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Review

Climate change and the current 'food crisis'

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Abstract

Many reasons are being advanced for the current 'food crisis' including financial speculation, increased demand for grains, export bans on selected foodstuffs, inadequate grain stocks, higher oil prices, poor harvests and the use of crop lands for the production of biofuels. This paper reviews the present knowledge of recorded impacts of climate change and variability on crop production, in order to estimate its contribution to the current situation. Many studies demonstrate increased regional temperatures over the last 40 years (often through greater increases in minimum rather than maximum temperatures), but effects on crop yields are mixed. Distinguishing climate effects from changes in yield resulting from improved crop management and genotypes is difficult, but phenological changes affecting sowing, maturity and disease incidence are emerging. Anthropogenic factors appear to be a significant contributory factor to the observed decline in rainfall in southwestern and southeastern Australia, which reduced tradable wheat grain during 2007. Indirect effects of climate change through actions to mitigate or adapt to anticipated changes in climate are also evident. The amount of land diverted from crop production to biofuel production is small but has had a disproportionate effect on tradable grains from the USA. Adaptation of crop production practices and other components of the food system contributing to food security in response to variable and changing climates have occurred, but those households without adequate livelihoods are most in danger of becoming food insecure. Overall, we conclude that changing climate is a small contributor to the current food crisis but cannot be ignored.

Keywords: Climate variation, Crop production, Food security, Yield, Biofuels

Review Methodology: We searched the following databases: CAB Abstracts and Web of Knowledge Science (keyword search terms used: climate change and food security, food crisis, drought and Australia, yield and climatic trends, and biofuels and food security). We used the references from articles obtained by this method and from the Intergovernmental Panel on Climate Change, Fourth Assessment Report (2007) to identify additional relevant material.

Introduction

The present 'food crisis' of worldwide increases in food prices and some, localized, food shortages has attracted much attention and comment in the general press (e.g. *The Economist* 19–25 April 2008). A variety of reasons, many operating on different timescales, has been given for these increased prices of food including speculation, the falling value of the US dollar, increased demand for grains, export bans on selected foodstuffs, inadequate grain stocks, higher oil prices, poor harvests and the use of crop lands for the production of biofuels.

Whatever the short-term drivers of prices, the prices of most cereals have been rising slowly since 2000 but especially since 2005. Wheat, for example, increased from $105 per tonne in 2000 to $167 per tonne in January 2006 to $481 per tonne in March 2008 [1]. Prices reflect several different components of food systems that are also altering rapidly as a consequence of changes in several supply and demand factors. On the demand side, economic growth in countries such as China and India coupled with urbanization and the increasing influence of the retailing sector is pushing up the consumption of meat and dairy products (projected to increase by up to 2.4% per year between 2007 and 2016 [2]). On the supply side, the diversion of a significant proportion of the USA maize crop to bioethanol production (25% of the crop in 2007) coupled with poor harvests of wheat in Australia and parts of eastern Europe reduced the amount of long-distance tradable grains at a time when global cereal stocks (about 400 Mt) were at their lowest levels since the early 1980s. Maize exports from the USA averaged 47 Mt/year from 2000 to 2005, but in 2007, 80 Mt went to ethanol refineries. Oil prices have also risen, leading to increased fertilizer, transport and distribution costs, and a growing realization that world cereal and energy prices are not independent [2, 3]. The linkage is clearly seen in wheat prices, which, like oil prices, tripled between January 2000 and July 2007, and in the doubling of maize and rice prices over the same period [2].

The lack of stocks may be a major factor in the short-term increase in grain prices [4], but while the current high prices are unlikely to be sustained as farmers increase production in 2008, they are likely to remain relatively high for the medium term [5]. This will bring benefits to some producers but poses problems for the poor, governments of low-income countries and aid agencies supplying food, although with the appropriate policies, higher prices could provide incentives to produce local food and stimulate agriculture [6].

To these short- and long-term issues can be added the reality of climate change, and its likely growing importance in the future as a factor affecting food production [7, 8]. The purpose of this paper is to review the present knowledge of recorded impacts of climate change and variability on crop production, and to estimate its contribution to the current ‘food crisis’. Such contributions might arise directly through the impact of existing climate change and/or climate variability on crop production, or arise indirectly through actions to mitigate or adapt to anticipated changes in climate.

