

Cereal production in Drylands

RECENT TRENDS IN WORLDWIDE CEREAL PRODUCTION

The world's food supply is obtained either directly or indirectly from plants, but fewer than 100 are used for food (Burger, 1981). Worldwide, about 50 species are cultivated actively, and as few as 17 species provide 90 percent of world's food supply and occupy about 75 percent of the total tilled land on earth (Harlan, 1976). The important plant species include wheat (*Triticum aestivum*), rice (*Oryza sativa* L.), maize (*Zea mays* L.), potato (*Solanum tuberosum*), barley (*Hordeum vulgare*), sweet potato (*Ipomea batatas*), cassava (*Manihot esculenta*), soybean (*Glycine max*), oat (*Avena sativa*), sorghum (*Sorghum bicolor*), millet (*Pennisetum typoides*), rye (*Secale cereale*), peanut (*Arachis hypogaea*), field bean (*Dolichos lablab* var. *purpureus*), pea (*Pisum sativum*), banana (*Musa paradistaca*), and coconut (*Cocos nucifera*).



Eight cereal grains — wheat, barley, oat, rye, rice, maize, sorghum and millet provide 56 percent of the food energy and 50 percent of the protein consumed on earth (Stoskopf, 1985). Cereals continue as the most important source of total food consumption in the developing countries where direct consumption of grains provides 54 percent of total calories and 50 percent for the world as a whole (FAO, 2006). Wheat and rice are by far the most widely consumed cereals in the world. Maize is a major crop for both direct and indirect human consumption because it is a major energy feed for animals. Wheat, rice, and maize constitute approximately 85 percent of the world's production of cereals.

Cereal crops are grown in countries across the globe. One or more cereal grains are basic crops in the seven major areas of the world — Africa, North America, South America, Asia, Europe, Oceania, and the former USSR (Stoskopf, 1985). Adapted cereal crop species and cultivars within each species are found in all latitudes from 60° N to 50° S, on soils ranging from slightly acid to alkaline, in both arid and well-watered regions. Only rice is slightly more confined to low/middle latitudes. Rice is mostly grown under irrigated conditions and maize is usually limited to irrigated areas or regions where precipitation is both adequate and dependable. Wheat is the most widely grown cereal crop and is extensively grown in dryland regions under both non-irrigated and irrigated conditions. Every month of the year, a crop of wheat is being harvested somewhere in the world, from as far south as Argentina to as far north as Finland. Wheat is best suited to areas between 30° and 50° N latitude and 25° and 40° S latitude. Wheat is a major crop of the United States and Canada, Australia and is grown extensively in almost every country in Latin America, Europe and Asia. Well defined environmental conditions must be met, however, with respect to temperature, precipitation, frost-free period, and soil if wheat production is to be successful. Winter wheat crops usually produce higher yields than spring wheat and are more extensively grown. Two factors limit the growing of winter wheat — the ability to overwinter high latitudes and a vernalization or cold temperature-photoperiod interaction at low latitudes (Stoskopf, 1985). Maize can be grown as far north as the 50th parallel in Canada and over

most of the United States, throughout Mexico and Central America, to as far south as central Argentina and Chile (about 35° S latitude) in South America (Stoskopf, 1985). Maize is also adapted to Africa, central Europe and Asia, making it a crop that is universal in its adaptation.

Production data for cereals in the major world regions — in the period 1961 to 2006 are presented in Annex 3, Table 1. Those figures and Table 3 show that world population of cereals increased 2.53 times in that period. In 2006, wheat, rice and maize accounted for more than 87 percent of cereal production, compared with 73 percent in 1961. Maize has shown a rapid increase in recent years and accounted for 31 percent of the cereal production in 2006 compared to only 23 percent in 1961. This percentage will almost certainly increase further in future years, as more maize is used for production of biofuel. In terms of food security, a very positive fact is that cereal production has increased at a faster rate in the developing countries than in the developed countries. From 1961 to 2006, cereal production in developing countries increased 2.7 times compared to 2.3 times for the developed countries. The production in developing countries increased from about 190 kg/capita in 1961 to about 250 in 1985, but has remained almost constant for the last 20 years. For the entire world population, cereal production per capita increased from 286 kg in 1961 to 371 kg in 1990, and has decreased slightly since 1990 (Table 3). The impact of increasing amounts of maize (and other cereal crops) being diverted from food to industrial uses, creates some uncertainties for the future.

