Human Carrying Capacity of Asia as Influenced by Environmental Resources

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Key words: *carrying capacity, Asia, food, environment, climate*

1. Agriculture as the fundamental basis for survival of the human being

The 6.4 billion people in the world are living on the Earth, utilizing following two kinds of energy: (1) food energy, and (2) fossil fuel energy. Food energy is the fresh solar energy because crops are converting into the biomass a part of solar energy incident upon crop fields at the present. On the other hand, the energy in petrolium, coal, and natural gas is the fossil solar energy, because these were provided through the photosynthetic activity of primitive plants during the geological age. As well known, the fresh solar energy within foods is the fundamental energy for the survival of the human being as living thing. The fossil solar energy is mainly used to develop and maintain the highly civilized human society.

Food energy is provided with agriculture, animal husbandry, and fishery. Among them agriculture is playing the most important role in supporting the life of the human being. Agriculture is the most oldest industry in the world, because it has initiated 10 to 8 thousand years ago. Since then, many people have concentrated their effort to increase and stabilize food production in each district of the world. Particularly, the 2nd Industrial Revolution started at the middle of the 20th century has resulted in the drastic change in agriculture of the world. Namely, the agriculture has shifted from so-called old fashioned agriculture to high yielding agriculture by introducing many agrotechniques and products developed in the industrial sector.

Figure 1 indicates the secular change in the human population, cereal production, and average temperature of the world during the past 150 years. As can be seen in this figure, projected trends of the world human population and cereal production during the coming 50 years period are also depicted with that of the global mean air temperature estimated from global climate models (GCMs).

High yielding agriculture assisted by well developed science and technology has succeeded to

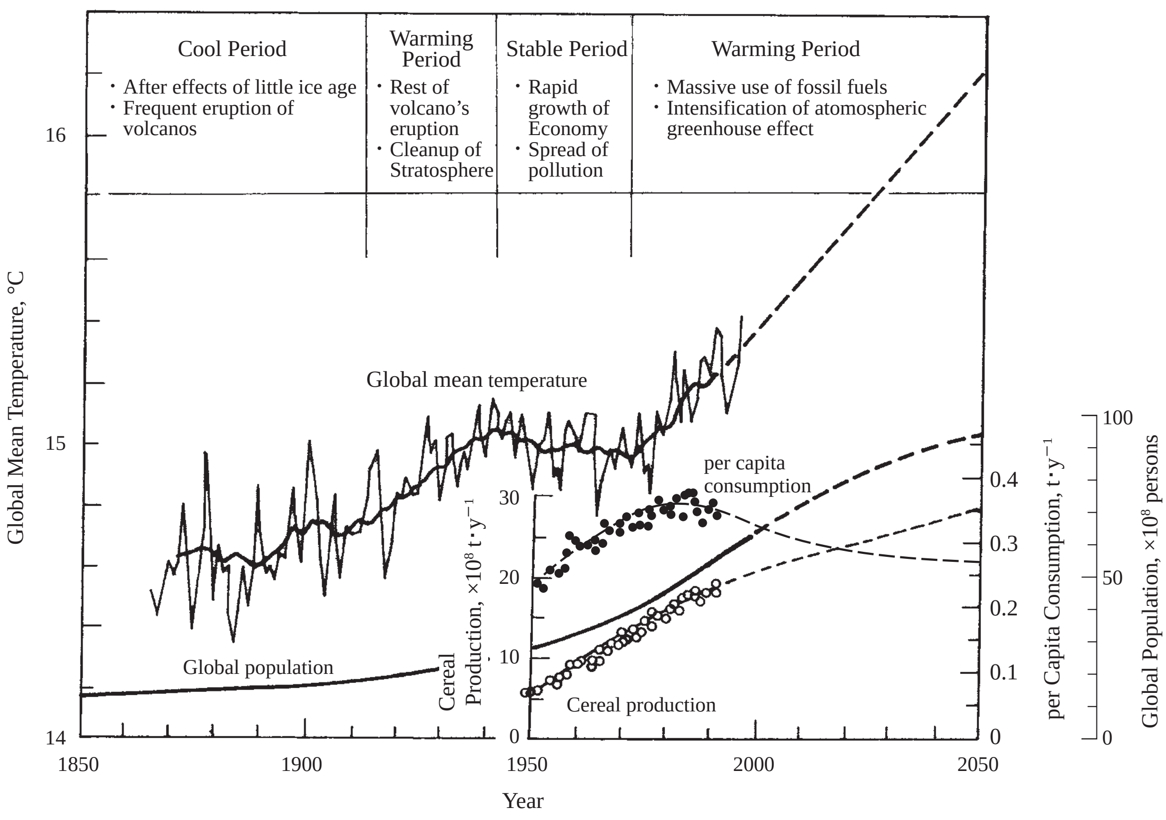

Fig. 1 Secular changes and projections of global climate, world population and world cereal production during the period 1850 to 2050