Present Effects of Climate Change and Variability

Climate Change and Yield

The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) [9] drew attention to the effects of either increasing mean temperature or its variability or both on the probability of occurrence of more extreme temperatures and hence on crop performance (Figure 1). The effect of increasing the mean temperature is relatively straightforward, with the frequency distribution moved towards hotter and away from colder temperatures. However, increased variability of temperature becomes very important if biological responses are non-linear and there are absolute thresholds for particular processes. Increasing variability of weather (and thus climate) may stem from three sources [9, 10]:

(1) changes in the mean weather such as an increase in annual mean temperature and/or precipitation;

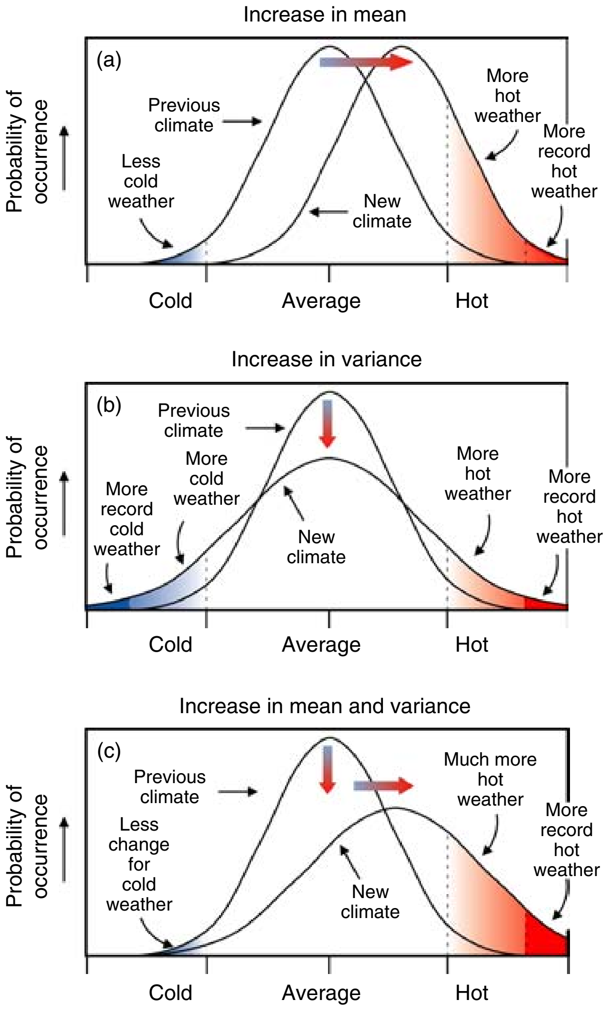

Figure 1 Postulated changes in the distribution of temperatures involving changes in (a) mean, (b) variance and (c) both on the frequency of occurrence of extreme conditions [9]

(2) a change in the distribution of weather so that there are more frequent extreme weather events such as physiologically damaging temperatures or longer periods of drought; and

(3) a combination of changes to the mean and its variability.

All three possibilities would produce higher maximum temperatures, hotter days and more intense precipitation and drought events. A key question for food security is how any such changes in weather variability would be manifest in crop production; interestingly, changes in pests and diseases associated with particular crops are also likely but are rarely considered explicitly in current models. Typically, models of crop productivity demonstrate that increased annual variability of weather results in increased variation of yield [10], although this is not always so and is often dependent on the precipitation scenario that is considered. This result implies that

Table 1 A summary of investigations of the estimated contribution of existing climate change or climate variability to crop performance

