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Population growth and loss of arable land

Bo R. Döös*

Global Environmental Management, Packhusgränd 6, SE-111 30 Stockholm, Sweden

Abstract

I discuss the loss of cropland in developing countries in connection with the ongoing land conversion caused by the growing population and socio-economic development, resulting in an increased demand for housing, industry, infrastructure, etc.

Based on assumptions about the required space per capita for other purposes than agriculture, the portion of this area that is removed from presently used cropland, and the quality of the available land reserves, the required demand for land reserves has been calculated.

The main conclusions are that during the next three decades (i) the loss of cropland is likely to be within the range 30–60 Mha, (ii) the reserve land utilized will be about 100–200 Mha, and (iii) the reserve land still in use after 30 years, about 50–100 Mha.

Keywords: Cropland loss; Cropland protection; Land reserves

1. Introduction

I address the consequences of the growing world population which implies an increasing demand for housing, industry, roads, airports, recreation, etc. In particular, I will be concerned that during this transformation of the natural landscape, considerable areas of croplands are being lost.

Certainly, this problem is not a new one. Since many cities were founded in agricultural areas, urban expansion is an ongoing threat to farmland (Gardner, 2001). As pointed out by Norse (1992) much of the lost land can be expected to be prime agricultural land located on coastal plains and in river valleys.

Several studies have been devoted to the effect of urbanization on agriculture. An overview of the literature that deals with the various aspects of the rural–urban conversion issue has been presented by Bhadra and Brandão (1993). Much of the urban economics literature draws its basic elements from the work of Johann Heinrich von Thünen originally published in 1824 (von Thünen, 1966).

According to a study presented by US Aid (1988), the expected loss of arable and due to urbanization between 1990 and 2020 was estimated to be 14 Mha, representing only about 1 per cent of world cropland. Based on this estimate Rosegrant et al. (1999), concluded that a possible loss of this magnitude is small compared to the potential expansion in crop area.

However, later studies (see Table 1) have indicated that the loss of cropland might be much larger, and that there is a need for more realistic estimates of the future loss of cropland. These estimates are required to provide a solid and convincing base for the formulation and implementation of policy responses. Here may, in particular, be mentioned a detailed study of the recent and expected near-future land use changes under conditions of high population pressure in Java, Indonesia (Verburg et al., 1999).

2. The need for protection of cropland

The need for protection of the available land resources is receiving an increasing attention, both by national governments and by several international organizations. However, it appears that the opinions about the seriousness of this issue are somewhat different. To simplify the discussions I will divide the opinions into two classes: seriously concerned and unconcerned.

(i) *The problem does require serious attention*

With regard to this class of opinions, it should in particular be mentioned that the agreement of the

*Tel.: +46-8-20-35-70.

E-mail address: doos@misu.su.se (B.R. Döös).

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Table 1
Estimated loss of arable land according to various studies

Source		Loss of rural land per capita (m^2)	Loss of arable land per capita (m^2)	Loss of arable land per year (Mha/year)	Loss of arable land after 30 years (Mha)
Bogue (1956)[a]	MDCs	688–1052	—	—	~300
US Aid (1988)	LDCs	—	—	0.476	14
Norse et al. (1992)	1000–2500				300
Kendall and Pimentel (1994)	—	—	—	2–4	60–120
FAO (1995)	Mean	210	—	—	—
	India		35	—	—
	Canada	640	378	—	—
Döös and Shaw (1999)	LDCs	500 ± 250	250 ± 125	2 ± 1	60 ± 30
	MDCs	500 ± 250	250 ± 125	0.1 ± 0.1	3 ± 3
Sundquist (2000)	LDCs	500	—	—	—

[a] Based on data from 1924 to 1954 (reported by Muth, 1961).

nations at the United Nations Conference on Environment and Development in Rio de Janeiro, 1992, to launch a comprehensive programme aimed at developing an "*Integrated Approach for the Planning and Management of Land Resources*".

The broad objective of this programme is to facilitate allocation of land to the uses that provide the greatest sustainable benefits and to promote the transition to a sustainable and integrated management of land resources (UNCED, 1993).

It should also be mentioned that this UN conference established a programme "*Promoting Sustainable Agriculture and Rural Development*". The priority of this programme was specified to be on maintaining and improving the capacity of the higher potential agricultural lands to support an expanding population.