increase the world cereal production at a so rapid speed as shown in Fig. 1. Namely, the world cereal production increased approximately linearly from 0.6 billion ton in 1950 to 2.0 billion ton in 1990s, indicating that the average increasing rate of cereal production was 28 million ton/y. Although the world population increased from 2.5 billion persons in 1950 to 6.0 billion persons in 2000, the per capita food production increased almost linearly from 250 kg/y to 360 kg/y during this period, improving the nutrition level of people, particularly in developed countries.

The modern high yielding agriculture has been established and operated by using simultaneously the following four resources in set, at need, and at relatively low cost:

a. environmental resources
(soil, water, solar radiation, air, weather, wind etc)
b. biological resources
(high yielding improved crops and domestic animals)
c. technological resources
(effective fertilizers and chemicals, efficient agromachines, useful integrated systems for agrotechnological services)
d. energy resources
(fossil energy, atomic energy)

The distinct achievement in cereal production during the later half of the 20th century is thought to be because of the two facts: one is the introduction of high yielding agriculture and other the relatively stable world climate during this period. As shown in Fig. 1, the world climate for this period was stable, compared with climates before and after this period. The relatively stable world climate is thought to contribute partly to the rapid increase in the world cereal production during the second half of the 20th century.

However, as shown in Fig. 1, specialists of the world food problem (e.g., Kendall and Pimentel, 1994) expect that the increase in world cereal production will be weakened in the 21st century mainly due to environmental constraints such as global warming, shortage of water resources, degradation of cultivated lands, and slowdown of development speed of high yielding agrotechnology. Figure 1 shows that the slowdown in increasing speed of world cereal production will result in the decrease of the per capita cereal production and consequently the decline of nutrition level of people, particularly of developing countries.

Figure 2 indicates the drastic increase in the annual production of rice, wheat, and corn (maize) in Asia. Rice, wheat, and corn (maize) are important staple food for Asian people. The rapid increase in the annual production of these crops, as well known, has resulted from the introduction of high yielding agriculture into Asian countries. The rapid increase of crop production due to the introduction of high yielding agrotechnology into many developing countries was an epoch making event in the world history of agriculture, and is well known as the green revolution. The green revolution, though it was temporary, has fairly improved the balance of demand and supply of foods in many Asian countries. By using the production data in Fig. 2, the average increasing rates of those three crops over the period 1960 to 1999, respectively, were estimated as follows:

Rice	5.689 Mt/y
Wheat	4.417 Mt/y
Corn	3.333 Mt/y

Since the cultivation areas of those crops have been maintained at nearly constant levels during the period 1960 to 1999, the rapid increase in annual production of those crops is thought to be mainly because of the rapid increase in yield of those crops.

Although the high yielding agriculture is expected to bring about higher production independently of time and region, as crop statistics indicate clearly, the crop production is still sensitive or vulnerable to

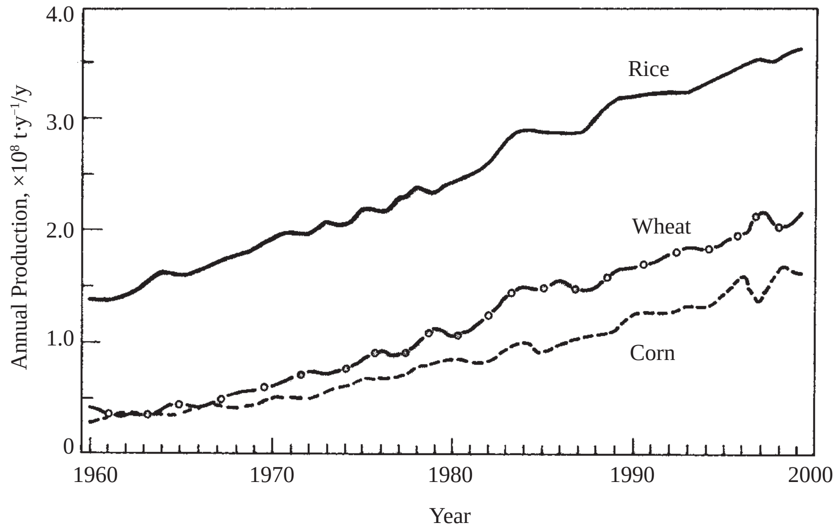

Fig. 2 Secular changes of annual production of rice, wheat, and corn in Asia (reproduced from Ito, 2001)

fluctuation and changein environmental conditions, particularly climatic conditions. Furthermore, the uncurbed growth in the world population, excessive urbanization and expanding industrialization are posing severe threat to the survival of the human being and other living things on the Earth.