Crop	Location	Finding	Source
Cereals (rice, wheat and maize)	China	Warming trends for 1981–2000 (especially minimum temperatures) at five sites associated with earlier crop development and negative impact on yield (except one site, in the north, which was positive)	[15]
Maize	Canada (Quebec)	Effect of climate change (warming) on yield indiscernible in comparison with effects of changes in technology for 1973–2005, but July temperature and May precipitation explained 62% of yield variability	[28]
Multiple crops	Czech Republic	Climate change (higher mean temperature and increased sunshine hours) in 1951–2000 favoured yields of wheat, barley, rape, sugar beet, rye, maize and legumes but had no effect on oat, flax, potato, hops or wine grapes	[26]
Multiple crops	Global	Global warming during 1981–2002 decreased yields by 4.3 kg/ha/year for wheat and maize, and by 6.95 kg/ha/year for barley. There was no discernable effect of rice, soybean or sorghum	[27]
Multiple crops	USA (California)	Climatic trends for 1980–2003 had mixed effects on crop yields with orange and walnut increased, avocado decreased, and wine and table grapes, almonds, lettuce, strawberries, hay, cotton, tomatoes and pistachios unaffected	[29]
Pulses	Canada and USA (Northern Great Plains)	Climate warming (about 0.7 °C) has encouraged expansion of areas of the cool-season pulses (pea, lentil and chickpea), and of warm-season common bean	[19]
Rice	India (Indo-Gangetic Plain)	Decrease in solar radiation (because of aerosol pollution) and increased minimum temperature associated with declining yields for 1985–2000	[18]
Sugar beet	UK	Climate change (mainly warmer weather) accounted for two-thirds of the measured yield increase for 1976–2004	[16]
Wheat	Australia	Climate change (mainly via increased minimum temperatures) accounted for 30–50% of the 0.5 t/ha yield increase for 1952–92	[20]
Wheat	India (Indo-Gangetic Plain)	Decrease in solar radiation (because of aerosol pollution) and increased minimum temperature associated with increasing yields for 1985–2000	[18]
Wheat	Mexico	Climate change (especially cooler nights) can explain much of the increased yield for 1988–2002	[17]
Winter rye	Germany	Warmer winter temperatures and an associated earlier start to the growing season were probably an influence on yield increases in the period 1987–96	[25]
Winter wheat	UK	Climate change had no effect on grain yield for 1976–2004	[16]

increased weather variability may lower the security of food supply in terms of both amount and quality. Drought and floods are already major weather factors influencing food security in sub-Saharan Africa [11], present as an on-going issue in some communities and as a 'shock' in others [12].

While model predictions of crop responses to projected climate changes are numerous, relatively few assessments have been made of the effects of the measured changes in climate that have occurred in the last 50 years or so – a period in which the global mean air temperature has increased by 0.13 °C per decade [13]. Table 1 summarizes the information available from a range of studies examining climate and yield records at different scales and over different time periods, using a wide range of statistical and process-based modelling approaches.

Table 1 shows that a majority of such assessments have been made on temperate cereals grown in northern mid-latitudes with very little information available for crops in the tropics. Overall, the results are, perhaps expectedly, variable and demonstrate differences in response between crops at the same sites. When associated with other studies, though, there are some common features:

(1) Many of the analyses note an increase in mean temperature of about 1.0–1.4 °C over the last 30–40 years ([14] Germany, [15] China, [16] UK), often with a larger change in minimum than in maximum temperatures ([15] China, [17] Mexico, [18] India, [19] Northern Great Plains, [20] Australia); none of the studies detected any trend in precipitation.

(2) Warmer temperatures have resulted in phenological change and there is some evidence for changes to disease incidence and to farming practices. In the UK, 25 of 29 events (including emergence, flowering and harvest of different crops) were advanced by an

average of 5.5 days in the 1990s compared with the 1980s with response rates ranging from 4 to 12 days earlier per °C for an increase of 1.4 °C in January–March mean air temperature [21]. Similar advances in phenology were found for apple, sweet cherry, winter rye, sugar beet and maize in Germany [14] and for rice in China [15]. There is some evidence that farmers in northern latitudes have already adapted to the warmer temperature by, for example, sowing spring crops earlier; the date by which 50% of the UK sugar beet crop is sown has advanced by about 15 days since the 1970s [16]. In Finland, outbreaks of late blight on potato occurred 2–4 weeks earlier in crops grown in the period 1996–2002, compared with those grown in 1933–1962; shortened rotational periods between potato crops may also have contributed to this change [22].

(3) The effects of changed temperatures (not all are warmer) on crops are complex because different species have different base and optimum temperatures for development, some processes are daytime only (e.g. photosynthesis) while others occur throughout the day (e.g. respiration), and many processes are nonlinearly related to temperature [10]. Globally, average diurnal temperature range has decreased because minimum temperatures have risen faster than maximum temperatures [23], but the consequences of this for crop production are still to be fully explored [24]. Cooler temperatures were associated with increased yields of wheat in Mexico [17] and rice in India [18] (i.e. in warm countries), while in mid-latitude countries, yields were often increased at higher temperatures because such temperatures facilitated winter growth [25] and/or were accompanied by greater irradiance [26].