Also on a national level there exists concern about the limitations of land resources, and how they are controlled. Thus, in many countries attention is devoted to obtain a better understanding how land use is controlled, and to design mechanisms to ensure that land resources are used sustainably. For example, as reported by the United Nations Development Programme (UNDP, 2001), following significant losses in the nation's arable land, the Chinese government has toughened control over the land use of arable land.

(ii) *Scarcity of land appears to be no serious problem*

In the interim report on the forward assessment by FAO of possible future developments the following optimistic statement is made: "Considering the future, a number of projection studies have addressed and largely answered in the positive the issue whether the resource base of world agriculture, including its land component, can continue to evolve in a flexible and adaptable manner as it did in the past, and also whether it can continue to exert downward pressure on the real price of food." (FAO, 2000).

As pointed out by Scherr and Yadav (2001), by the year 2020, land degradation may pose a serious threat to food production and rural livelihoods, particularly in poor and densely populated areas of the developing world. They emphasize the need for appropriate policies to encourage land-improving investments and better land management if developing countries are to sustainably meet the food needs of their populations.

3. Nature of the problem

Basically, the problem addressed here can be divided into two parts: The first one is to estimate the amount of rural land that will be transformed due to the needs of the growing population, and to what extent this will result in loss of cropland. The second problem is to evaluate as realistically as possible the availability and quality of land reserves.

3.1. The loss of cropland

As is illustrated in Fig. 1, the main driving forces behind the transformation of land are the growing population and socio-economic developments resulting in demands for a higher living standard.

In this context, note that it is not the urbanization that is to be blamed for this land transformation. *The increasing population have their demands regardless whether they live in rural or in urban areas.* For example, urbanization may actually reduce the loss of land. Households in villages and rural areas in the Republic of Korea, for example, consume six times more land per capita for residential purposes than households in Seoul (WRI, 1996).

As to the question about the magnitude of the different types of land use transformations that are taking place, little reliable information is available.

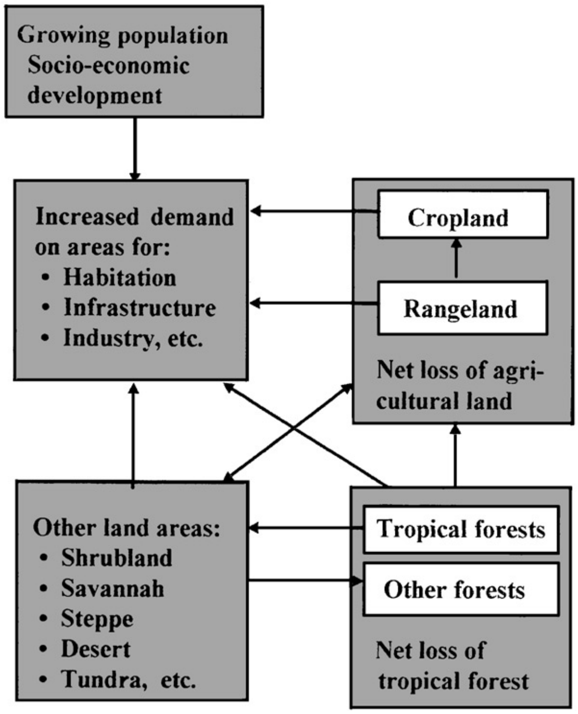

Fig. 1. A schematic illustration of the changes in land use caused by the growing population and other driving forces.

However, as has already been indicated, it is to be expected that a substantive portion of the land required is taken from existing cropland.

3.2. The quality and availability of land reserves

As is indicated in Fig. 2 and shown in Table 2, there exist extensive land resources of various qualities in several developing countries. These lands are expected to have potential for growing rainfed crops. Thus, as can be seen in this table, the resource base includes about 1.8 billion ha in addition to the about 1 billion ha that are already in cultivation.

Certainly, this looks very promising. However, there are some aspects that make the picture less rosy:

First, as can be seen in Table 2, in some regions there is little, or no land left of the category *Very suitable*. Certainly, this is what can be expected—the best land is always first taken. As expressed by Young (1999), the estimated availability of cultivable land in developing countries is greatly exaggerated.

Second, the definition of the various levels of the quality of the land resources can give a false impression. Thus, it is enough for a piece of land to support a single crop at a minimum yield level for it to be deemed suitable FAO, 2000).

