reported overall loss potential in wheat production due to plant health problems as 50% and actual losses as 29% despite management practices. For soybean, they estimated that 51% of attainable production is endangered by insects, pathogens, viruses and weeds, and that 50% of maize production would be lost if it were not for crop protection interventions. For cotton, it was reported that there was an 82% total loss potential and percentage of cotton production protected by crop protection practices varied from 37% in Central Africa to 65% in Australia where cotton is intensively grown. These are enormous losses even with the use of crop protection practices.

In 2006, Oerke undertook a further analysis of losses in 6 major crops (wheat, maize, cotton, soybean, potato and rice) from 2001 to 2003 as he considered that production systems had changed significantly since the mid 1990s especially with the advent of transgenic varieties. However, despite advances in breeding and improved crop protection practices, Oerke (2006) reported actual losses of 29% in wheat (with variations in regions from 14 to 40%), 40% losses in potatoes (with variation between regions of 24 to 59%) and 29% actual losses in cotton (with variations between regions of 12 to 48%). Oerke (2006) also noted that in tropical and sub-tropical areas, conditions conducive to disease e.g. high temperature and high rainfall were often associated with higher losses. In terms of food security, these are precisely the areas that will require better productivity.

Oerke (2006) concluded that crop loses to weeds, insects, pathogens and viruses continue to reduce available production of food and cash crops worldwide and again emphasised that quantitative data on crop losses is very limited. The generation of experimental data is time consuming and laborious; losses vary from growth season to growth season due to variations in incidence and severity of disease; and estimates of loss are fraught with problems. However, one comprehensive set of field data (from 1998 to 2008) comes from the State of Georgia in the US via the University of Georgia, Extension Service (Fig. 1).

Some of these crops (cotton, wheat, maize and soybean) are similar to those analysed by Oerke and Dehne (2004). Crop losses are presented by the Extension Service as a percentage reduction in crop value due to a range of pests including pathogens, viruses, nematodes etc. The monetary value of this damage and the cost of management measures is presented in millions of dollars.

Over the decade from 1998 to 2008, the percentage of the wheat crop (Fig. 1a) damaged decreased from 12% in 1998 to 2% in 2008 although there was an increase in 2001 and 2002 which was translated into an increase in terms of financial loss (over $1 million). As spending on management increased from 2002 onwards, percentage losses and financial losses declined until 2007 when financial losses increased sharply, presumably due to increasing cereal prices affecting the value of the lost crop. Similarly with maize (Fig. 1b) financial losses increased dramatically from 2007, again presumably due to high cereal prices impacting on the value of lost crop. Percentage losses did decline from 25% in 1998 but remained around the 12–15% level throughout the decade; this level of loss occurred despite a cost of over $1 million per annum on management practices. A similar trend was seen for soybean (Fig. 1c) with financial losses due to damage of the crop increasing from 2006 and the cost of management also increasing dramatically from 2006 onwards. Yet despite management practices, losses remained at ca 8–12% throughout the decade with a high of 14% in 2005. For cotton (Fig. 1d), percentage reduction in crop value ranged from 8 to 22% despite management costs of $10–14 million per annum. The value of the damage varied enormously. For vegetables (Fig. 1e), damage declined from 2002 but still amounted to a loss of 3–10% of the value of the crop; financial losses also decreased but remained in the order of $18–51 million while management practices cost $14–23 million.

Overall, increased spending on management can decrease losses. Cost benefits are variable and dependent on prices and this was particularly noticeable after 2007. The losses incurred also mean that other inputs (apart from pest management inputs) such as fertilizers, labour, energy and water are also lost (wasted). This should be considered in the context of declining oil and natural gas reserves and declining water resources. In addition, these losses occurred in an agricultural system equipped with sophisticated monitoring and access to modern management techniques. If these losses can occur in such an agricultural system, what chance have developing countries with little infrastructure and little access to the best management practices? Few governments in developing countries have systematic research and monitoring programmes to gather data on crop losses and their causes (Pinstrup-Anderson 2000). Better ways of monitoring pest and disease occurrence in the field are essential and some novel methods are being trialled e.g.