(4) Statistical methods have developed to permit the analysis of long-term weather and yield records and, most recently, the separation of effects of climate change from those of genetic and agronomic improvements [15, 27]. Generally, the climate effects are small relative to the increased yields resulting from technological improvements [27, 28], but they can be regionally significant [16, 17]. There are several examples where there has been no apparent effect of the climate change that has already occurred on some crop yields [26, 28, 29]. This might be because either these crops are well adapted to both the old and new climates, or varieties and management have been adapted to take advantage of the new climate or something of both.

(5) Process-based computer simulations are relatively few but facilitate exploration of the contrasting performance of different crops in similar regions. For example, simulations of sugar beet yields in the UK based on daily weather data indicated that changes in weather during the growing season, including those permitting earlier sowing, accounted for about two-thirds of the increased sugar yield measured in the national variety trials in the period 1976–2004 [16]. Of the 0.204 t/ha/year increase measured in trials, 0.114 t/ha/year arose from improvements in the weather and a further 0.025 t/ha/year from earlier sowing. The remainder (0.065 t/ha/year) was probably a consequence of improved varieties, improved agronomy and elevated atmospheric CO_2 concentration. There was no indication in these simulations that yields became more variable with time. These results contrasted with those for simulated wheat yields at the same site, which suggested that climate had almost no effect over the same period. The difference in crop response to climate changes was possibly a consequence of the differences in yield-forming processes in the two crops and their responses to temperature. Sugar beet remains vegetative throughout the growing period so that warming accelerates canopy development and thereby increases yield, whereas wheat forms a distinct reproductive structure (the ear) so that while warming advances flowering, it reduces the period of grain filling and thereby does not benefit yield. It is notable that while crop simulations of potential yields of rice and wheat in the Indo-Gangetic Plains [18] demonstrated negative effects on the basis of measured changes in radiation and temperature since 1985, actual yield trends measured in the field were indeed negative for rice but positive for wheat. These studies together demonstrate the difficulties of extrapolating results from one crop to another.

Drought in Australia

One continent in which recent climate change, through drought, has had a profound effect locally, with knock-on effects on the global grain market, is Australia. Wheat crops are produced in both the southwest and southeast regions of Australia with rainfall produced by mid-latitude storms and fronts in the winter half of the year in the two regions. To what extent, though, is the three-decade long decrease in rainfall in southwestern Australia and the recent decade-long drought in southeastern Australia related to the globally changing climate and how much is simply the result of natural variability? In southwestern Australia, the decline in winter rainfall (May–July) has been evident since about 1970, resulting in 15–20% less rain than previously [30]. Several factors may have caused this decline. Sea surface temperatures in the southern and tropical western Indian Ocean increased around 1970, and statistical analysis shows an inverse correlation between rainfall and sea surface temperature [31]. However, including only natural external forcings (solar variability and volcanic aerosols) in atmospheric circulation climate models did not reproduce the rainfall decline, and this could only be achieved by including anthropogenic sulphate aerosols and greenhouse gas (GHG) emissions [32].

Figure 2 Annual production and exports of Australian wheat grain for 1996–2007 [36]

Clearance of native perennial vegetation for annual cropping also appears to have contributed to the decrease in rainfall [33, 34] so that anthropogenic factors appear to be a significant contributory factor to the observed decline in rainfall.

In southeastern Australia, rainfall has decreased since 1997 so that annual mean rainfall has been 14.1% below the long-term mean, with drier than average autumns (when crops are typically sown) accounting for 61% of the reduction [35]. This decade-long reduction in rainfall appears to be independent of the El Niño Southern Oscillation (ENSO) impact, which in any case, has only a weak effect on autumn rainfall in southeastern Australia. Such low rainfall has occurred before (1900–9 and 1936–45) but the present drought is unusual because of the dry autumns brought about by a shift in atmospheric circulation. Furthermore, the combination of consecutive dry years, high daily maximum temperatures and cold night-time temperatures (with frosts) is unusual, and a role for anthropogenic-forced climate change via increased GHG concentrations, at least on temperature, seems likely [35].