Third, most reserves are currently under forest or permanent pastures, and the demand for maintaining land in both forests and pastures is growing (Norse et al., 1992). Actually, conversion of forestland to agriculture is already a prime force in driving forest loss in the tropics (WRI, 1998).

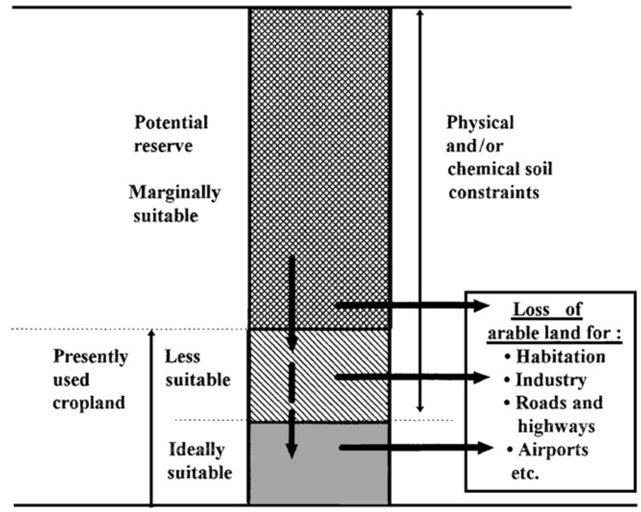

Fig. 2. A schematic illustration of the present extent of cropland in developing countries (about 1000 Mha) and the reserve lend considered to have potential for growing rainfed crops (about 1800 Mha). The arrows indicate the ongoing changes of land use, implying a successive decrease of quality of the land being used for crop growing.

Table 2
Land with rainfed crop potential in developing countries (million ha) and population (billions)

	Sub-Saharan Africa Latin America	Near East and North Africa South Asia East Asia	All developing countries
Very suitable	842	266	1109
Suitable	783	218	1001
Moderately suitable	289	111	400
Marginally suitable	183	90	273
Total land suitable	2097	685	2782
Land in use	433	526	960
Population	1.2	3.6	4.9

Sources: FAO (2000) and UN (2001).

Fourth, the availability of land reserves is smallest where they are most in demand. Thus, in the Near East/North Africa region, there is virtually no spare land available for agricultural expansion. In South Asia, the agricultural land is almost totally developed; land expansion is likely to account for only about 4 per cent of production growth through 2010 (WRI, 1996).

Fifth, the financial costs of bringing land reserves into production can be prohibitive in many developing countries (Fischer et al., 2001). Instead, in regions with limited opportunities to expand cropland, considerable efforts are being devoted to intensify food production, for example, by the use of quick-growing seeds, increased use of fertilizers, shortening the land fallow periods. However, as expressed by WRI (2000), continued agricultural intensification need not inexorably lead to environmental degradation.

Nevertheless, environmental degradation does happen, and it can result in a negative circle of development. The cycle begins with the need for increasing the food production caused by the increasing population, at the same time as croplands are decreasing. This leads to an intensification of agriculture and this in turn implies an increased risk of soil degradation and a further loss of cropland. Among the most vulnerable areas for such developments are South and Southeast Asia, where populations are among the densest and agriculture is the most extensive (WRI, 2000).

4. Calculations of the likely loss and gain of cropland

In the following I estimate (a) the expected annual loss of cropland due to the increasing demand for land areas for other purposes than agriculture, and (b) the required utilization of available land reserves in order to satisfy the future demand for food production. This is illustrated schematically in Fig. 3.

In the calculation of this demand for expansion of cropland, each year the present cropland is diminished by an area proportional to the annual population increase, the reserve land is on an average less productive than the present cropland, and that the reserve land can only be expected to be sufficiently productive during a limited number of years.

4.1. Assumptions

In order to derive expressions for calculating these two quantities I introduce a number of simplifying assumptions. Thus, I assume, as a minimum requirement, that the present per capita food production can be maintained despite the increasing population and the ongoing degradation of the environment. In making this assumption, account is taken to recent projections of crop productions by FAO (2000) and the International Food Policy Research Institute (Rosegrant et al., 2001).

Due to the limitation of reliable observational data, it is unrealistic to carry out the study for the individual world regions. Moreover, I decided to limit the study to the less-developed countries (LDCs) in view of the comparatively little cropland which will be lost in the more developed countries due to the expected minor changes of the population in these countries.