In order to mitigate and/or solve the anthropogenic threat and to make sustainable symbiosis among whole living things, it is needed to make clear the upper limit of human population that could survive using natural resources in a given region and/or country, without causing any disturbance on regional and global environments. This upper limit of human population means the human-carrying capacity of a given region and/or country.

2. Phytoclimatic characteristics of Asia

Asia, the largest continent in the world, has land area of 46.614 million km^2 and population (3.8 billion people) of 63% of the world population. From climatic point of view the land of Asia is considerably different. Since Köppen (1931) adopted climatic elements such as mean annual temperature, mean annual precipitation, and those seasonal variations as predictable variables for the classification of phytoclimates, many studies have been made to describe the geographical distribution of phytoclimates on the Earth. Since then many climatic indexes have been studied and used to characterize phytoclimatic difference among regions.

In this report, the following radiative dry index (RDI) is used

$$RDI = R_n/Lr \quad (1)$$

where R_n is the mean annual net radiation at surface under actual conditions,

r is the mean annual precipitation,

L is the latent heat of vaporization of water.

Table 1 shows characteristics of phytoclimatic zones in relation with values of RDI. In areas with RDIs between 0 and 2, energy supply counterbalances to rainfall, allowing vigorous development of natural vegetation with higher productivity (NPP, t dry matter/(ha·y)). In general, high yielding agriculture has been conducted in areas with RDIs between 0 and 2, and with sufficient solar radiation. With increasing

Table 1 Characteristics of phytoclimatic zones

RDI	Climate	Primary Productivity			Potential Evapo-transpiration mm·y^{-1}
0–2	Humid–Subhumid	Solar radiation	Low	Low	200–400
			High	High	1000–1500
2–7	Subhumid–Semiarid	Lower and Unstable (Irrigation farming)			1000–1500
7–10	Semiarid–Arid	Considerably low (Semidesert)			1000–2000
＞10	Desert	Extremely lower or nothing			1500–2000 ＞2000

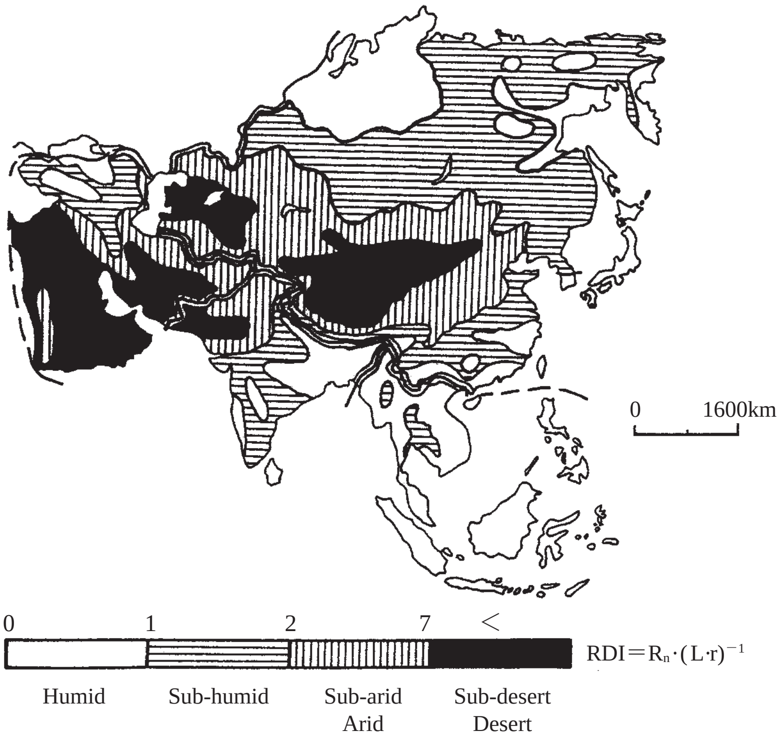

Fig. 3 Geographical distribution of radiative dry index (RDI) in Asia

RDI energy supply becomes gradually excessive and rainfall becomes deficient, resulting in the decline of natural vegetation. In areas having RDIs between 2 and 7 natural vegetation is very scarce and its productivity is limited due to the shortage of water resources.