The consequences of the dry conditions on grain production and exports have been significant (Figure 2). Exports of wheat grain in undroughted years are typically about 16 Mt (70% of the wheat produced) but in the two dry seasons of 2002/03 and 2006/07 decreased to about 8.5 Mt (87% of production) [36]. Although the wheat produced in Australia is only a small proportion of global production (mean 3.4% over the period 1995–2007), exports from Australia were, on average, 13.9% of the wheat that was globally traded over the same period. Variation in climate in Australia, then, has a disproportionately large effect on wheat markets if Australian production is diminished.

Climate Variability

Several studies have raised the prospect of substantial effects of increased climate variability on crop production in the future [37–39]. Such variation can arise because of short-term extremes such as hail, frost and flooding or as a consequence of changes to large-scale circulation patterns like the ENSO and North Atlantic Oscillation (NAO). Crop production in many countries in the tropics is markedly influenced by the ENSO (e.g. maize yields in Zimbabwe [40]; rice yields in Indonesia [41]) and in southeast Asia is associated with dry conditions. For example, in Indonesia, 93% of droughts between 1830 and 1953 occurred during El Niño years [42]. Similarly, in north and northwest China, rice yields decreased during warmer El Niño years in the period 1962–80 by about 2–20% for each 1 °C increase in May–September sea surface temperature anomaly in the tropical Pacific Ocean [43]. The NAO influences European and Scandinavian climates through its effects on winter storm tracks across the northern Atlantic Ocean. The main influence is on winter climate, but the winter NAO also affects the following summer climate, especially the likelihood of drought. In the UK, a positive winter NAO index was associated with a low rate of herbage (grass and forbs) growth, accounting for 22% of the interannual variation in growth rate [44]; this association was mediated via the potential soil moisture deficit.

Variations in weather are already a major consideration for crop production in sub-Saharan Africa [11, 45, 46], and models of future production show that large parts of Africa are likely to be adversely affected by climate change (e.g. [47]). This has raised concerns that were extremes to become more common, then African agriculture would suffer disproportionately. The ENSO has been shown to be closely linked to rainfall variability in several parts of the continent (especially in the south and east, e.g. [40]), and on occasions to severe droughts such as that occurred in southern Africa in the early 1990s. Is there any evidence, though, that climate variability is increasing?

While there is some evidence of changes in temperature extremes in southern and West Africa [48], there is no conclusive evidence that the incidence of ENSO-associated droughts is increasing [49]. Farmers have developed strategies to cope with the climatic uncertainties, but these are typically risk spreading in nature and focused more on mitigating the negative aspects of poor seasons rather than exploiting the positive opportunities offered by good seasons [50]. For example, farmers in the semi-arid tropics of Kenya overestimated the proportion of poor years but underestimated the proportion of good years with the result that most farmers remain poor and vulnerable to future climatic shocks [50].

Mitigating Climate Change

Growing crops for biofuels has been highlighted as a factor in the current food crisis because of its direct competition with land for food production. It is noteworthy, though, that the area occupied by biofuels in 2007 was only 2 Mha, compared with 1500 Mha of crops and 4500 Mha of pastures worldwide. While the reasons for growing crops for biofuels are complex (including increased energy security, increased supplies of transportation fuels and decreased net emissions of GHGs), the indirect effect of climate change on modifying land use and food production is evident.

Biofuels have been suggested as a means of mitigating climate change because current photosynthetic activity, rather than fossil fuel, is used to produce energy, thereby reducing net CO_2 emissions. However, it is only in the first production cycle that CO_2 is mitigated (i.e. removed from the atmosphere); on combustion it is released again and subsequent production cycles only substitute for fossil fuels. Prior to the industrial revolution, biomass energy was the world's dominant source of energy and even today accounts for about one-third of the energy derived from non-fossil fuel sources [51]. Concerns about climate change in the European Union coupled with a desire to reduce dependence on oil imports in the USA, Brazil and elsewhere have resulted in increased production of biofuels to meet the requirements of various policy instruments. Although biofuels comprise only 2% of global biomass energy, and replace only about 1.7% of the fuels used for transportation, they are locally important (e.g. in Brazil where there is 40% petroleum replacement) and are of growing importance in the plans of several countries (including China) [52]. However, a consequence of the rapid, recent growth in the biofuels market is a much closer integration of the agricultural and energy sectors with the use of food and feed crops for fuel 'altering the fundamental economic dynamics that have governed global agricultural markets for the past century' [52].