Between 1961 and 1994, wheat yields increased at an average annual rate of about 2 percent in developing countries except China and India, the two largest wheat producers (Pingali and Rajaram, 1999). In the Near East/North African countries and the wheat-producing countries of sub-Saharan Africa, wheat yields grew at about 2.4 percent/year from 1961 to 1994. This compared with about 1.8 percent for Latin America, which started at a higher base. Yields in India rose sharply in the early years of the Green Revolution, from the mid-1960s until the late 1970s. In China, grain yields rose rapidly after rural reforms began in 1978. Between 1978 and 1990, wheat yields increased from 1.8 to 3.2

TABLE 3
Trends in world production of cereals

| | 1961 | 1970 | 1980 | 1990 | 2000 | 2006 |
|----------------------------------|------------------|-------|-------|-------|-------|------|
| | (million tonnes) | | | | | |
| Wheat | 222 | 311 | 440 | 592 | 580 | 606 |
| Rice | 216 | 316 | 397 | 520 | 597 | 635 |
| Maize | 205 | 266 | 397 | 483 | 589 | 695 |
| Sorghum | 41 | 56 | 57 | 57 | 59 | 56 |
| Millet | 26 | 33 | 25 | 30 | 27 | 32 |
| Total cereals * | 877 | 1 193 | 1 550 | 1 953 | 2 051 | 2221 |
| Cereals/capita (kg) | 286 | 323 | 349 | 371 | 339 | 336 |
| Used for feed (%) | 31 | 37 | 37 | 33 | 33 | |
| Arable land (million ha) | 1 266 | 1 302 | 1 331 | 1 383 | 1 380 | |
| Irrigated land (million ha) | 139 | 168 | 210 | 244 | 271 | |
| Fertilizer used (million tonnes) | 31 | 69 | 117 | 138 | 137 | |

* Totals rounded independently

Source: FAOSTAT (www.fao.org)

tonnes/ha, maize yields from 2.8 to 4.5 tonnes/ha and paddy rice yields from 3.9 to 5.7 tonnes/ha. In 2002, Chinese grain yields for wheat, maize and paddy rice were 3.9, 5.0 and 6.3 tonnes/ha, respectively (FAO, 2003c).

The rise in grain production, particularly in developing countries between the 1960s and 1990s was largely a result of increased irrigation and inorganic fertilizer use, along with better crop varieties, pest control, and other management improvements. Between 1961 and 2000, the irrigated area in developing countries more than doubled. The amounts of fertilizer used increased 24 fold in developing countries and 34 fold in the developing countries in Asia (FAOSTAT, 2007). Fertilizer use in developed countries doubled during the same period. As a group, developing countries have been narrowing the gap in grain production with developed countries.

Despite the increase in cereal production in developing countries between the 1960s and the 1990s, in recent years, a decrease in the major producing countries has been recorded. For example in China, the production of grain, particularly wheat, has declined from 123 million tonnes in 1997/98 to 100 million tonnes in 2000/01 (Hsu, Lohmar and Gale,

2001) with a production of 91 million tonnes being recorded in 2004 (FAOSTAT, 2007). The decline is attributed to a combination of drought, oversupply, reduced government support, shift to higher-income crops and a shift in emphasis from quantity to quality. China's production of wheat, maize and rice fell by a combined total of 32 million tonnes in 2004 compared with 1999 (FAOSTAT, 2007).

While global food demand is increasing, the agricultural resources for producing grains are being diverted increasingly from cereal production to other agricultural and non-agricultural activities. Pingali and Rajaram (1999) forecast that the global demand for wheat in 2020 will be 40 percent greater than the 552 million tonnes produced in 1997, mainly because of increased demand in developing countries. Pingali and Pandey (2000) projected that global maize demand in 2020 will be 50 percent greater than the 558 million tonnes produced in 1995. The increased demand for maize in recent years has largely been driven by rising incomes and the consequent growth in meat and poultry consumption.