Figure 3 gives a simplified geographical distribution of RDI in Asia (after Hare, 1970). It is clear that the humid and sub-humid regions (RDI＜2) in Asia include Siberia, northeast district of Asia, southeast Asia, and Indian subcontinent. On the other hand, semi-arid regions having RDIs between 2 and 7, and desert margin and true desert regions having RDIs over 7 are mainly located in West Asia and Central plateaux buttressed by ranges of mountains. In those regions natural vegetation is quite poor due to unfavorable climatic conditions, that is, excessive solar radiation, few rainfall, extremely large annual and diurnal range of temperature. As Table 1 indicates, the annual potential evapotranspiration in those regions is more than 1500 mm, implying that much water supply is needed to conduct irrigation farming.

The following percentage distribution of lands with different RDIs is obtained from data analysis of Fig. 3. This result indicates evidently that the land area:

RDI	0–1	1–2	2–5	5–10	＞10
area %	25.3	25.4	19.4	22.9	7.0

with phytoclimatic conditions suitable to the development of natural vegetation and consequently agriculture is about 50% of the whole land area (46.614 million km^2) of Asia. Particularly, the land area with climatic conditions (0＜RDI＜1) fitted for the rain fed cultivation of rice plants is only 25.3% of the whole land area. Therefore the development of water resources should become the most important and urgent problem in spreading irrigation farming toward sub-humid and semi-arid regions.

3. Supply-demand relation of foods and human-carrying capacity

The carrying capacity of the human being is closely related to the supply-demand relation of foods in a given region. Figure 4 shows the factors influencing the supply-demand relation of foods. In the demand side, the population growth and income rise are expected to play an important role in the increase of food consumption. In the production (supply) side, the combination of environment, resources, and technology could affect the production of foods in given regions. Namely the food production should be influenced positively or negatively by the good or bad combination of factors in the production side. If the bad combination of those factors resulted from uncontrolled growth of world population and global economy, the global ecosystems on which whole living things on the Earth depend closely should face up to crisis.

As described above, the carrying capacity of human being in a given region depends closely on many factors including natural resources and social conditions. Among them, the amount of cereals produced in a given region is the most important determinant for the human-carrying capacity. Therefore, under conditions that any foods are not imported from other regions, the human-carrying capacity (C, persons) of a given region can be expressed as follows:

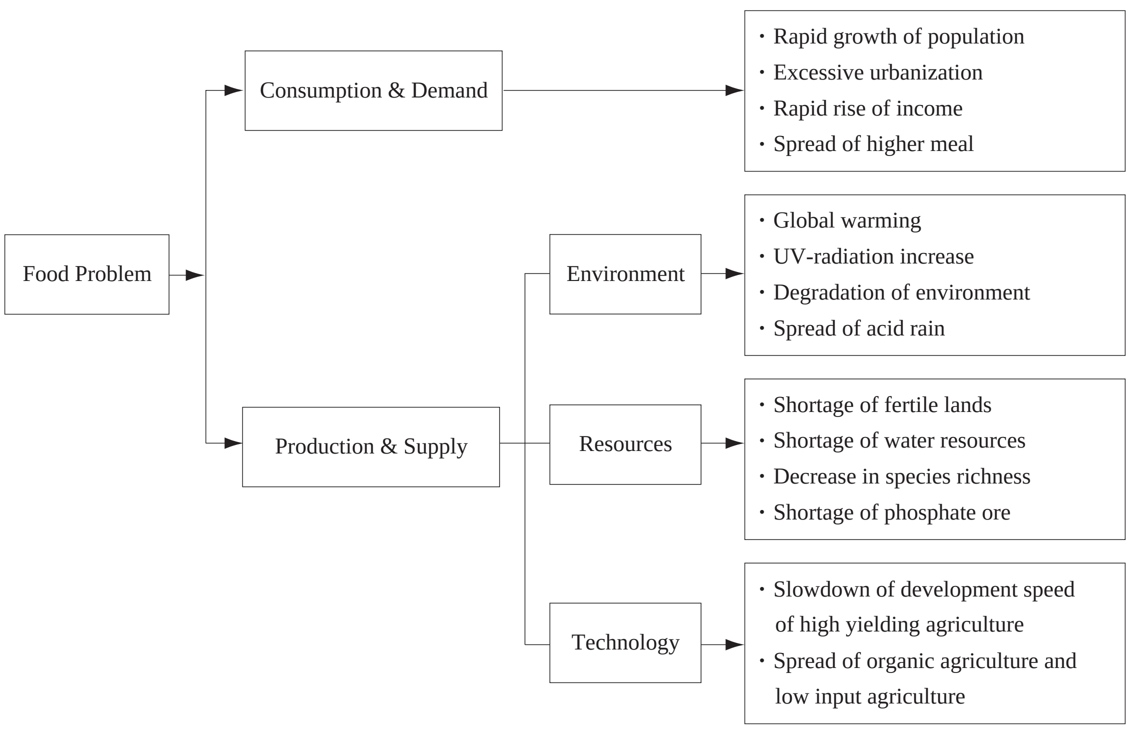

Fig. 4 Factors influencing supply-demand relation of foods

$$C = \Sigma A_i Y_i / \Sigma e_i \quad (2)$$

where A_i and Y_i denote, respectively, the cultivation area (ha) and the average yield (t/ha) of the i-th crop, e_i is the per capita annual consumption (t/capita) of the i-th crop.

Equation (2) indicates clearly that the human-carrying capacity is strongly influenced by the following three elements:

a. landuse pattern (A_i)
b. climate and level of agrotechnology (Y_i)
c. living standard (e_i)

1) Change in landuse pattern influencing area of arable lands

The human being is intensively using land resources for the following purposes:

a. providing food, fiber, and others
b. harvesting timber, and firewood
c. locating residential districts
d. locating factory districts
e. constructing transportation systems.

Since the total land area of a given region is constant independently of time, with the increase in population density in particular region, forest lands and/or natural grasslands are converted first into arable lands, then as development proceeds a portion of the arable lands is used for residential and other purposes. Therefore, it is reasonable to assume that the percentage of forest and/or natural grasslands decreases monotonically with increasing the population density. On the other hand, the dependence of the percentage of arable lands on the population density can be characerized by a curve with a peak in an intermediate range of the population density (Uchijima, 2001; Uchijima and Ohta, 2000).

Figure 5 is a schematic graph showing changes in percentages of forest, arable, and urbanized lands with population density in wet and warm climatic zones.

Circles in Fig. 4 denote the percentage of arable lands for the individual countries in Asia (FAO, 1998). Fairly large scatter of points indicates that change in landuse pattern is influenced not only by the

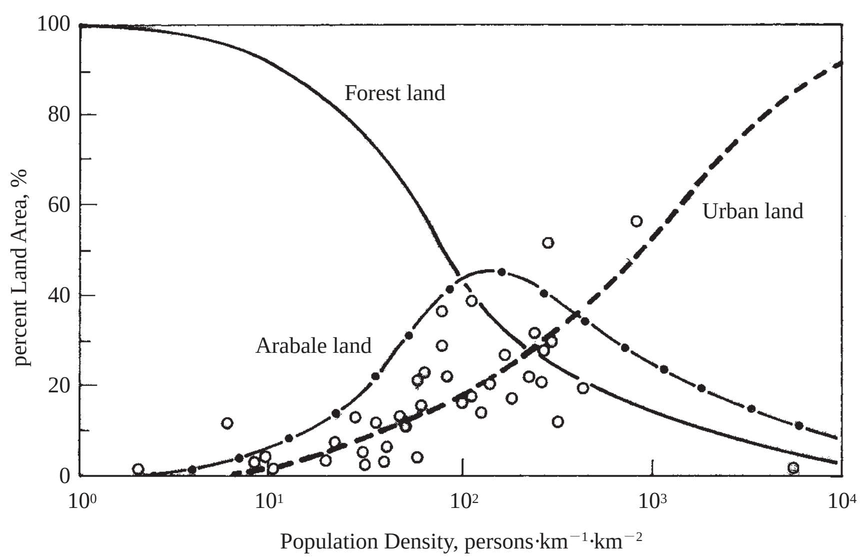

Fig. 5 Schematic graph showing change in landuse pattern with population desnsity

population density but also by other factors such as topography, climate, and industrialization. The following relation is obtained to relate the percentage of forest area (r_f, %) with population density (p, capita/km^2) and phytoclimatic conditions (Uchijima and Ohta, 2000).

$$r_f = 100\exp\left[-\left\{0.018\,\overline{RDI} + (p/100)^{0.54}\right\}\right] \quad (3)$$

where $\overline{RDI}$ is the average value of RDI on a given region.

Equation (3) implies that the area of forests and consequently the land area available on the use of agriculture and forestation decreases with increasing the aridity of climate (RDI).