In 2004, total global primary energy supply was about 463 EJ/year (1 EJ=10^{18} J) of which about 15–60 EJ/year was biomass (mainly fuel wood, charcoal and dung) [53]. Annual global net photosynthesis is estimated at about 3150–4000 EJ and, theoretically, a significant proportion of this could be made available for energy without detriment to food production [54]. However, while the potential is there, technical and other limitations mean that, in practice, only about 53 EJ of liquid biofuels for transportation will be available by 2050 (compared with 1.3 EJ currently) [54].

The interaction of four major factors will determine the success or otherwise of biomass energy in future [55]:

1. the intrinsic productive capacity of land and ocean ecosystems;
2. the alternative uses for the land and water resources used for biomass energy production;
3. the effects of biomass energy technologies on offsite factors such as pollution and invasive species; and
4. the conversion processes for increasing the energy yield per unit of biomass and from each unit of land or water.

All four factors have implications both for the production of food and of GHGs, but especially factor two. Several studies have attempted to calculate the net effect of growing crops for biofuels on GHG emissions after allowing for energy inputs such as fertilizer applications, cultivation and other inputs in the production process [56–58]. Overall, bioethanol from Brazilian sugarcane with an energy yield of 116 GJ/ha has the greatest GHG mitigation potential, reducing emissions by about 100% compared with petroleum [52]. The comparable GHG reductions for maize bioethanol, soybean biodiesel and cassava bioethanol were 13–52, 41 and 40%, respectively [52]. The reduction for oil palm biodiesel is probably as great as that for sugarcane bioethanol, but for both crops the values are highly dependent on whether the plantations are on newly cleared or long-term arable land. Clearing land for new biomass crops can result in GHG emissions that are much greater than any benefits provided by biofuels because soils and plant biomass are biologically active stores of carbon that are decomposed by microbes when disturbed, releasing large quantities of CO_2 [59, 60]. For example, replacing a lowland tropical rainforest in Indonesia or Malaysia with oil palm to be used for biodiesel would produce about 610 Mg CO_2/ha, which would take about 86 years to recoup from the use of biodiesel instead of fossil fuel, while soybean diesel replacing Amazonian rainforest producing >280 Mg CO_2/ha would take about 320 years [60]. Conversely, the creation of permanent forest from grassland and cropland will, over a 30-year period, reduce CO_2 in the atmosphere by at least as much as any existing technology for producing liquid biofuels [59]. These disadvantages of converting forests and grasslands with large carbon stocks in their soils to biofuel production have focused attention on the potential use of abandoned agricultural lands for this purpose [55, 61], and on the need to avoid the conversion of grasslands and forests to cropland as a consequence of existing cropland used for food grains being diverted to be used for biofuel [62].

While the actual amount of land converted from food production to biofuel production is currently slight, the trend is likely to remain upwards, especially if oil prices remain above US$60. What has had an effect is that the increased production of maize bioethanol in the USA has reduced the amount of maize available for trade. About 25% of the USA maize crop was used for bioethanol in 2007 and this has significantly reduced the 55–60% of maize that the USA normally contributes to global trade [52]. This, coupled with the other factors driving up food commodity prices, is affecting the food security of low-income people in the developing world.

Adapting to Climate Change

Agricultural Productivity and Food Security

There is a substantial body of work that shows that agricultural production is sensitive to climate change and variations in climate, and from this the deduction is made that potential effects of climate changes in future productivity are likely to be negative in regions that are already water-limited or positive in regions that are temperature-limited [63]. However, crop production alone cannot ensure food security and other factors related to availability, plus components of access and utilization, are essential contributors to robust food systems [64, 65]. To date, most assessments of the potential impacts of climate change have only addressed effects on production, and so have not considered the full range of adaptation options that might be available to societies to ensure food security [66].

Several studies have indicated that resilience of households to climate shocks such as drought is markedly affected by access to information, cash and other assets (Africa [12], Asia [67] and Indonesia [68]). For example, a study of households in Sulawesi, Indonesia, investigating the consequences of El Niño-related droughts found that household drought resilience was positively influenced by the possession of assets that could be readily converted into cash as well as by access to credit [68]. Resilience was substantially enhanced by those with a high level of technical efficiency in agricultural production (i.e. those that made optimal use of inputs through skilful crop management) because income from crops was increased during years of typical climatic conditions facilitating the accumulation of assets and savings that could be used to offset or smooth the effects of drought via food purchases. Similarly, in the present food crisis, it is those households without adequate livelihoods that are most in danger of becoming food insecure [6].