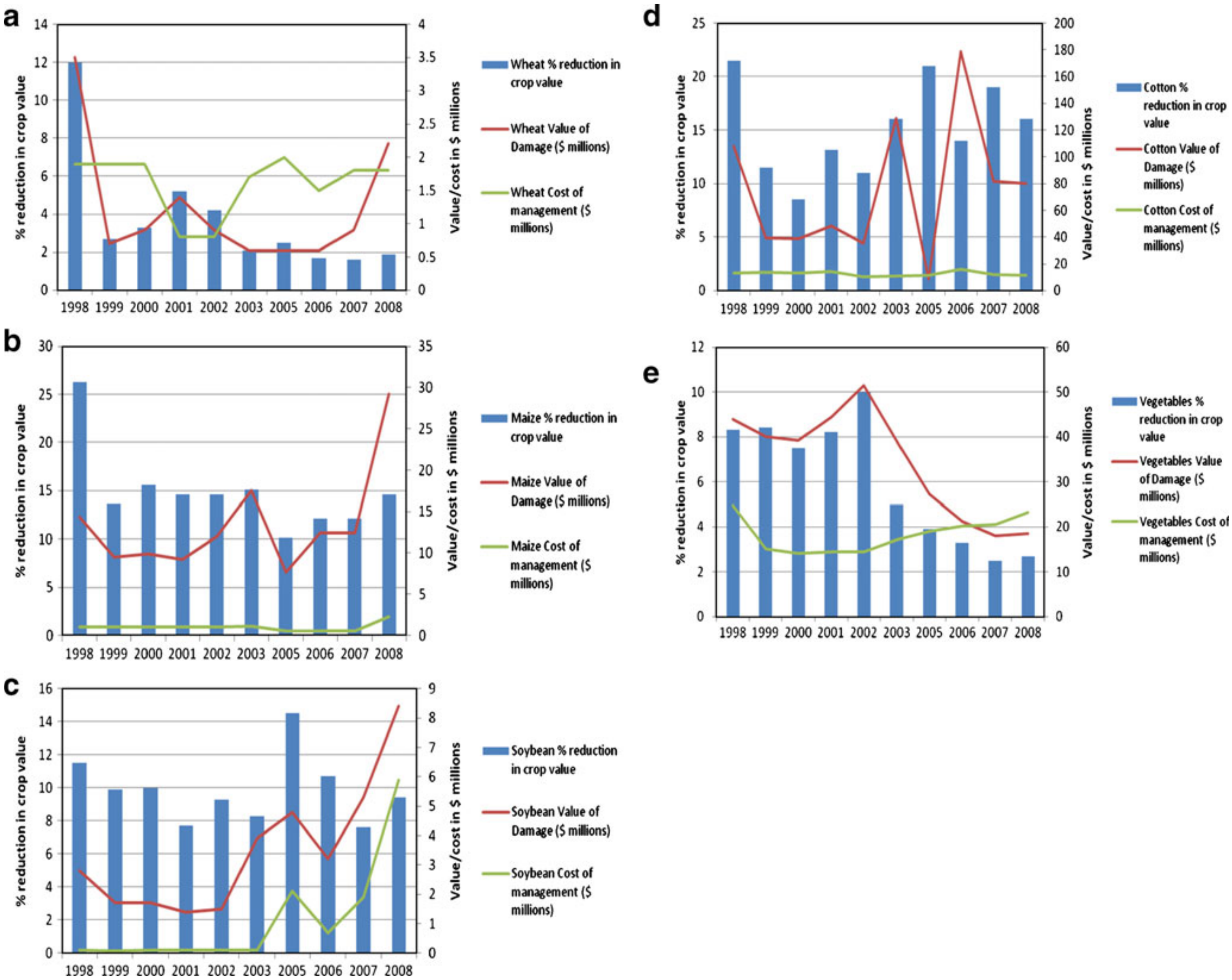

Fig. 1 Percentage reduction in crop value due to biotic constraints, value of the damage ($ millions) and cost of management ($ millions) for five crops in the State of Georgia for years 1998–2008 (University of Georgia 1998–2008; adapted by Flood and White unpublished). Please refer to the online edition for a colour version of this figure

Plant Health Systems based on mobile plant clinics (see later) but systematic quantitative data on losses from pests and diseases are also urgently needed. Such information is not just essential for food security but also for trade and the regulations that govern trade. Increasingly, phytosanitary regulations are affecting decisions on trade, which have an impact on the whole supply chain, not least the producer.

Losses in the retail sector and at the consumer's table

In addition to the pre- and post-harvest losses, increasingly there is recognition of how much wastage there is in food production in the retail area and at home. Godfray et al. (2010) reported 30–40% of food produced being wasted in both developing and the developed world but the causes of this wastage are very different. In the developing world, losses are mainly attributable to the absence of food-chain infrastructure and the lack of knowledge or investment in storage technologies on the farm, although data are scarce. For example, in India, it is estimated that 35–40% of fresh produce is lost because neither wholesale nor retail outlets have cold storage (Nellemann et al. 2009). However, in the developed world, wastage mainly occurs in the retail or food service areas and at home and the volume of waste has grown dramatically in recent years. Reasons for this waste are complex and include the fact that consumers are only willing to purchase food of the highest cosmetic standards so retailers discard edible but slightly blemished products. Commercial pressures can also encourage waste eg "buy one get one free" while litigation and lack of education on food safety have led to a reliance on "use by" dates, whose safety margins often mean that food fit for consumption is thrown away. Different strategies are required to tackle this waste. In developing countries, public investment in transport infrastructure would reduce the opportunities for spoilage, whereas better-functioning markets and the availability of capital would increase the efficiency of the food chain, for example, by allowing the introduction of cold storage. Existing technologies and best practices need to be spread by education and extension services, and market and finance mechanisms are required to protect farmers from having to sell at peak supply, leading to gluts and wastage (Godfray et al. 2010). There is also a need for continuing research in postharvest storage technologies including improved technology for small-scale food storage. Waste in developed countries could be reduced by alerting consumers to the issue as well as advocacy, education, and possibly legislation to reduce waste in the food service and retail sectors.

Consequently, one very important aspect of food security is reducing these losses in the field (production), at the post harvest-stage, and indeed at the consumer's table. For the purposes of this paper, the discussion will focus on pre-harvest losses and the need to address plant health problems in order to improve productivity.

Plant health and productivity

Despite these enormous pre-harvest losses due to insects, pathogens, and weeds, and their impact on food security, plant health remains the poor relation as compared to human and animal health. The limited information available on actual crop losses from pests and diseases perhaps illustrates the fact that the importance of plant health is often overlooked.

As an example of the limited awareness of plant health issues, a search of Google revealed 18 million hits for Swine Flu (to March 2010) as compared to ca. 39,000 hits for Ug99. Similarly, from April 2009 to March 2010, CABI received requests for 681 records on Swine Flu from the CAB Abstracts and Global Health databases, but only 17 requests for records on Ug99. Mankind is more concerned about human diseases and animal diseases capable of infecting humans directly but is less interested in plant diseases as they are seen as less of a threat, and yet plant pests and diseases can have far reaching consequences. Biblical plagues remind us of the effects on crop production and food security (Large 1940; Carefoot and Sprott 1969). Further examples are tabulated in Lenné (2000) and include the great Bengal rice famine of 1942–43 associated with a devastating epidemic of brown spot (*Bipolaris oryzae*). Other examples are African Cassava Mosaic Virus (Otim-Nape et al. 1997; Vurro et al. 2010) and sorghum ergot in Latin America (Bandyopadhyay et al. 1998).