In addition, I introduce the following assumptions:

(a) The population $n(t)$ in the LDCs increases each year by a constant number Δn:

$$n(t) = n(0) + \Delta nt = n(0)[1 + \gamma t], \quad (1)$$

where $\Delta n = \gamma \cdot n(0)$ is the average annual increase of the population. The values of the parameters in this

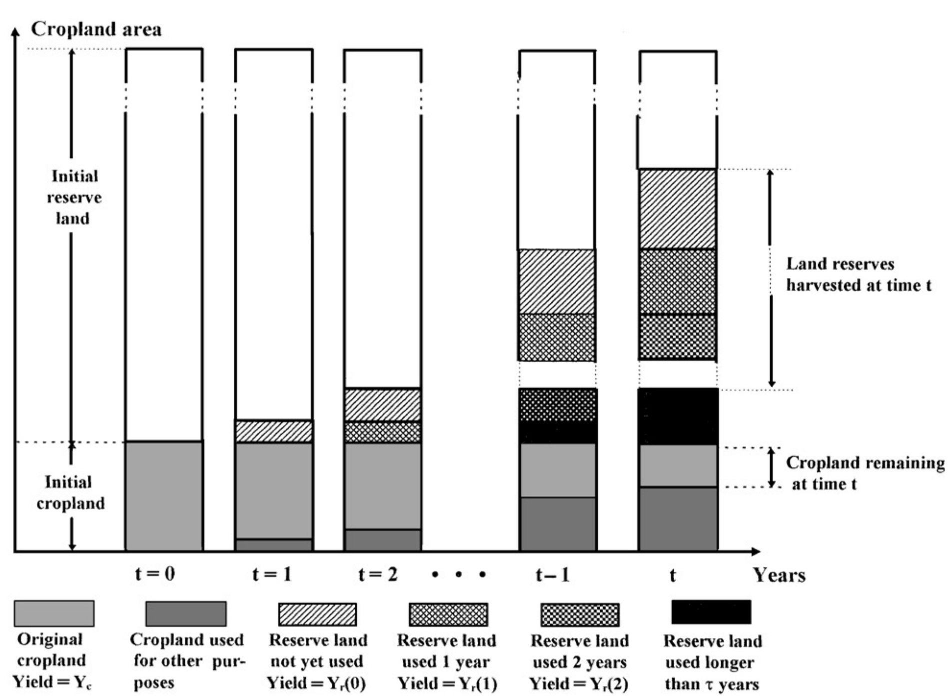

Fig. 3. A schematic illustration of: (i) the annual loss of the presently used cropland due to demands of land for other purposes than agriculture; (ii) the required annual expansion of cropland; and (iii) that the productivity of the land reserves decreases with time, and that after τ years, the productivity has decreased to an unacceptable low level.

expression are based on estimates published by the United Nations Population Division (UN, 2001):

$n(0) = 4.87$ billion,

$\Delta n = 65$ million,

$\gamma = 0.0133.$ (b)

The change with time of the extent of cropland for grain and all other crops can be expressed by the following formula:

$$C(t) = C(0) - \Delta Ct, \quad (2)$$

where $C(0)$ is the present area of arable land in use, ΔC is the annual loss of the present cropland

For this loss of cropland I use the following formula:

$$\Delta C = \alpha\beta\Delta n, \quad (3)$$

where α is the area required per capita for other purposes than food production, β the portion of this area removed from presently used cropland.

For the computation of the change of the cropland area I use the following values:

$C(0) = 960$ Mha,

$a = 500\ m^2$,

$b = 0.5.$

The value of $C(0)$ is obtained from FAO (2000). The value used here represents the years in 1995/97. For this period the harvested area was reported to be 877 Mha and the cropping index 0.91.

The values of α and β are based on information from numerous studies, including Norse et al. (1992), Kendall and Pimentel (1994), Waggoner (1994), Döös and Shaw (1999and Sundquist (2000).

It is likely that the parameter α will increase with income growth. However, this is not taken into account here.

As compared with all the other parameters, the choice of a realistic value for β is perhaps the most problematic one.

As is indicated in Fig. 1, there are numerous lands providing the space required for the various human activities, and their individual contributions are different in different regions. However, the currently used cropland represents a major source for these other activities.