According to the FAO production year book (FAO, 1998), the area of arable lands (including the lands for permanent crops) in Asia is as follows:

$$5.58 \times 10^6 \text{ km}^2$$

This indicates that 17.5% of the whole land area of Asia is already used to produce foods, fibers, and others (in this calculation, the land area of Siberia of Russia is excepted). As already discussed in the foregoing part of this paper, since the land area with phytoclimatic conditions suitable for the agriculture is only half of the whole land area of Asia, it seems reasonable to expect that roughly one-third of the land area suitable for the development of natural vegetation and consequently of the food production has been already converted into arable lands during human history, destroying the valuable terrestrial ecosystem in Asia. In order to solve the food problem to be caused by the increase in the population of Asia during the 21st century, more lands should be exploited. However, there are difficulties in finding new land that could be exploited for food production. This is because most of the unexploited land up to the present is either too dry, too wet, or too cold for agriculture, and the productivity of this new land would be much lower than that of lands under cultivation.

2) Climate influencing crop yield

Although the high yielding agriculture has succeeded to increase crop yields of the world, the food production is still affected by fluctuation and/or change in climate. The important cimatic limit in the world is insufficient rainfall, severe cold, intensive tropical cyclone and so on. Particularly, insufficient rainfall during the growing period of crops has caused frequently droughts and given severe impact on regional human society.

On the other hand, the continuous increase in the concentration of greenhouse gases (CO_2, CH_4, N_2O, CFCs etc.) is now thought to alter the global climate. Although there are large difference between the GCMs (Global Climate Model or General Circulation Model), the model experiments project that the global mean surface temperatures will rise between 2.0 and 4.5 °C by the end of the 21st century (see Fig. 6), that warming will be greater in winter than summer, and that warming will also be greater at higher latitude than lower latitude. Furthermore, the models project that rates of evaporation and transpiration will increase due to higher surface temperature, and that convective precipitation with localized intense rainstorms will increase than supersaturated precipitation with uniform rain distribution. Therefore, it is expected that the use efficiency of streamflow will decrease in many regions, particularly in sub-humid and sub-arid regions.

Another important consequence of the global warming is sea-level rise, because coastal zones and islands are very vulnerable to the sea-level rise. The models projected a sea-level rise of 0.14 to 0.8 meters for 1990 to 2100, with a central value of 0.47 meters. Since coastal zones in Asia are important producing areas of rice that is staple food for many Asian people and densely populated, the projected sea-level rise, though it seems to be not so dangerous, is expected to cause severe damage to the agricultural production and consequently the society in those zones.

Global warming is expected to cause not only changes in mean climate, but also changes in the frequency of extreme weather events (such as severe storms, heat waves, severe droughts and damaging frosts). As the history of famines in the world shows clearly, those extreme weather events have been a major threat on agricultural production in the world. In general the relationship between mean climate and the frequency of extreme weather events is non-linear. Therefore, the global warming can induce significant changes in the frequency of extremes. That is, intensive storm, heat wave, summer drought, tropical cyclone, and so on may become more frequent and give much damages on food production in the 21st century (e.g., Parry, 1990; Rosenzweig and Hillel, 1995; Uchijima, 1993). However, much more work on this issue is needed before we can more exactly estimate effects of expected extreme weather events on agriculture.

3) Human-carrying capacity of Asia

Assuming the continuation of present trends of the population growth, cereal production, and per capita cereal consumption in Asia, we can estimate the human-carrying capacity of Asia for the first half of the 21st century. At first the population growth is assumed to follow the UN-medium projection (UN-Population and Vital Statistics, 1998) leading to about 5.27 billion persons by 2050. Next the production data of cereals of Asia (Ito, 2001) were used to project the trend of cereal production for the same period. Figure 7 indicates the cereal production during the period 1960 to 1999 with the secular change in the Asian population. The cereal production data in Fig. 6 were substituted into Eq. (4) to project the future cereal production of Asia.

$$P_x = P_{99} + (F \times R \times n) \qquad (4)$$

where P_{60}, P_{99}, and P_x are the whole cereal production in 1960, 1999, and X-year, respectively,

$R[=(P_{99} - P_{60})/39]$ is the average growth rate of cereal production over the period 1960 to 1999,

n is the number of years from 1999 to X-year,

F denotes a coefficient (0.0 to 1.0) characterizing overall effects of environmental change and agrotechnologies on the cereal production.

As Eq. (4) indicates, it is needed to project the trend of per capita annual consumption ($E_x = \Sigma e_i$) during the period 2000 to 2050. The data of population and cereal production of Asia for the period 1960 to 1999 were used to calculate the secular change in per capita consumption of whole cereals and its projection. Figure 7 shows the secular change (thick solid line with circle) and the projection (long-dashed line) so obtained.