Throughout human history, plant pests and diseases have impacted on food-related policies, on demographics and on world trade. The classic example is the Potato Famine in 19th century Ireland. The Corn Laws (protectionist legislation) that were introduced in 1815 at the end of the Napoleonic War to prevent the import of cheaper "foreign" wheat into Britain, had had the effect of keeping domestic wheat prices artificially high. Food prices rose dramatically, people spent most of their earnings on food and this depressed the national economy because people had no money to buy manufactured goods. The poor working class (rural and urban) were denied access to sufficient food as they had little income to buy it. Like their modern day counterparts in developing countries, the rural poor of 19th century Ireland were particularly vulnerable and they relied on a high-yielding staple (potato) for their own consumption and, in good years, for sale in local markets. They also grew small amounts of cereals to sell (cash crops) for farm rents as they were smallholder tenant farmers. Over reliance on this staple crop led to widespread starvation when repeated harvests failed in the 1840s due to wet summers and the germplasm being very susceptible to potato blight caused by the Oomycete, *Phytophthora infestans*. The combination of a susceptible host, the presence of the pathogen and conducive environmental conditions allowed for the development of the epidemic but it was the socio-economic conditions that made the situation worse. Using the little money they could get from selling what crops they had to buy food, they had no money for rents and many were turned off the land and migrated to the towns and cities so swelling the numbers of urban poor looking for work. Cholera and other associated diseases spread in the cramped conditions of the workhouse and urban slums. Political pressure grew for the repeal of the Corn Laws and this was finally achieved in May 1846. One consequence of the repeal of the Corn Laws was that Britain moved towards becoming a free trade nation, albeit too late for millions of rural poor. Some food relief was organised by charitable institutions and individuals and some by the state but as many observed this was "too little too late". Rural Ireland was too remote from the corridors of power. Census results from 1841 compared to those in 1851 indicated 2 million people had either perished or had emigrated to Britain and the US.

There are many modern parallels to this historical example, characterised by high food prices, over-reliance on staples, limited access to food due to low incomes, the need for income diversification, the spread of infectious diseases through populations of starving people, and changing demographics. The most able will always try to escape the worst of food insecurity and this is already occurring as people in many developing countries increasingly move away from the land and into urban areas where they believe they can secure better incomes to buy food.

Could a plant disease have such an impact in the 21st century? In many ways, certainly in the developed world, there has been complacency about plant health issues especially since the Green Revolution. Plant health issues are often overlooked because it is assumed that they can be managed but, as we have seen, even under the best of agricultural systems enormous losses may occur and management practices can cost billions of dollars.

One current example of a plant disease that could cause a severe impact on global food production and productivity, on global food prices and livelihoods and on global demographics, is Ug99, the virulent race of black stem rust of wheat, *Puccinia graminis tritici*, that has spread from Africa and is threatening the wheat fields of South Asia and the high yielding wheat varieties developed under the Green Revolution. Most varieties grown in Australia, the US, China and Europe are also susceptible.

Black stem rust of wheat (Ug99)

Race Ug99 of *P. graminis tritici* was discovered in Uganda in 1998 and reported in 1999 (Pretorius et al. 2000). It causes symptoms similar to those of other stem rust races (Fig. 2) but this race has virulence for gene *Sr31* known to be located in the translocated chromosome 1BL.1RS from rye (*Secale cereale*) and which confers resistance to most races of the pathogen. Gene *Sr31* is widely utilized in wheat worldwide, particularly in the Indian subcontinent, China, Europe, and South America. Ug99 was designated as TTKS by Wanyera et al. (2006) using the North American nomenclature system (Roelfs and Martens 1988) but most authors continue to use the designation Ug99. This race not only carries virulence to gene *Sr31* but also virulences for most of the genes of wheat origin that have been bred into modern wheat varieties as well as virulence for gene *Sr38* introduced into wheat from *Triticum ventricosum*. Gene *Sr38* is present in several European and Australian cultivars and a small proportion of new CIMMYT germplasm (Singh et al. 2006). Race Ug99 carries a unique combination of virulence to known and unknown rust resistance genes present in wheat germplasm and it is likely that this has evolved to overcome the complex of resistance genes within modern high-yielding varieties of wheat. It is these wheat varieties that are the successors of the original "Green Revolution" which has allowed productivity to rise in many countries including in Europe, the US and India. CIMMYT (2005) estimated that at least two thirds of the wheat grown in India and Pakistan is very susceptible to Ug99. Thus, a major and growing concern is that a very significant proportion of global wheat germplasm is potentially at risk from race Ug99. Reynolds and Borlaug (2006) estimated that this area might amount to 50 million ha of wheat grown globally i.e. about 25% of the world's wheat area.

Fig. 2 Symptoms of *Puccinia graminis tritici* race Ug99 on wheat. Key: Please refer to the online edition for a colour version of this figure. Source: USDA

Following its detection, investigations were made in adjacent countries in East Africa which revealed that the same race may have migrated to sites in the Rift Valley province of central Kenya by 1998/1999, with subsequent advancement to sites in Eastern Kenya by 2001 (Singh et al. 2006). It can also be noted that there were reports of stem rust, possibly attributable to race Ug99, from the Western Rift Valley of Kenya as early as 1993 (KARI unpublished). In 2003, race Ug99 was detected in Ethiopia and by 2005 there were reports from at least six sites in dispersed locations (Singh et al. 2006). Evidence suggests that Ug99 is now established in the Eastern African highlands and spreading, although extensive field survey results detailing exact distribution are currently unavailable (Singh et al. 2006). The East African highlands are a known 'hot-spot' for the evolution of new rust races (Saari and Prescott 1985) due to favourable environmental conditions there plus the year-round presence of host plants which favour the build-up of pathogen populations. In Kenya, it has been estimated that wheat loses due to Ug99 are over 70% of total production in some areas (Vurro et al. 2010). Production losses have already led to higher prices in local markets with a resulting impact on low income families and an increase in food insecurity. This is a foretaste of its likely impact in the high-yielding production systems of South Asia and beyond.

Singh et al. (2006) stated that Ug99 was likely to spread beyond the East African region. Physical barriers, such as mountains and oceans, do not inhibit rust spore (urediniospore) dispersal. The mobility of rust spores on prevailing winds led an international panel of rust scientists to conclude that it is only a matter of time until Ug99 reaches across the Saudi Arabian peninsula and into the Middle East, South Asia, and eventually East Asia and the Americas (CIMMYT 2005). In addition, there is documented evidence connecting East Africa with West and South Asia for migration of rust races of East African origin (Singh et al. 2004).

GIS tools were used by Hodson et al (2005) as a framework to integrate relevant factors determining likely movement of Ug99 (Fig. 3). These factors included the status and distribution of Ug99, prevailing winds, climatic factors that favour survival and sporulation, distribution of wheat production zones, human populations within those production zones, historical migration patterns of rust races originating in East Africa, and known susceptibility of existing cultivars.