With the chosen values for these parameters, the following estimate for the annual loss of the present cropland in developing countries is obtained:

$$\Delta C = \alpha\beta\Delta n = 0.5 \times 500 \times 65 \times 10^6\ m^2 = 1.625\ \text{Mha}.$$

Due to the limited information available with regard to the parameters α and β, the estimate of ΔC is bound to be very uncertain. However, we can with some confidence expect that its value will be within the range 1–2 Mha.

Thus, during a 30-year period the loss of cropland would be 30–60 Mha.

(c) The yield $Y_c(t)$ of the present cropland is increasing at a rate that would permit the present per capita food production to remain unchanged with time provided there are no losses of cropland. To satisfy this condition, the yield has to increase with time according to the following formula:

$$Y_c(t) = Y_c(0)[1 + \gamma t]. \quad (4)$$

(d) The analysis assumes that productivity of the reserve land:

- is initially less than the present cropland,
- is decreasing with time,
- is expected to decrease to an unacceptable low level after a limited period of time (see Fig. 3).

Given these assumptions I will use the following expression for the change of the yield with time of the reserve land:

$$Y_r(t) = v^t Y_r(0) = \mu v^t Y_c(0) \quad \text{for } t \leqslant \tau, \quad (5a)$$

$$Y_r(t) = 0 \quad \text{for } t > \tau, \quad (5b)$$

where μ is a measure of the quality of the reserve land in relation to the present cropland, v is a measure of to what extent the productivity of the reserve land changes with time, and τ is the period of time beyond which the productivity of the reserve land has decreased to an unacceptable low level, and has to be abandoned.

The following values have been chosen for these parameters:

$m = 0.9,$

$n = 0.95,$

$\tau = 9$ years.

With these values, the yield of the reserve land will have declined to about 57 per cent of the yield of the present cropland.

The choice of these values for the parameters v, μ and τ are based on the assumption that a large part of the land gained in the LDCs is less suitable for use as cropland. This is particularly true with regard to the land gained through deforestation. As is well known, in many regions the soils of tropical forests are not suitable for agriculture (Dufour, 1990; Faminow, 1998). Crop yields decline rapidly, and in some cases the yield of slash-and-burn agriculture falls by as much as 50 per cent within the second year of production (Sanchez, 1976).

4.2. The required use of land reserves

Making use of the assumptions (a)–(e), the crop production for a given region, at time t, can be written in the following way:

$$P(t) = [C(0) - \Delta C t] Y_c(0)[1 + \gamma t] + \Delta R(t) Y_r(0) + \Delta R(t-1) Y_r(1) + \ldots + \Delta R(1) Y_r(t-1) \quad \text{for } 1 \leqslant t \leqslant \tau, \tag{6a}$$

$$P(t) = [C(0) - \Delta C t] Y_c(0)[1 + \gamma t] + \Delta R(t) Y_r(0) + \Delta R(t-1) Y_r(1) + \ldots + \Delta R(t-\tau+1) Y_r(\tau-1) \quad \text{for } t > \tau. \tag{6b}$$

The first terms in these two expressions thus represent the production of what is left of the original cropland, and the following terms, the production gained from land reserves.

Expressions (6a and 6b) may also be written in the following form:

$$P(t) = [C(0) - \Delta C t] Y_c(0)[1 + \gamma t] + \sum_{k=1}^{t} [\Delta R(k) Y_r(t-k)] \quad \text{for } 1 \leqslant t \leqslant \tau, \tag{7a}$$

$$P(t) = [C(0) - \Delta C t] Y_c(0)[1 + \gamma t] + \sum_{k=t-\tau+1}^{t} [\Delta R(k) Y_r(t-k)] \quad \text{for } t > \tau. \tag{7b}$$

Making use of the expression for the change with time of the yield of the reserve land (5), we can write (7a and 7b) in the following form:

$$P(t) = [C(0) - \Delta C t] Y_c(0)[1 + \gamma t] + \sum_{k=1}^{t} [\Delta R(k) v^{t-k}] \mu Y_c(0) \quad \text{for } 1 \leqslant t \leqslant \tau, \tag{8a}$$

$$P(t) = [C(0) - \Delta C t] Y_c(0)[1 + \gamma t] + \sum_{k=t-\tau+1}^{t} [\Delta R(k) v^{t-k}] \mu Y_c(0) \quad \text{for } t > \tau. \tag{8b}$$