A paradigm shift to the use of cereals for producing ethanol for fuel is presently occurring, which

could have far-reaching consequences. Maize in the U.S. and wheat in Europe are being used in rapidly increasing quantities for producing ethanol for fuel as a result of changes in the cost and availability of oil, concerns over fuel supply, fuel security and Kyoto Protocol compliance. Although it is too early to fully determine the impact of this, the fact that food systems and energy systems are competing for cereals is a historic development. The U.S. produces about 40 percent of the world's corn and has usually exported about 20 percent of this accounting for about 60 to 70 percent of the exports from all nations. However, ethanol production is increasing so rapidly in the U.S. that exports will almost certainly be reduced significantly and the price of exported maize is likely to increase significantly. The Institute for Agriculture and Trade Policy (2006) reported that ethanol production consumed less than 5 percent of the U.S. corn crop 10 years ago. In contrast, ethanol production consumed about 14 percent of the 2005 crop, and estimates indicate that it was more than 20 percent in 2006. Furthermore, an additional 58 plants are currently under construction or being expanded to supplement the more than 100 ethanol production plants. Europe and China are also using cereals as feedstock for ethanol fuel. The competition for maize and other cereals has resulted in an increase in price, and while this will result in increased production of cereals, the amount used for food could decrease and this could decrease meat production and the amounts of maize available for exports – raising issues of food security. In December, 2006, the National Development and Reform Commission of China ordered local governments to stop approving new projects that process maize for industrial uses. China used more than 23 million tonnes of maize for industrial uses in 2005, an increase of 84 percent from 2001, while production of maize increased only 21.9 percent over the same period (People's Daily Online, 2006). The population in many dryland areas is increasing significantly and it will become increasingly important that these areas are as self-sufficient in cereal production as feasible. Developing countries must either produce sufficient grain for their needs or produce enough foreign exchange to import their needs. The escalating use of grain for fuel production will almost certainly result in smaller amounts available for import and higher costs.

Pingali and Rajaram (1999) claim serious concerns about future wheat supplies have emerged for the first time since the start of the Green Revolution. Newer generations of HYVs continue to improve on yields of earlier varieties. However, starting in the 1990s, the rate of growth in yield potential has slowed considerably. In environments favourable for wheat production, the economically exploitable gap between potential yields and farmer yields has been reduced considerably in the past three decades. Therefore, given existing technologies and policies, the cost of marginal increments in yield could exceed the incremental gain. In addition, decades of poor water management have caused large tracts of irrigated land to be abandoned or cultivated at lower levels of productivity due to salinization (Ghassemi *et al.*, 1995). The Indian Punjab, Pakistani Punjab, the Yaqui Valley in northwest Mexico and the irrigated wheat areas in the Nile Valley all exhibit visible signs of land degradation attributable to salinity build-up. Salinity is thought to affect nearly 10 million ha of wheat in developing countries (Ghassemi *et al.*, 1995).

THE ROLE OF LIVESTOCK IN CEREAL PRODUCTION

It is forecast that livestock will play an increasingly important role in cereal-producing regions in arid and semi-arid regions in future. In addition to consuming cereal grains, livestock utilize large tracts of land by grazing and foraging in these pastoral/agropastoral systems.

Global livestock numbers are increasing rapidly. Between 1970 and 1990, annual meat consumption per capita in developing countries increased from 11 to 18 kg, and by 2000, it had reached almost 27 kg (FAO, 2006). Milk consumption in developing countries increased from 29 kg per capita in 1970 to 38 kg in 1990 and 45 kg in 2000. Although these gains are very significant, they are still far below the 90 kg meat and 214 kg milk per capita in the industrial countries (FAO, 2006). The growth in demand for meat and milk products will continue, particularly in those developing countries where incomes and living standards are improving. The effect of this on cereal-growing areas will vary depending on the region. The average proportion of total

cash income derived from livestock is much higher in semi-arid and subhumid regions than in more humid regions, where crop production is the principal income source. Sandford (1988) reported that 40 percent of Africa's human agricultural population and an estimated 57 percent of the ruminant livestock live in the semi-arid and subhumid regions of sub-Saharan Africa. Income from livestock in these drier regions accounted for more than half of farmer incomes, compared with less than 10 percent in the humid regions. Livestock systems are usually less variable livelihood sources than grain systems, and they also provide opportunities for increasing the use efficiency of limited water resources (Srivastava *et al.*, 1993). This assertion is supported by Sandford (1988), who reported that the variations in annual livestock output in the Ethiopian highlands were ± 10 percent compared with ± 32 percent for grain production. This evidence indicates that mixed-farming systems can be expected to be considerably more sustainable than purely arable systems in dryland regions.