Route A (Fig. 3) matched that described by Singh et al. (2004) for the Yr9-virulent race of *P. striiformis*, and this was considered the most likely route that Ug99 would take. The second route (B), connecting East Africa directly with southern Pakistan and western India, has no known precedent and is highly speculative.

FAO subsequently reported Ug99 in Yemen following an FAO mission there (FAO 2007) and later in Iran (FAO 2008b). In Iran, the government informed FAO that the fungus had been detected in some localities in Broujerd and Hamedan in Western Iran. These observations tend to confirm the prediction of Hodson et al. (2005) that Route A is the most likely path of dispersal.

From Iran, likely spread will be to Afghanistan and through to South Asia's important cereal growing areas such as the Punjab, which provides food for hundreds of millions of people in South Asia. The situation is likely to be particularly bad in Pakistan and Afghanistan, two nations that rely heavily on wheat for subsistence. Also, the prominence of 'mega-cultivars' 'PBW343' and 'Inqualab 91' in India and Pakistan, both of which have proved highly susceptible to Ug99, will mean that there will be wide-scale impacts on livelihoods and national economies unless more resistant germplasm is disseminated and planted. Only 0.3% of a total reported area of over 44 million ha planted to known cultivars in the epidemiologic zone was rated as being moderately resistant to Ug99.

The impact of Ug99 could be particularly severe as its spread is coinciding with an historical low in the world's wheat reserves (lowest for four decades) so there is less wheat available in areas affected by the rust. Availability of wheat has decreased in part due to a decrease in production (3.6% in 2005, 6.9% in 2006) but demand is also involved (FAO 2008a). Dramatically changing consumption patterns have been associated with the rapid economic growth in Asia, notably in China and India, increasing urbanization and a growing global "middle class" which has led to changes in diets especially with regard to meat and dairy products which are heavily dependent on cereal production as feedstuffs. There have also been changes in demand in the use of cereals and other foodstuffs, including for biofuels. Shortages due to losses from this rust will only impact further on the poor as wheat prices are bound to rise again.

Fortunately, strategies are being put in place to mitigate losses and epidemics from Ug99 (Singh et al. 2006). Reducing the area planted to susceptible cultivars in the Arabian Peninsula, North Africa, Middle East and West and South Asia is the best strategy if major losses are to be avoided when race Ug99 migrates to these areas. The 'Global Rust Initiative', launched during 2005 and led by CIMMYT in partnership with ICARDA and various National and Advanced Research Institutions, uses the

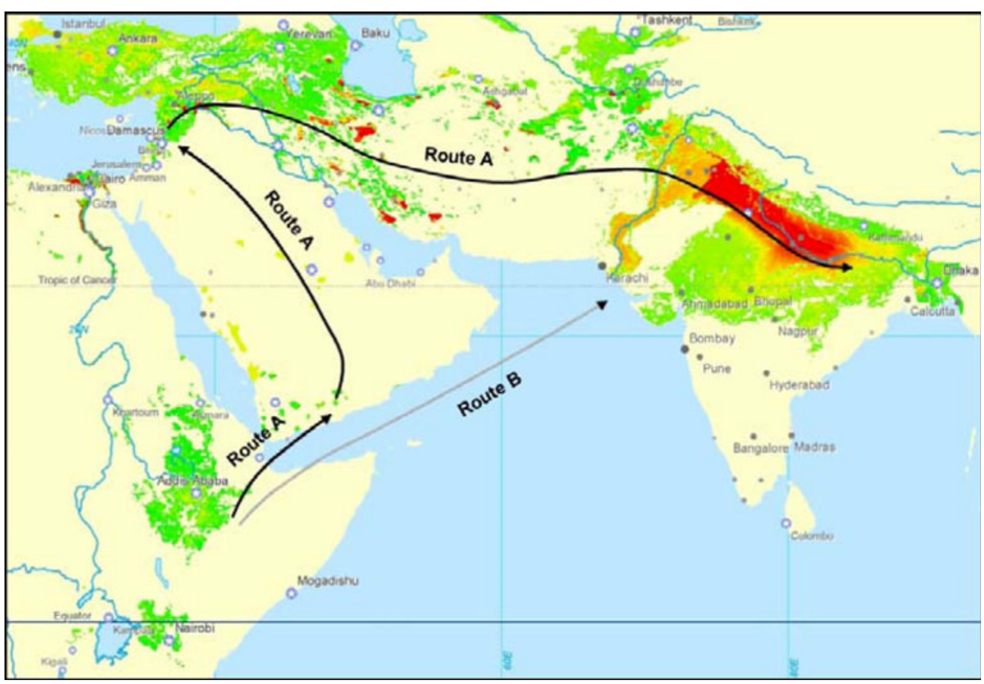

Fig. 3 Potential migration routes for *Puccinia graminis tritici* race Ug99 based on prevailing airflows and regional wheat production areas. Based on Hodson et al (2005). Key: Route A via Arabian Peninsula, Middle-East and South Asia is considered to have a higher probability. Wheat production areas Green to Red (increasing wheat production). Please refer to the online edition for a colour version of this figure. Figure is reproduced courtesy of CAB Reviews

following strategies to reduce the possibilities of major epidemics: (1) monitoring the spread of race Ug99 beyond eastern Africa, (2) screening of released cultivars and germplasm for resistance, (3) distributing sources of resistance worldwide either for direct use as cultivars or for breeding, and (4) targeted breeding to incorporate diverse resistance genes and adult plant resistance into high-yielding adapted cultivars and germplasm.

More recently (2008), the Gates Foundation funded ($28.6 million) the new Durable Rust Resistance in Wheat project (3 years) that will bring together 15 institutions to combat the emergence of new variants of the pathogen http://www.wheatrust.cornell.edu. Objectives include dissemination of resistant seeds in vulnerable areas, fostering global awareness and tracking the global spread of races such as Ug99 as well as prospecting for new sources of rust resistance in other species related to wheat, such as wild wheat and wild barley. Screening fungicides for efficacy against Ug99 is also ongoing (Wanyera et al. 2009).