In order to derive expressions for the required utilization of reserve land to compensate for the loss of the initial cropland, I make use of (8a and 8b) and the following formula that expresses that the production per capita remains unchanged:

$$P(t) = C(0) Y_c(0)(1 + \gamma t). \tag{9}$$

This gives:

$$\sum_{k=1}^{t} [\Delta R(k) \mu v^{t-k}] = \Delta C t(1 + \gamma t) \quad \text{for } 1 \leqslant t \leqslant \tau, \tag{10a}$$

$$\sum_{k=t-\tau+1}^{t} [\Delta R(k) \mu v^{t-k}] = \Delta C t(1 + \gamma t) \quad \text{for } t > \tau. \tag{10b}$$

With the aid of these equations the following expressions for the required annual increase of the utilization of reserve land $\Delta R(t)$ are obtained:

$$\Delta R(t) = \{t - (t-1)v + \gamma[t^2 - (t-1)^2 v]\} \mu^{-1} \Delta C \quad \text{for } 1 \leqslant t \leqslant \tau, \tag{11a}$$

$$\Delta R(t) = \{t - (t-1)v + v^{\tau}[t - \tau - (t-\tau-1)v] + \gamma[t^2 - (t-1)^2 v + v^{\tau}[(t-\tau)^2 - (t-\tau-1)^2 v]]\} \mu^{-1} \Delta C \quad \text{for } t > \tau. \tag{11b}$$

These expressions for the annual increment of reserve land are given in Table 3 for the particular case $\tau = 9$ years.

5. Results

Clearly, there exists considerable uncertainty with regard to the values selected for the various parameters occurring in the solutions for $\Delta R(t)$. It should also be recognized that I do not take into account that these parameters exhibit significant variations both in time and space.

For the purpose of simplifying the presentation and discussion of the results I divide the parameters into the following two groups:

(i) *Parameters that can be considered to be known with a fair amount of accuracy. This group may include*:

$C(0) = 960$ Mha,

$n(0) = 4.87 \times 10^9$,

$\Delta n = 65 \times 10^6$,

$\gamma = 0.0133$.

With regard to g, I also use this parameter in the formula (4) that expresses that the yield of the original cropland is increasing at the same rate as the population.

(ii) *Parameters that are more uncertain and deserve special attention. To this group I assign*:

$v = 0.95$,

$\mu = 0.9$,

$\tau = 9$ years,

$\Delta C = 1.5 \pm 0.5$ Mha.

In order to study the sensitivity of the choice of these parameters, I will consider the results obtained in three cases (A, B and C) using different sets of choices of v, μ and τ (see Table 4).

The summary of the results presented below refer to values obtained for the medium variant of the annual loss of cropland ($\Delta C = 1.5$ Mha) and $t = 30$ years.

Case A. The result obtained in this case is based on the values of v, μ, τ and ΔC given above. Thus, by using

Table 3
Calculated required utilization of reserve land in order to ensure a constant annual crop production per capita, despite (i) an annual loss of present cropland, (ii) that the productivity of available land resources is decreasing with time, and (iii) that the land gained can only be used during limited period of time

Year	Cropland at time t $C(t)$	Land reserves gained at time t $\Delta R(t)$	Production at time t $P(t)$
0	C	0	$P(0)$
1	$C-\Delta C$	$(1+\gamma)\mu^{-1}\,\Delta C$	$(1+\gamma)P(0)$
2	$C-2\Delta C$	$[2-v+\gamma(4-v)]\mu^{-1}\,\Delta C$	$(1+2\gamma)P(0)$
3	$C-3\Delta C$	$[3-2v+\gamma(9-4v)]\mu^{-1}\,\Delta C$	$(1+3\gamma)P(0)$
4	$C-4\Delta C$	$[4-3v+\gamma(16-9v)]\mu^{-1}\,\Delta C$	$(1+4\gamma)P(0)$
5	$C-5\Delta C$	$[5-4v+\gamma(25-16v)]\mu^{-1}\,\Delta C$	$(1+5\gamma)P(0)$
6	$C-6\Delta C$	$[6-5v+\gamma(36-25v)]\mu^{-1}\,\Delta C$	$(1+6\gamma)P(0)$
7	$C-7\Delta C$	$[7-6v+\gamma(49-36v)]\mu^{-1}\,\Delta C$	$(1+7\gamma)P(0)$
8	$C-8\Delta C$	$[8-7v+\gamma(64-49v)]\mu^{-1}\,\Delta C$	$(1+8\gamma)P(0)$
9	$C-9\Delta C$	$[9-8v+\gamma(81-64v)]\mu^{-1}\,\Delta C$	$(1+9\gamma)P(0)$
10	$C-10\Delta C$	$\{10-9v+v^9+\gamma[100-81v+v^9]\}\mu^{-1}\,\Delta C$	$(1+10\gamma)P(0)$
11	$C-11\Delta C$	$\{11-10v+v^9(2-v)+\gamma[121-100v+v^9(4-v)]\}\mu^{-1}\,\Delta C$	$(1+11\gamma)P(0)$
12	$C-12\Delta C$	$\{12-11v+v^9(3-2v)+\gamma[144-121v+v^9(9-4v)]\}\mu^{-1}\,\Delta C$	$(1+12\gamma)P(0)$
⋮	⋮	⋮	⋮
20	$C-20\Delta C$	$\{20-19v+v^9(11-10v)+\gamma[400-361v+v^9(121-100v)]\}\mu^{-1}\,\Delta C$	$(1+20\gamma)P(0)$
⋮	⋮	⋮	⋮
30	$C-30\Delta C$	$\{30-29v+v^9(21-20v)+\gamma[900-361v+v^9(441-400v)]\}\mu^{-1}\,\Delta C$	$(1+30\gamma)P(0)$
⋮	⋮	⋮	⋮