By substituting values of P_x and E_x into Eq. (2), we can estimate approximately the human-carrying capacity of Asia over the next 50 years. The results so obtained are shown in Table 2, with the Asian population projected by UN (1998). In this table, $F = 1.0$ means that the present trend, pattern, and activity relating to the cereal production of Asia assume to continue over the next 50 years. F-value less than 1.0 implies that the growth rate of cereal production will decrease due to the possible consequence of climatic changes, degradation of soil, shortage of water resources, ground-level ultraviolet radiation increase, and slowdown of development speed of agrotechnology. For example, Kendall and Pimentel (1994) have assumed that the average growth rate of global cereal production over the next 50 years will reduce to about half of that (33.6 Mt/y) over the period 1950 to 1990. Using the growth rate so assumed, they studied the demand and production relation of food in the world over the next 50 years.

As shown in Table 2, the human-carrying capacity projected on the basis of production and consumption of cereals is lower than the UN-projected Asian population. Particularly, the gap between the UN-projection and our projection becomes gradually large due to the proportional decrease in cereal production with the reduction of F-values. Since the estimate of F-value depends on many factors most of which are uncertain, it is not so easy to make useful and accurate forecasts. However it is expected that the

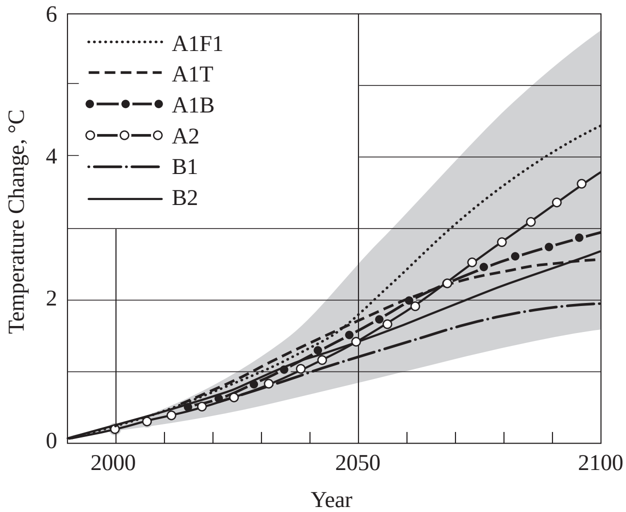

Fig. 6 Projected global mean surface temperature changes for six emission scenarios (Source, IPCC, 2001)

Carbon emission scenario

A1 storyline

- Global economy grows very rapidly and population reaches a peak in mid-century and declines thereafter.
- New and more efficient technologies are introduced rapidly.
- Regional differences in per capita income are substantially reduced.

A1F: fossil fuel is used intensively.

A1T: energy source is converted into non-fossil fuel energy sources.

A1B: energy source is balanced across all sources.

A2 storyline

- Economy development is primarily rigionally oriented.
- Social theme is self-reliance and preservation of local identities.
- Economic growth and technological change are more fragmented and slower than other storylines.

B1 storyline

- Economic structures change towards a service and information economy.
- Emphasis is on global solution to economic, social and environmental sustainability.

B2 storyline

- Global population increases continuously at a rate lower than A2.
- Emphasis is on local solutions to economic, social and environmental sustainability.
- Economic development is intermediate and less rapid than in the B1 and A1 storylines.

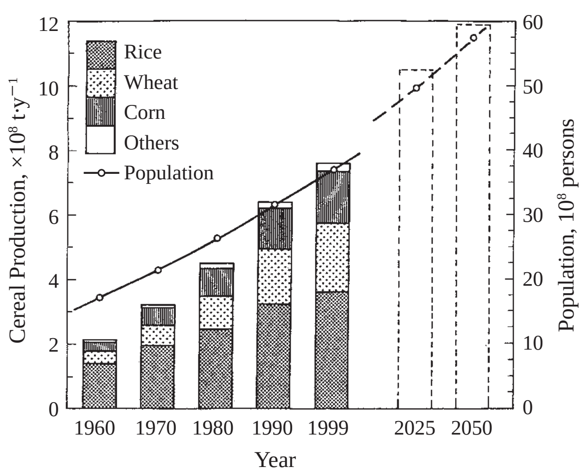

Fig. 7 Secular changes and projections of cereal production and population of Asia