Trans-boundary pests and diseases such as Ug99 represent serious threats to food security. For example, they threaten the livelihoods of millions in South Asia, and hence national economies and the political stability of the region. Ug99 is also a threat to wheat production worldwide and yet few people outside the specialist scientific community are aware of it. This illustrates the need for increased awareness about plant health issues by the public, and by policy makers and decision makers who should be aware of the impact on food security, and should be committing funds to dealing with plant health issues. It is highly likely that climate change will have a further impact on the distribution of plant pests and diseases by aiding spread to new areas as well as potentially creating more conducive conditions, making endemic problems worse.

Another example of a trans-boundary disease that has already had a significant effect on African producers is Coffee Wilt Disease which attacks *Coffea* species in Central and Eastern Africa.

Coffee Wilt Disease (CWD)

Whilst coffee is not a staple food crop, its production has indirect implications for food security through decreasing income security. Food security means having access to food which often requires income for its purchase. For many of the rural poor, growing a cash crop such as coffee provides this much needed income. Over-reliance on one or two crops can have significant consequences, so diversification into production of staples plus cash crops like coffee can bring some insurance to the poor. However, the resurgence of Coffee Wilt disease (CWD) caused by *Fusarium xylarioides* has removed that insurance from many smallholder coffee producers across Central and Eastern Africa. The disease kills coffee bushes so that, very soon after its detection on-farm, farmers will experience complete loss of income from coffee. Yields decline rapidly; a 77% loss in yield of robusta coffee at the national level in Uganda was reported by Hakiza et al. (2009). Drastic yield reductions and hence income reductions, force smallholder coffee farmers to diversify further or even leave agriculture altogether, sometimes after generations of coffee cultivation.

Fusarium xylarioides (sexual form, *Gibberella xylarioides*) invades the coffee tree and colonises the xylem system. External symptoms exhibited by coffee plants affected by CWD are generally similar to those of other vascular wilt pathogens. Colonization of the vascular system induces host responses which disrupt water conduction and this is manifested as wilting and desiccation of leaves followed by defoliation, and die-back of affected branches (Fig. 4a, b, c). Symptoms may appear at any stage of crop growth and the rate at which they develop varies. Once affected, death of the plant is inevitable and in mature trees it usually occurs between three and fifteen months after first appearance of symptoms. Young plants may be killed within a few weeks of infection. Symptoms can be more pronounced on one part of the tree, a likely consequence of initial infection occurring on one of several main stems, but defoliation gradually extends to the entire plant. Coffee berries that would normally be green may redden as if ripening prematurely, but often remain intact on shoots following defoliation. Other external symptoms include the swelling of the trunk and the appearance of vertical or spiralling cracks in the bark of mature trees. Small blackish-brown perithecia (sexual stage) of the fungus, similar in appearance to dark soil particles, may be produced in the cracks of the bark (Fig. 4e). Characteristic bluish-black staining of the wood can be observed directly beneath the bark (Fig. 4d).

Despite being known since 1927, attacking *Coffee excelsa* near Bangui in the Central African Republic, then known as Oubangui-Chari (Figueres 1940) and being a serious constraint to production of *Coffea excelsa, C. caneophora and C. arabica* during the 1940s and 1950s (Flood 2009), following concerted international action in the late 1950s and 1960s the disease was considered to be of minor importance. Management of the disease included a) systematic sanitation over vast areas where affected coffee plants were uprooted and destroyed; b) where possible, relocation of coffee production to new locations; and c) replanting with resistant germplasm. Implementation of these recommendations reduced the impact of CWD and literature produced during the 1970s and 1980s referred to this as a minor disease.

However, in remote areas of the Democratic Republic of the Congo (DRC), the disease continued to be observed,