Table 4
Sensitivity of the calculations of the requirements of reserve land to the choice of the parameters: μ, v and ΔC

Cases		Parameters			Loss of original cropland after 30 years (Mha)	Reserve land gained at year 30 (Mha)	Utilization of reserve land after 30 years (Mha)	Reserve land harvested after 30 years (Mha)
		μ	v	ΔC (Mha)				
Case A	High			2.0	60	12.3	209	97
	Medium	0.9	0.95	1.5	45	9.3	157	73
	Low			1.0	30	6.2	105	49
Case B	High			2.0	60	4.0	93	93
	Medium	0.9	1.0	1.5	45	3.0	70	70
	Low			1.0	30	2.0	47	47
Case C	High			2.0	60	3.6	84	84
	Medium	1.0	1.0	1.5	45	2.7	63	63
	Low			1.0	30	1.8	42	42

the value 1.5 Mha for the annual loss of cropland, as shown in Table 4 and Fig. 4, the following estimates are obtained:

- loss of the original cropland: 45 Mha,
- reserve land gained: 157 Mha,
- reserve land in use: 73 Mha,
- reserve land abandoned: 84 Mha.

Case B. This case is designed to study the sensitivity of the result to the choice of the parameter v, the annual decline in yield on reserve lands.

By choosing the value $v = 1$, the following expression for the yield of the reserve land is obtained from (5a):

$Y_r(t) = 0.9\ Y_c(0).$

Thus, in this case it is assumed that the yield of the reserve land remains constant in time, and implicitly it implies that there is no upper limit (τ) for the use of the reserve land. Consequently, the demand for the use of reserve land is considerably less. For the medium value of the annual loss of cropland ($\Delta C = 1.5$ Mha) the following estimates are obtained:

- loss of the original cropland: 45 Mha,
- reserve land gained: 70 Mha,
- reserve land in use: 70 Mha,
- reserve land abandoned: 0 Mha.

Case C. This case is designed to examine the sensitivity to the choice of the parameter μ that