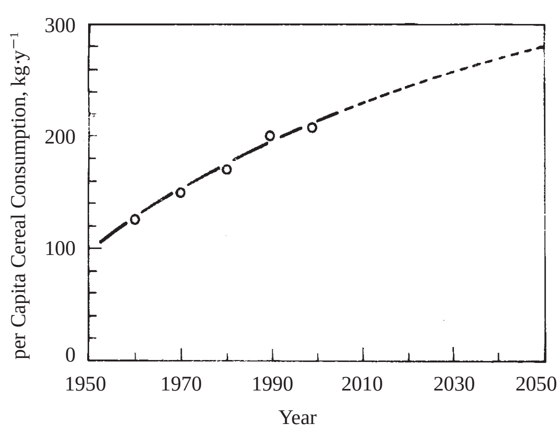

Fig. 8 Secular change and projection of per capita cereal consumption (average) of Asia

Table 2 Estimated human-carrying capacity of Asia

	2025				2050			
UN-projected population (×10^8)	47.20				52.70			
Overall coefficient (F)	1.00	0.90	0.80	0.70	1.00	0.90	0.80	0.70
Projected cereal production (×10^8 t·y^{-1})	10.88	10.53	10.19	9.84	14.24	13.56	12.87	12.19
Projected cereal consumption (kg·y^{-1})	250				275			
Projected carrying capacity (×10^8 persons)	43.5	42.1	40.7	39.4	51.8	49.3	46.8	44.3
ΔP*, (×10^8 persons)	−3.7	−5.1	−6.5	−7.8	−0.9	−3.4	−5.9	−8.4

* ΔP＝(UN-projected population)−(Projected carrying capacity)

value of F influencing cereal production in the 21st century will become less than 1.0 mainly due to shortages of natural resources and irreversible environmental degradation to be caused by unimpeded population growth and excess urbanization in this continent. Table 2 indicates evidently that the Asian population over the next 50 years is getting close to its limit to be determined by the present agrotechnologies and natural resources. Although a part of the food deficit shown in Table 2 could be met with the production of tuber crops (potato, sweet potato, taro and cassava etc.) and podded crops (beans, soy bean etc.), it is reasonable to conclude that the Asian population projected by the UN (1998) over the next 50 years will exceed its human-carrying capacity estimated from supply and demand relation of foods, that is, from its food production capacity.

The following four means are expected to solve the gap between the UN-projection of Asian population and our projection of Asian human-carrying capacity, and to supply enough foods to Asian people.

a: control of uncurbed growth of population,
b: control of food consumption increase with income rise,
c: import of foods through international trade system,
d: increase in food production.

The first two (a and b) are unfeasible as a solution for feeding Asian people, because those are expected to be faced with big social resistance. If world food production increases smoothly over the next 50 years even though adverse effects of global climate changes are expected, Asian countries could import enough foods from major crop exporting countries such as USA, Brazil, Australia etc. through international trade system. However many countries in Asia are classified into so-called developing country and thus their capability of food importation maybe quite beyond their need. Therefore the import of foods from other countries is not anticipated as major mean for the solution of the projected gap between supply and demand of foods in Asia over the next 50 years. The most feasible mean to solve the projected gap between supply and demand of food in Asia may be the increase in cereal production (d).

This would require the more expansion of arable lands and greater efforts for increasing crop yield. Although some studies suggest that there may be much potentially available land in Asia, converting it to crop fields would be costly in energy input and expected degradation of environment. Moreover crop yield of newly expanded crop fields should be considerably low compared with that of existing croplands. The above two facts are thought to limit realistically the more expansion of crop lands. Intensification of production through double or triple cropping and increase in yields of crops on existing croplands should contribute to solve the gap between the UN-population projection and our projection based on supply and demand of foods of Asia over the next 50 years.

If these attempts were made successfully, excessive human appropriation of lands, fresh water, and other natural resources would give irreversible damages on terrestrial and coastal ecosystems on which the human being and many wild lives depend closely. For example, Vitousek et al. (1986) estimated that the human being now appropriates nearly 40% of the potential production of terrestrial vegetation and Uchijima (1993) reported that about 25% of the actual production of terrestrial vegetation is harvested for only human use. The excessive human appropriation of the biomass production as mentioned above is attended with the overuse of land-, water- and biological resources of each district, resulting in the irreversible degradation of regional environment and ecosystem. Those would bring about the human-caused large-scale extinction of species.

Therefore, problems of supply-demand relation of foods and consequently human-carrying capacity would require highly organized global and regional effort by both the developed and the developing countries as pointed out by Kendall and Pimentel (1994).

Therefore, the study and development of super-high yielding agrotechnology, by which much foods than the present would be produced without causing any degradation and/or pollution of foods and surrounding environments, should have priority both regionally and globally.

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