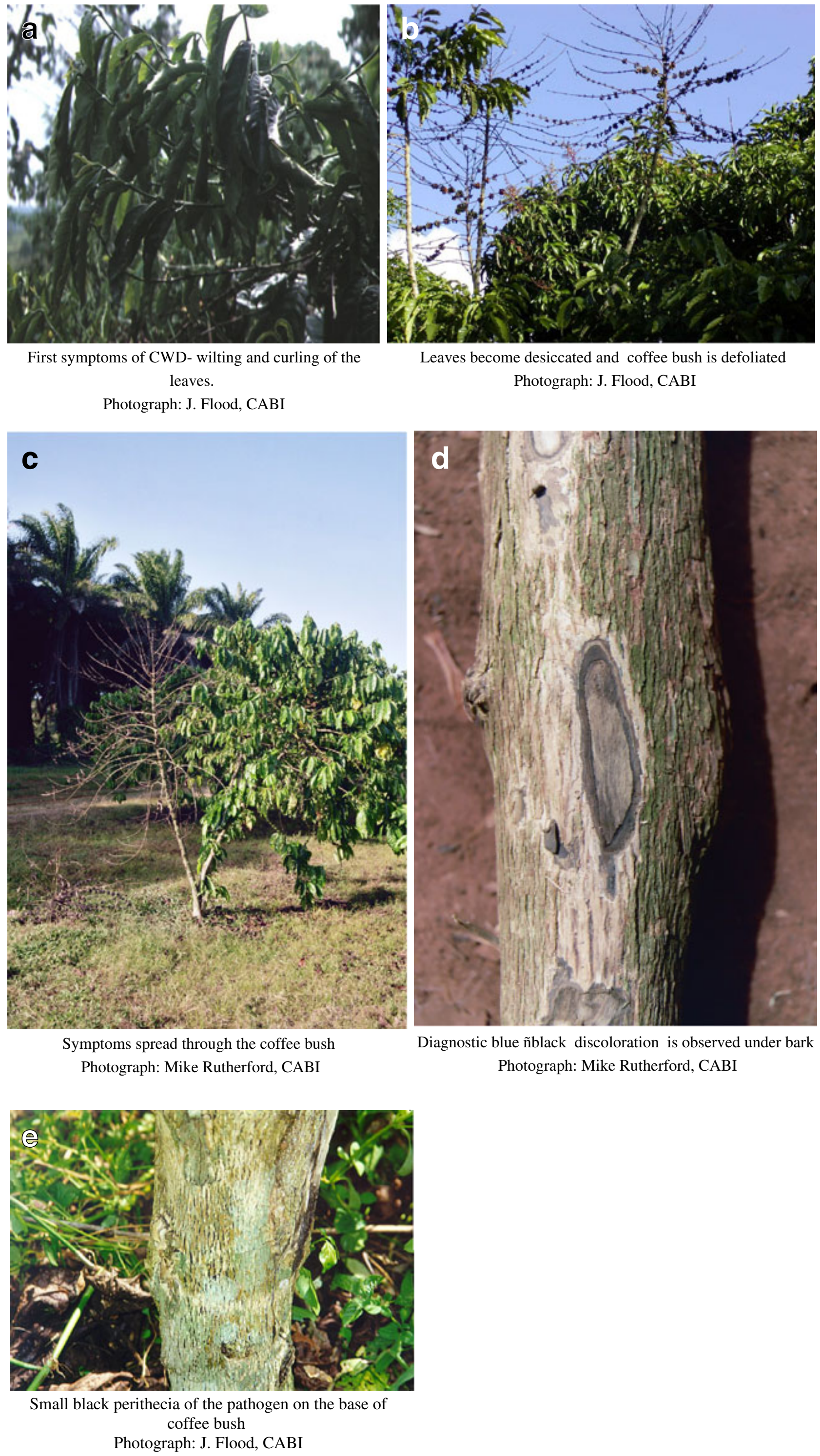

Fig. 4 Symptoms of Coffee Wilt Disease. Please refer to the online edition for a colour version of this figure

especially around abandoned plantations in the north-east of the country. As early as the 1970s, farmers had observed the disease in abandoned plantations and during a survey conducted from 1974 to 1975, a number of Institut National d'Etudes et de Recherches Agronomiques (INERA) fields around Yamgambi were also reported to be affected (Kalonji-Mbuyi et al. 2009). Throughout the 1980s, reports began to circulate again of a wilt-like disease affecting coffee around the town of Isiro and surveys were conducted. In 1995, CABI's plant clinic laboratory received samples of diseased coffee plants from the Managing Director of Esco Zaire sprl (Mr Philip Betts) and *Fusarium xylarioides* was isolated. These samples had been collected from robusta coffee in Beni and Rutchuru, again indicating that the disease was widespread in the region. In 1995, OZACAF (Office Zaireois du Café) now ONC (Office National du Café) prepared a detailed report for the International Coffee Organisation (ICO) in which they outlined the seriousness of the disease on the economy of north-east DRC.

In March 1996, ICO facilitated contact between OZACAF and CABI. CABI was then asked to prepare an independent report on the nature and extent of the problem. A survey of plantations and smallholder farms was conducted in the north-east of DRC in July 1996 (Flood 1996). Farmers interviewed called the disease "Coffee AIDS". One agriculturist reported that he had observed the disease first in the 1970s on a large abandoned plantation on the road to Aketi, which confirmed other reports that the disease had re-emerged as a serious problem in this part of Africa at that time—just when most scientific authorities considered it as a minor problem (Flood 1996). Surveys were also undertaken in adjacent Uganda in the mid 1990s and these confirmed the presence of the pathogen there (Hakiza et al. 2009).

In 1997, a proposal for a funded programme of work to alleviate the problem was developed and submitted to several donor agencies including the Common Fund for Commodities (CFC), the European Union (EU) and the UK Department for International Development (DFID). Subsequently, the Regional Coffee Wilt Programme (RCWP) began and was a fully integrated programme of activities addressing different aspects of the disease and its management. For further details see Phiri and Baker (2009).

Despite the successes of the RCWP, including screening and selection of resistant germplasm, raising awareness of the symptoms for early detection, recognition of good sanitation practices coupled with rapid eradication of diseased trees and improved husbandry, such as reducing wounding of trees, the disease has continued to spread much more extensively within DRC and has been reported in the province of Equateur, so threatening coffee production in Western Africa. It has continued to spread throughout all coffee-growing districts in Uganda and into Tanzania and continues to be a problem of *C. arabica* in Ethiopia (Girma et al. 2009). It has been estimated that the disease has cost $1 billion so far in terms of lost production and cost of management practices (Phiri and Baker 2009). Severe impacts on the incomes and livelihoods of coffee farmers in affected areas of DRC, Uganda, Ethiopia and Tanzania have been observed (Musebe et al. 2009) and producers have had to diversify away from coffee production, either growing other crops or moving into non-agricultural activities.

What can we learn from the outbreak of CWD as an example of a major epidemic of such a commercially important crop as coffee so extensively grown in Africa? Essentially, the enormous impact it has had across the continent was largely due to a lack of preparedness for a major epidemic caused by a pest or disease in coffee-producing countries in Africa. This was despite the fact that, just a few decades previously, the disease had reached epidemic proportions in several African coffee-producing countries and had caused major effects on production and on several *Coffea* species. Wild *Coffea* species which are sources of resistance against many diseases are also killed by this disease. Inadequate preparedness was compounded by failures to understand the seriousness of the threat and failures to respond quickly with counteractive measures. National governments were initially slow to recognise the threat to their economies and to producer livelihoods and these delays were made worse by the failure of the international community to recognise the seriousness of the situation at an early stage. CWD was considered to be a minor problem, and one already under control. Undoubtedly, if there had been fewer delays, the disease could have been managed more effectively and its spread limited. However, due to the remote location of many of the initial disease foci, many years elapsed from the start of the new epidemic in DRC (probably commencing in the 1970s) to the time when the international community became aware of the seriousness of the situation in that country in the 1990s, and of the likely spread of the pathogen to other countries. Uganda and adjacent countries were not alerted to the seriousness of the situation until it was too late.