The Challenge of Adaptation and Sustainability

The issue of appropriate adaptation to climate change and variation is becoming a pressing issue [69]. In the UK, growers of sugar beet have already adapted their crop husbandry to the warmer weather through earlier sowing resulting in enhanced yields because of the longer growing period [16]. Similarly, relatively simple and inexpensive changes to crop management (such as using crop genotypes with longer growing periods that take advantage of earlier sowing) might be advantageous in some areas, especially if water is available throughout the growing season. For example, models of cropping systems in northern and central Italy show that despite the positive effect of increased [CO_2], climate change would depress crop yields by 10–40% if current management practices were unaltered (largely because of the warmer air temperatures accelerating the phenology of current cultivars), whereas a combination of early planting of spring and summer crops and the use of slower-maturing winter cereal cultivars should allow present yields to be maintained [70]. However, a major caveat to this conclusion was that 60–90% more irrigation water would be required to maintain grain yields under conditions of climate change.

Human adaptive practices to climate may also have the benefit of changing the underlying associations between climate and production. In north and northwest China, the negative association of yields and ENSO events before 1980 was reversed subsequently because a new irrigation system ensured that sufficient water was available for rice crops to benefit from the greater number of sunshine hours (and hence greater potential photosynthesis) during El Niño periods [43]. This study highlights the uncertainties associated with translating simple climate/yield relations to projections of food security.

While attempting to adapt food systems to cope with climate change, it will also be important to ensure that the changes proposed do not exacerbate climate change or other aspects of environmental degradation (i.e. that they contribute to sustainability) [64]. As described earlier, past and continuing clearance of land for agriculture (extensification) has made a significant contribution to GHG emissions, and this has led to calls for more intensive systems that are both high yielding and more environmentally benign [71]. Past intensification over the last 50 years or so has saved substantial areas of grassland and forest from clearance but has generally increased GHG gas emissions as a consequence of greater fertilizer use, and resulted in environmental degradation in some areas as a consequence of water pollution, soil erosion and loss of biodiversity. The increasing global demand for food will be met mainly by intensification of existing areas of crop production, but this will require substantial investment in research to increase the efficiency of use of added inputs, to develop improved germplasm with durable disease resistance and enhanced nutrient use efficiency, and to reduce emissions to water bodies and the atmosphere [72, 73]. One beneficial consequence of the 'food crisis' is that agriculture and food security are back on national and international agendas.

Conclusions

- The current 'food crisis' is a result of several interacting factors simultaneously affecting the supply and demand functions of food systems.
- Recent publications have identified increases in mean temperature of about 1.0–1.4 °C over the last 30–40 years in different regions; this is more a consequence of increased minimum than maximum temperatures. There has been no discernable trend in precipitation. Warmer temperatures have resulted in phenological changes with some evidence for changes to disease incidence and to farming practices (sowing dates and genotypes).
- Effects on yields have been variable, with positive, negative and no effects reported. There is a suggestion that effects on vegetative crops such as sugar beet may be more readily discernable than those on cereals.

- The direct contribution of climate change to the present food crisis is slight. However, anthropogenically assisted changes in rainfall patterns in the wheat belt of Australia have contributed to the drought and directly reduced tradable grain on world markets. Attempts to mitigate climate change (combined with attempts to ensure local energy security) through biofuel production have also affected the world market for tradable maize grain. These direct and indirect effects of climate change have affected grain prices.
- Future mitigation and adaptation strategies for food systems to cope with climate change must ensure that the changes proposed do not exacerbate climate change (e.g. through land use changes that emit more GHGs) and that they contribute to sustainability.
- Increased food prices have disproportionately affected the poorest people with households without adequate livelihoods in most danger of becoming food insecure: 'In the medium term, economic and agricultural growth can offset the damage (of higher food prices), but this will require more determined efforts to boost food production' [6]. 'Placing agricultural and food issues onto the national and international climate-change policy agendas is critical for ensuring an efficient and pro-poor response to the emerging risks' [2].

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