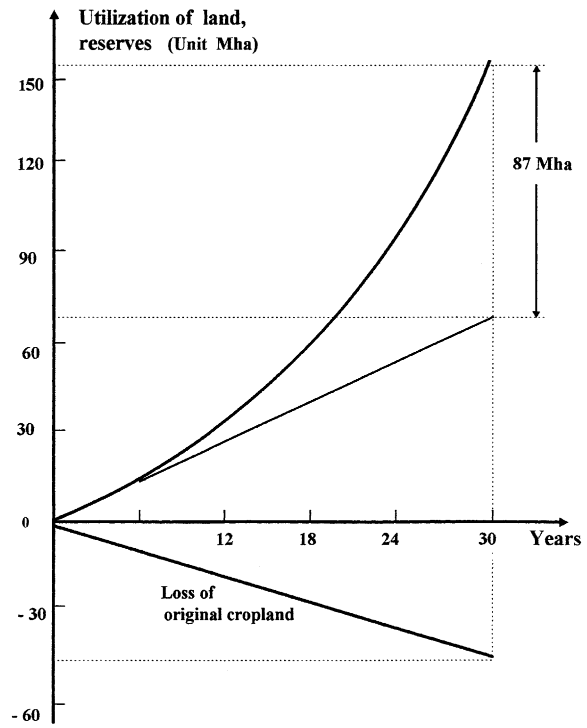

Fig. 4. The lower thick line represents the rate of loss of the present cropland, and the upper thick curve the required utilization of reserve land to ensure that the present per capita food production can be maintained despite that the productivity of the reserve land decreases by 5 per cent annually (Case A). The thin line indicates the corresponding need for reserve land assuming there is no decline with time of the productivity of the reserve land (Case B).

expresses the ratio of the yields of the reserve land and the present cropland. As can be seen in expression (11) and Table 3, the annual increase or the reserve land is directly proportional to this parameter, and is therefore easy to evaluate. Thus, for the value $\mu = 1$, the medium case ($\Delta C = 1.5$ Mha) gives:

- loss of the original cropland: 45 Mha,
- reserve land gained: 63 Mha,
- reserve land in use: 63 Mha,
- reserve land abandoned: 0 Mha.

Impact of climatic change. It deserves to be pointed out that the greenhouse gas induced climatic change is expected to result in a general reduction in potential crop yields in most tropical and sub-tropical regions for most projected increases in temperature (McCarthy et al., 2001). In turn, this can be expected to result in an additional demand for reserve land.

6. Discussion of the results

Undoubtedly the results widely differ from the several cases describing the required need for reserve land to ensure that the present per capita food production can be maintained, despite the annual loss of present cropland.

Thus, the question is whether it is possible to narrow the ranges of uncertainties. In attempting to achieve this I assume that:

(a) on an average, the yield of the reserve land probably is at least 10 per cent poorer than the yield of the cropland, i. e. $\mu \leqslant 0.9\cdot$ This implies that *Case B* may be considered more realistic than *Case C*.
(b) the decline of the yield of the reserve land assumed in *Case A* is somewhat exaggerated. It might be more plausible to assume that the value of v will be in the range:

$$0.95 \leqslant v \leqslant 1.$$

Actually, in some limited regions there may be no significant decline of the yield of the reserve land, i.e. $v = 1$.

Based on these two points, and disregarding the uncertainty given to the parameter ΔC representing the annual loss of cropland, the tentative conclusion may be drawn that the extent of the used reserve land should be within the range: 70 and 157 Mha (see Fig. 4).

By also taking into account the uncertainty assigned to this parameter ($\Delta C = 1.5 \pm 0.5$ Mha), the uncertainty becomes considerable greater. As can be seen in Table 4 it may fall between 50 and 200 Mha.

7. Conclusions

The present rate of loss of cropland caused by the need for space for other purposes than agriculture may not be considered to be the most serious threat to the food production. This may, to some extent, explain why comparatively few steps are being taken for protecting the remaining cropland.

Nevertheless, there exist compelling reasons for not taking a complacent view with regard to the possible magnitude of such losses in a longer time perspective. Thus, the present study identifies a number of points that deserve attention:

- It is estimated that during the next three decades 30–60 Mha cropland will be taken out of production in the developing countries due to demands for space and due to demands other than food production.
- During this 30-year period it can be expected that in order to ensure a constant per capita food production, about 100–200 Mha reserve land will be made use of. At the end of this 30-year period about 50–100 Mha will remain in production.
- It is often claimed that considerable land reserves do exist. However, most of these reserves are currently

under forest or permanent pastures, and the demand for both forests and pastures is growing.

- In some regions there is little, or no land left of the category *Very suitable*. Certainly, this is what can be expected—the best land is always first taken.
- The productivity of some of the land reserves can be expected to decline with time, and only be used for a limited period of time. This is particularly true with regard to cropland gained from tropical forests.
- The availability of land reserves is smallest where they are most in demand, namely in the Near East/North Africa region and in South Asia.
- For obvious reasons, particular care needs to be taken to protect land in regions where reserves are scarce. In such regions the cropland is beginning to suffer from problems caused by continued agricultural intensification.

As an overall conclusion it may be stated it can hardly be motivated to use present cropland for any other use than food production. The validity of this statement is strengthened by the fact that in all likelihood the loss of cropland needs to be replaced by land reserves with poorer productivity.

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