Even when the international community was alerted, some delays continued, with many years elapsing from the initial surveys conducted in the 1990s to project activities being implemented in the field in the early 2000s. Fortunately, as in the case of Ug99, funding agencies have responded and a concerted course of action has been planned to try to mitigate the effects of the spread of CWD but, in the years intervening between recognition of the threat from the disease and obtaining donor support, the disease had become widespread in Uganda and had emerged in Tanzania. In retrospect, whilst a programme such as the RCWP was clearly urgently needed for the long-term understanding of the pathogen, to raise awareness across the coffee sector and to initiate breeding programmes for the sustainable management of CWD, there should also have been a mechanism for developing countries to obtain international funds quickly in order to respond much more rapidly and restrict disease spread. This would have involved alerting coffee stakeholders in affected countries and adjacent countries as well as conducting emergency sanitation measures. Some national governments did not wait for intervention from the international community. Given the gravity of their situation, a strategy was developed in Uganda using internal funds. Further surveys were conducted to ascertain the full extent of the problem and a programme of awareness-raising for farmers and a research strategy, including a breeding programme, were initiated. Uganda was fortunate enough to have a good research base and agricultural infrastructure to be able to implement these activities. Similarly, Tanzania initiated surveys and alerted producers in robusta growing areas adjacent to Uganda. These activities undoubtedly received a much deserved boost from international funds channelled through the RCWP and progress has been much more rapid. Participating countries also benefited from institutional capacity building both through training programmes and improvements in infrastructure. International and regional expertise were also mobilised through the RCWP. In the case of Uganda, useful lessons were learned from CWD as can be seen from the speed of the national response to banana bacterial wilt (*Xanthomonas campestris* pv. *musacearum*) which emerged in Mukono in 2002. Farmers were mobilized quickly to conduct sanitation, a research agenda was identified and funded internally by the national government—all within 1 year of the initial report of the disease. As with Ug99, much relies on breeding of resistant germplasm. Resistant coffee material has been identified; multiplication of this material to cope with increased demand from farmers is now a new challenge.

Despite regional and national successes, CWD remains endemic to many parts of Central and East Africa and is still spreading. In order to try to prevent the same problems arising again in adjacent countries, regular surveys should be undertaken and the coffee sectors in these countries alerted to the threat to their industry. We need to improve national capacity to recognise and deal with threats like CWD and encourage adjacent countries to put a strategy in place to facilitate this. As early recognition of CWD symptoms is a crucial part of successful management, making authorities and producers in neighbouring countries aware of the presence of the disease and its imminent threat is essential. The disease is spreading in Equateur Province in DRC, putting robusta coffee production there under threat as well as robusta production in adjacent countries such as Congo, Central African Republic, Gabon and Cameroun. In many remote areas, traffic of people and goods, including coffee, across porous borders is likely to add to the risk of further disease spread.

In addition, isolates of the pathogen from arabica coffee in Ethiopia are pathogenic to arabica coffees grown in Kenya and the Kenyan coffee sector needs to be aware of this. Indeed, this disease is not just a threat to African coffee production, as coffee from other producing countries has been shown to be susceptible (Girma et al. 2009). The disease is a threat to coffee production globally and coffee producers worldwide should be made more aware of it.

Detection, identification and monitoring (DIM)

Management of these trans-boundary pests and diseases is heavily dependent on early detection so that eradication can be attempted and, if this is not possible, management practices can be established. Early detection in a country is generally considered the most neglected phase of disease management (Holt 1999). Just as there are few systems in place to gather data on pest losses, so systems for effective detection, identification and monitoring (DIM) are not in place, and in some cases information about new threats are ignored by the authorities. Globally, the public bodies with mandates for DIM in plant disease (the National Plant Protection Organisations and research institutes in Ministries of Agriculture) are facing growing challenges to detect and identify plant diseases of economic significance. These challenges include lack of knowledge of the symptoms of these alien pests and diseases amongst key stakeholders such as producers and customs officials at ports; and the use of pesticides which could temporarily mask symptoms but do not eliminate the causal agent so allowing it to establish in the field. Also, as phytosanitary concerns are involved more and more with trade, there may be a tendency not to admit the presence of a particular pest in-country especially where this could have trade implications and so the pest spreads, unchecked. Lack of real-time surveillance feedback and sometimes sketchy distribution information can lead to delays in response. Geographical remoteness can also play a part, as does armed conflict and natural disasters and this is certainly true in the spread of CWD. When mass movements of people take place in areas of conflict or due to natural disasters, then plant pests and diseases can spread too with far-reaching consequences. The conflict that erupted in the remote areas of Eastern DRC during the 1990s, coupled with the presence of various guerrilla groups in the region throughout the 1980s and 1990s undoubtedly contributed to the spread of CWD on robusta coffee. Further constraints to DIM include inadequate legal and regulatory frameworks, and weak institutional arrangements in many developing countries. There may be a lack of resources, lack of public and media awareness, poor co-ordination, and there may be a regional as opposed to a national perspective. If one country responds and others do nothing, the pest will spread. This is especially true where a vector is involved.

Given the impact that pests and diseases are having on productivity, the earlier the threat is detected, the greater the chance of being able to manage or eradicate the pest or disease. This emphasises the need for better systems of monitoring and detection, especially in developing countries with poor infrastructure. One way of boosting early detection is to make the general public more aware of the issues involved (Kedera and Kuria 2005). Many initiatives exist globally to strengthen disease detection and surveillance. One I am familiar with is the CABI-led alliance, the Global Plant Clinic (GPC), which uses a plant health systems approach. This approach is unique in that it seeks not only to provide more effective advisory services but is also showing potential to act as a field-based early detection mechanism.

Global Plant Clinic

The GPC has developed a radical approach to delivering plant health services to farmers, advising on plant health problems and detecting emerging plant pests (insects, diseases, and weeds) in-country through plant health clinics (Bentley et al. 2009). Agricultural extension has been so weakened by decades of declining support that it often fails to deliver what farmers need. The GPC aims to build capacity of local systems by linking stakeholders (including extension, technical experts, agro-input suppliers and diagnostic laboratories) to deliver advice to farmers at the point of demand. The concept of plant healthcare networks evolved as scientists explored ways of providing support to farmers seeking advice on crop health problems. Local plant clinics run by plant 'doctors' are set up in rural marketplaces or other places where farmers congregate, generally once a week (Fig. 5). Plant doctors, normally from organisations with an extension mandate, e.g. government agencies or NGOs, operate the clinics. Farmers bring in samples of diseased plants for identification and advice (Fig. 5). Instant feedback is provided for the more recognisable problems whether they are biotic or abiotic. When a problem is difficult to diagnose, plant doctors can request advice and control options from experts. Samples can be sent for diagnosis to national laboratories. If further advice is needed, or if laboratories lack equipment and materials for tests, samples can be sent to the GPC laboratory in the UK. Links with local input suppliers (at some clinics) ensure that plant doctors know which treatments are available so that the advice they give is relevant. In Bangladesh, for example, certification of suppliers following training courses has encouraged reduced sales of fake agrochemicals. Training programmes for plant doctors teach them to look carefully at symptoms, interview farmers and visit farms where necessary. Plant doctors learn to make a diagnosis and give advice only if they are confident they are right and only to recommend inputs available locally. Fact sheets are used to describe technical knowledge in accessible language which can be shared more widely. The GPC encourages clinics to record and share data related to clients, symptoms, diagnoses and recommendations. The records provide the basis of a quality control system. For example, in Nicaragua, data are shared at monthly meetings of staff from several clinics and other experts. The clinic records also provide the basis of a community surveillance system that can allow early detection of new pests and diseases.