Mann (1991) reported that the most successful integration of crops and livestock in Australia has been in the cereal-livestock zone in the south of the country. The pasture phase is an important component of the system, and promotes high levels of both crop and livestock production where managed properly. Crop residues are available for livestock and careful grazing can help prepare the land for the following crop, while at the same time maintaining a suitable amount of cover for protection of the land. Although integration brings benefits to both crops and livestock, there are some constraints that may reduce flexibility in both cropping and livestock operations.

THE ROLE OF IRRIGATION IN CEREAL PRODUCTION

There is a water crisis today, not because of having too little to satisfy the needs of the population, but because of the difficulty of managing water so that people and the environment do not suffer (Cosgrove and Rijsberman, 2000). Twenty percent of the world's population do not have access to safe and affordable drinking-water. Even though people use only a small fraction of

renewable water resources globally, this fraction is much higher (up to 80–90 percent) in many arid and semi-arid river basins where water is scarce (FAO, 1996a). As populations increase in semi-arid regions, as is the case in many developing countries, water requirements for industry and domestic use are increasing at the expense of irrigation needs. As people in dryland regions improve their living standards, the competition for water will accelerate. The World Bank (2000) reported that the share of extracted water used for agriculture ranged from 87 percent in low-income countries, through 74 percent in middle-income countries, to 30 percent in high-income countries.

In the future, the way in which water is managed will have a dramatic effect on irrigation and thus on food production. Cosgrove and Rijsberman (2000) consider that a reduction in the rate of expansion of irrigated agriculture is crucial to deal with the water crisis. They call for a 40 percent increase in food production by 2025 with only 9 percent more irrigation water. This would require that the increase in food production comes, to a great extent, from non-irrigated agriculture.

Water for irrigation expansion is becoming harder to find and more costly to develop. At the same time, a proportion of currently irrigated land is threatened because of soil degradation, particularly the buildup of salts and depletion of water resources. For example, the Ogallala aquifer in the Great Plains of the United States of America supplies water for more than one-quarter of that country's irrigated area. In less than 50 years of pumping, many of the wells, particularly in the southern portion of the aquifer, have become so unproductive that the land has been returned to dryland management. Groundwater depletion is also a major problem in central and northern China, north-western and southern India, parts of Pakistan, much of the western United States of America, North Africa and the Near East. Postel (1999) concluded that unsustainable exploitation of groundwater might have become the single largest threat to irrigated agriculture, exceeding concerns over the build-up of salts in the soil.

Hsu, Lohmar and Gale (2001) discussed the effect of reducing water resources gradually on

wheat production in China. Irrigation has been a very important factor in the rapid growth of grain production in China. However, a lack of irrigation water in the future is a major constraint. The groundwater tables in the important wheat-producing provinces of Henan, Shandong and Hebei have been falling rapidly. More than half of the irrigation water supplies in Hebei and more than 40 percent in Shandong are from groundwater. Many rivers and streams in the area have also been overexploited and are dry for much of the year. In this region, wheat is heavily dependent on irrigation because the main growing period is in the dry spring season (Hsu, Lohmar and Gale, 2001).