Farmers bring their crops for diagnosis at Plant Clinic in Beshishahar, Nepal. Photograph: Solvieg Danielsen

Farmers discussing crop losses with plant doctors in Save, Rwanda. Photograph: Eric Boa, CABI

Fig. 5 Global Plant Clinic. Please refer to the online edition for a colour version of this figure

Numerous new disease reports have been published (Boa 2009) but the capacity-building part of this initiative should not be underestimated. The initiative allows the flow of technical support to smallholder farmers and extension workers in remote areas but is very much a partnership with the countries' existing support systems. Clinics have now been run in nine countries and "learning by doing" allows the GPC to discover what works. For example, it observed that organisations with an extension mandate and well run agencies that assigned clear roles for staff, with direct accountability to farmers, were more likely to run effective clinics and maintain a regular service. In Bolivia, farmers who adopted the clinics' recommendations such as application of appropriate pesticides more accurately, have increased their yields and their incomes, so contributing to their food security. Further details of the success of the plant clinic approach is documented in Bentley et al. (2009).

Another problem with regard to plant health is that in many developing countries, there is often a need to build capacity on phytosanitary policy and practice and one initiative to help address this lack of capacity in Africa is the establishment of a Centre of Phytosanitary Excellence (COPE) in Nairobi.

Centre of Phytosanitary Excellence (COPE)

For African nations to fully benefit from trade opportunities, compliance with international phytosanitary standards and the legislative requirements of the importing countries, capacity building is desperately needed in the phytosanitary field. If this capacity building is not undertaken then African countries' access to lucrative export markets may not reach its full potential. Thus, in 2008, CABI worked with the Kenya Plant Health Inspectorate Service (KEPHIS), the University of Nairobi (UoN), International Plant Protection Convention (IPPC) and Plant Protection Service of the Netherlands (NPPS), to develop an initiative to increase market access of African nations through compliance with international phytosanitary standards and the legislative requirements of the importing countries through the establishment of a Centre of Phytosanitary Excellence (COPE). The centre has been set up with a grant from the Standards and Trade Development Facility (STDF), with co-financing from KEPHIS and NPPS, but the aim is for the Centre to be financially self-sustaining and so it charges for its services.

COPE's mission is to provide phytosanitary capacity-building services to clients in the public and private sectors, so that countries are better able to prevent the introduction and spread of plant pests and to meet the phytosanitary requirements of international trade. Specifically, the project aims are:

1) To set up the legal and institutional framework for a Phytosanitary Centre of Excellence.
2) To set up a training unit to develop training opportunities in phytosanitary policy and practice appropriate to the needs of the region, including the establishment of an exemplary plant inspection facility and information management system for use as demonstration and training tools.
3) To set up a unit for applied pest risk analysis (PRA) generating PRAs according to relevant international standards and to establish a network of African pest risk analysts.
4) To promote the Centre and the services it will offer within the region.

COPE is essentially seen as a 'centre without walls' established to provide high quality services to plant health systems and services and, whilst expertise available in Africa is used wherever possible, collaboration with experts and organizations worldwide is encouraged.

Plant health is a vital part of long term food security. The initiatives outlined above such as the GPC and COPE are excellent examples of a "knowledge intensive" approaches to improve plant health systems globally. Such "knowledge intensive" approaches, as advocated by Evans (2009), will be needed in the 21st century as we struggle to increase productivity and improve food security for a growing population. However, such a new "Green Revolution" will only be successful and sustainable through partnership with in-country stakeholders and increased capacity-building within countries.

Conclusions

1. Rapid price rises in food through 2007 and 2008 have severely impacted on poverty levels and food security globally. Whilst good progress had been made towards achieving the Millennium Development Goal (MDG) targets prior to 2007, achieving these MDG targets including MDG 1 (the eradication of extreme hunger and the halving of poverty and hunger by 2015) is now threatened; poverty and hunger are increasing.
2. Raising productivity is a crucial part of that equation, especially in Sub-Saharan Africa and some parts of Asia where yields remain low compared to developed countries. Reasons for the low productivity are numerous and interlinked and include lack of inputs, a reduction in available water, lack of access to improved germplasm, poor infrastructure, poor credit availability and lack of access to knowledge. Climate change is likely to become increasingly important.
3. One area for improving productivity is to lose less of what we produce. Currently, one third to one half of all food produced is lost from "field to fork". This is due to pre- and post-harvest losses as well as waste in the retail sector and at the consumer's table. Reducing these losses should have a big impact on productivity and consequently on food security. Raising awareness of the importance of plant health by policy makers and other stakeholders is crucial.
4. Yet plant health issues are often ignored despite their impact on livelihoods and food security. One problem is the systematic monitoring of plant health problems in the field and the collection of reliable field data. We do

not know enough about the problems in the field until it is too late to implement eradication plans or even viable management programmes. Initiatives such as the Global Plant Clinic (GPC) can help strengthen surveillance and collect more accurate data as well as help to build capacity in-country on plant health.

5. Evans (2009) has advocated a new "Green Revolution" using "knowledge intensive" approaches but they will only be successful and truly sustainable through partnership with in-country stakeholders. The initiatives outlined in this paper such as the GPC and COPE are excellent examples of such "knowledge intensive" approaches that are being used by CABI and our partners globally to improve plant health systems through improved capacity within developing countries.

Acknowledgements I would like to thank my colleagues Dennis Rangi, Dannie Romney, Eric Boa and Gretel White for valuable discussions.

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