Globally, the development of irrigated land has been slowing. During the 1960s, irrigation area expanded 2.1 percent per year and reached a peak of 2.2 percent during the 1970s. The rate slowed to 1.6 percent during the 1980s and to 1.2 percent in the 1990s, and the rate from 2001 to 2003 was only 0.1 percent (FAO, 2008). Postel (1999) projected that the global irrigation base is unlikely to grow faster than 0.6 percent/year in the next 25 years, and that this figure may still turn out to be optimistic. Svendsen and Turrall (2007) reported that there were 208.7 million hectares of irrigated land in developing countries in 2002 and 68.1 million in developed countries. Molden *et al.* (2007) showed that while the world's cultivated land increased from 1 368 million hectares to 1 541 between 1961 and 2003, irrigated area almost doubled from 139 million hectares to 277 million. They showed, however, a marked decline in expansion during the past few years. Globally, donor spending on irrigation peaked in the late 1970s and early 1980s and then fell to less than half (Molden *et al.*, 2007). They stated that four factors contributed to the decline. First, there was a sharp drop in cereal prices. Second, there was growing recognition of poor performance of irrigation systems. Third, there was a rise in construction costs of irrigation infrastructure. Fourth, there was growing opposition to environmental degradation and social dislocation often associated with large dams. Recently, there has been renewed interest by the World Bank for reengaging in agricultural water management (World Bank, 2006). The sharp increases in cereal prices since 2005 could also result in renewed interest. World population

growth has also slowed in recent years, but per capita irrigation area peaked in 1978 and has fallen 5 percent since then.

It is estimated that irrigated land which to date cover 197 million ha in developing countries, will increase by 45 million ha by 2030 (FAO, 2002). Most of this increase will be achieved by providing irrigation to rainfed land or from land with rainfed potential not yet in use. Of the area currently irrigated, it is estimated that 42 million ha are in arid and hyper-arid climates, and that 5 million ha of the projected increase will be in such regions. The expansion of irrigation will be greatest in countries that have few land reserves and are hard-pressed to raise crop production through more intensive cultivation practices such as in South Asia, East Asia, and the Near East and North Africa. Four countries (India, China, the United States of America, and Pakistan) account for more than half of the world's current irrigated land. Ten countries, including the Islamic Republic of Iran, Mexico, Russia, Thailand, Indonesia and Turkey, account for two-thirds of the world's irrigated land (Postel, 1999). FAO (2003b) predicts an average increase of 0.6 percent a year between 1997/99 and 2030 in developing countries, compared with 1.6 percent a year from 1960 to 1990. Svendsen and Turrall (2007) state that this will still result in an increase to 45 percent of agricultural production coming from irrigated land by 2030. They also report that this will mean that the amount of water withdrawn for irrigation will increase by 12 to 17 percent above the present level.

Although the costs of developing land for irrigation vary widely both within and among countries, they are becoming increasingly difficult to justify. This is particularly true for cereal production. Future irrigation development will probably become increasingly limited to high-value crops such as vegetables, fruits, and tree crops. It is becoming more important to invest in dryland soil- and water-conservation practices that can increase grain production in dryland regions. Many of these areas already have existing and growing populations whose demands for grain exceed their production, and grain imports are essential. Although increases in dryland grain production may not be able to eliminate the need for imports, the amounts

can be reduced, while at the same time the increased production can improve the economic conditions and living standards of the people. An FAO study (FAO, 1998b) considered that it would be an error to disregard the potential to increase food production from dryland agriculture because of the difficulties associated with it; where dryland agriculture is inefficient, there is scope for increasing food production by improvement. Improving dryland agriculture also shortens the food cycle and enhances food security by producing the food where the consumers are located.

EXPANSION OF CEREAL PRODUCTION

Borlaug (1996a) suggested that improvements in overall crop management can still increase yields by 50–100 percent in much of South and Southeast Asia, Latin America, the Commonwealth of Independent States and Eastern Europe, and by 100–200 percent in most of sub-Saharan Africa. In the case of China, the United States of America, and the European Union, where yields are already high, it will be difficult to achieve further increases. According to Borlaug (1996a), the last major land areas for developing cropland are the acid soils of the Brazilian cerrado, of the Colombian and Venezuelan llanos, and of central and southern Africa.

The central cerrado of Brazil, with about 100 million ha considered potentially arable, is the single largest contiguous block of uncultivated land that can contribute to world food production in the next three decades. This could increase the world's arable land by about 7 percent. However, bringing these potentially arable lands into cultivation presents formidable challenges, and sustaining their productivity may be even more difficult. The soils of this area are mostly deep loam to clay-loam Ferralsols and Acrisols (Oxisols and Ultisols) with good physical properties, but highly leached of nutrients (Borlaug, 1996b). They are strongly acid, with toxic levels of soluble aluminium and manganese; most of the soil phosphate is fixed and unavailable to plants (Furley and Ratter, 1988; Sanchez, 1997). However, there are some varieties of wheat, maize, soybeans, rice, triticale and several species of pasture grass with aluminium tolerance. The degree to which crop production on these soils can be sustained is still a matter of

conjecture and further research.

The potential increase in arable lands in South America will be offset partially by losses in South Asia. Borlaug (1996b) suggests that 21 million ha are being cultivated in South Asia that should not be. These lands are either too arid or so vulnerable to erosion because of topography that they should be removed from cultivation. China has reported that there are 15 million ha of cropland in China with slopes greater than 25 degrees (almost 50 percent), with 70 percent of these lands in the west (China Ministry of Science and Technology, 2001). China began removing these lands from cultivation in Sichuan, Shaanxi and Gansu provinces in 1999. Pilot studies are underway to reclaim lands in 224 counties in 20 provinces and autonomous regions and municipalities in the central and western parts of China.

The Conservation Reserve Program (CRP) was established in the United States of America as part of the 1985 Food Security Act. Under the act, grass has been seeded or trees have been planted on about 14 million ha of highly erodible cropland. Although some of this land may be returned to crop production in the future, the CRP will probably result in a permanent reduction in cropland area.

In view of the probability that there will not be a large overall increase in the amount of arable land to meet the growing demand for cereal grains, yields will have to continue to increase significantly to meet demands not only for food but also for the range of feedstocks for biofuels. Grain yields are determined primarily by soil fertility and water. The 225 percent increase in cereal yields since 1961 has been due largely to a doubling of the extent of irrigated land and the more than fourfold increase in fertilizer use (Annex 3, Table 1). It is unlikely that these inputs can continue to grow at such a rate as, in order to meet future cereal demands, irrigated land would need to expand 20–30 percent by 2025. To meet this, irrigation-water usage would have to increase at least 17 percent above the 1995 level by 2025 (Shiklomanov, 1999; Seckler *et al.*, 1998), even using optimistic assumptions on yield and efficiency improvements. A 30 percent increase in irrigated area would require major investments in water infrastructure, including

large dams. This would probably result in severe water scarcities and risk serious deterioration of ecosystems. However, in contrast, a major reduction in the rate of expansion of irrigation could possibly lead to food shortages and rising food prices. There is already evidence that the rate of irrigation expansion is slowing. According to Rosegrant and Ringler (1999), the annual growth rate in global irrigated area declined from 2.2 percent between 1967 and 1982 to 1.5 percent between 1982 and 1993.

Additional increases in cereal production in developing countries may come from a combination of three approaches:

- The continuation of the development of irrigated lands coupled with HYVs, fertilizers, pesticides and other inputs. This approach has been extremely successful in the past few decades but is becoming increasingly difficult and expensive.
- The development of new areas for rainfed crop production. The FAO model for land resource potential (FAO, 2001a) indicates that there is considerable potential for additional cultivatable land particularly in sub-Saharan Africa and South and Central America. According to the model, 133 million ha of land in Africa are very suitable for rainfed cereal production, and another 558 million ha are suitable or moderately suitable. However, in 2000, only 340 million

ha were under maize and wheat cultivation. Thus, there are many constraints on cereal production in Africa other than soil and water resources. These constraints relate mostly to poor institutional, infrastructural and financial capacities of African countries.

- The improvement of soil- and water-management practices on existing rainfed lands. FAO (2007b) recently published a land productivity potential for agriculture particularly classifying the suitability of rainfed cereal production. The suitability of global land area for rainfed production of cereals with various levels of inputs: low, intermediate and high levels of inputs as well as variability in rainfed production is contained in Annex 4.

If more cereal grains can be produced with the same amount of water (or less) by better water management, water harvesting and water conservation, local food security will be enhanced and there will be less competition for water. The corollary is that more water will remain for household and industrial uses, also to sustain vital ecosystem functions. It is clear that the water-use efficiency of both irrigated and non-irrigated agriculture must be increased.

The following chapters focus on improving soil- and water-conservation practices to increase water-use efficiency in drylands.