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6. CARRYING CAPACITY FIRST LEVEL MODEL

6.1. CARRYING CAPACITY FIRST LEVEL MODEL

A first level carrying capacity model, combined with the population model, is created and used to identify the degree of food self-sufficiency of the selected country or region or the globe. It is clearly comparable, highly aggregate, with population first level model used in the chapter before.

If we define **popcp** as the population that a country (a region, etc.) could self-support from the point of view of its own agricultural food, then the population deficit, **popsdf**, in this country is

$$\mathbf{popsdf} = \mathbf{popcp} - \mathbf{pops} \text{ (“population relationship”)}$$

where **pops** is the total population in the country estimated as in the chapter before. And if **land** is the land of the country, then we redundantly have

$$\frac{\mathbf{popsdf}}{\mathbf{land}} = \frac{\mathbf{popcp}}{\mathbf{land}} - \frac{\mathbf{pops}}{\mathbf{land}}$$

where

$$\mathbf{popsds} = \mathbf{pops}/\mathbf{land}$$

is the population density,

$$\mathbf{crcp} = \mathbf{popcp}/\mathbf{land}$$

is the carrying capacity of this land, and

$$\mathbf{crcpsdf} = \mathbf{popsdf}/\mathbf{land}$$

is the population deficit density. Then the first equation can be rewritten as:

$$\mathbf{crcpsdf} = \mathbf{crcp} - \mathbf{popsds} \text{ (“densities relationship”)}$$

Also dynamics-viewed from the highest level of models hierarchy (remember the

discussion of chapter 4 and 5) we have that carrying capacity as a function of time is given by a growth equation:

$$\text{rcrp}_t(r) = \text{rcrp}_{t-1}(r) * (1 + \text{rcrcpm}_t(r) * \text{rcrcp}_t(r)/100)$$

This model will be referred to as the level 1 or the 1st level model (the notation s will be for the first level).

And at this point we can do exactly the same comments that we did in the chapter before: “The equation reflects the consistency aspect of carrying capacity dynamics in the broadest of terms. It should be remembered and pointed out that the most aggregate representation is not less accurate (“true”) than the more disaggregate representations such as those developed subsequently. If the growth rate **rcrcp** is known, the carrying capacity change follows the simple equation. The problem, of course, is that **rcrcp** encompasses an extraordinary range of uncertainties”.

But now the problem is also that the estimation of initial values of **rcrp** encompasses another kind of uncertainties related with real values, computations and changes in climate, soil, available land, yields, irrigation, etc.. But anyway, if we have access to this kind of data from some expert source (or from some more disciplinary low level model), then we can do, with this model, our policy scenario analysis like a first high level approach to the feasible evolution of the reality.

We can also take a look at the C++ source code of the first level (high) model of carrying capacity

Figure 6.1.

```

/*****
* CARRYING CAPACITY 1st LEVEL MODEL
*****/

if (year > firstYear)
{
    for (r=0; r<reg; r++) {

        /* Compute carrying capacity of the region*/
        crcp[r]=scrcp[r]*(1+rcrcpm[r]*rcrcp[r]/100.);

    }
}

```

```

for (r=0; r<reg; r++) {

    /* Compute carrying capacity deficit */
    crcpsdf[r]=crcep[r]-popsds[r];

    /* Compute carrying capacity index */
    increps[r]=crcep[r]/popsds[r];

    if (increps[r] > 1)
    {
        increps[r]=0;
    }

    /* Compute population capacity (land in 10^3he) */
    popcp[r]=crcep[r]*land[r]/1000.;

    /* Compute population deficit */
    popsdf[r]=pops[r]-popcp[r];
}

/* Backup carrying capacity variable */
screp[r]=crcep[r];

```

and we can identify, similar to the variables that we have described in previous chapter, the following variables. First of all

screp

is an internal program variable which is carrying capacity in the preceding year, and

rcrcpm

is a multiplier or scenario variable.

We also have defined one index of carrying capacity problematique of a country in the following way:

$$\text{increps} = \frac{\text{crcep}}{\text{popsds}} = 1 - \frac{\text{crcpsdf}}{\text{popsds}} = 1 - \frac{\text{popsdf}}{\text{pops}} = \frac{\text{popcp}}{\text{pops}}$$

and, obviously,

if	popsdf ≤ 0	then	incrcps $\equiv 1$
and if	popsdf > 0	then	$0 \leq \text{incrcps} < 1$
and if	popsdf \uparrow	then	incrcps \downarrow

6.2. FAO/IIASA/UN ASSESMENT TO POTENTIAL POPULATION SUPPORTING CAPACITIES OF LANDS IN THE DEVELOPING WORLD [B.3.7.]

Fortunately, the high level approach to our issue is directly possible because of the results of a detailed assessment of carrying capacity performed by the Food and Agriculture Organization, FAO, the United Nations, UN, and the International Institute for Applied Systems Analysis, IIASA (see all this section and specifically the Figure 6.5.). The objective was to determine the maximum potential for food production in order to obtain the upper limit of carrying capacity for each of the countries and regions.

This report is one of the most important studies on food carrying capacity that we have from the literature. Many remarkable recent books and papers cited it as a reference. In our study we also want to examine, by comparing FAO/IIASA/UN report with the most recent references on the issue and our integrated assessment using multilevel modeling approach within a goal-seeking paradigm, the “limits” and the possible inaccurate conclusions of the report. This is one of the general goal of the study, not of this chapter.

6.2.1. FAO/IIASA/UN CONCEPTS

We will now explain, as a summary, the principal concepts and methodology of this work (henceforth named FAO/IIASA/UN).

The ability of land to produce food is limited. The limits of production are set by **soil** and **climatic** conditions and the **use and management applied to the land**; "mining" of land beyond these limits will, at a long term, only result in degradation and ever decreasing productivity.

Accordingly, **there are critical levels of populations that can be supported**, in perpetuity, from any given land areas.

Any attempts to produce food for populations in excess of the restrictions set by soil and climatic conditions will, at a long term, result in failure. Degradation of land, hunger and eventual reduction in population are the outcome of such practices.

6.2.2. FAO/IIASA/UN METHODOLOGY

The four main components used in the study to quantify land production potential are:

- 1) **agro-climatic suitability**
- 2) **soil suitability**
- 3) degradation
- 4) seed requirements and wastage use.

Agro-ecological zones are identified and soil and climatic requirements for crops are matched with the soil and climatic inventories. The climatic inventory is taken into account in terms of both temperature and moisture. The crops considered were among the widely grown crops of the world such as millet, sorghum, maize, rice, wheat, soy bean, casala, etc. Each area of land is analyzed separately for these crops (grassland and livestock production are also taken into account) to find the most productive capacity for specific soil and climatic conditions. Prior to this analysis, deductions are made for land required for non-agricultural use, for irrigation including the present and projected contribution from these irrigated areas. Limitations imposed by degradation are also taken into account.

The rainfed crop production potentials, together with the production from irrigation, provide the basis for the estimation of potential population supporting capacities of the inventorized zones.

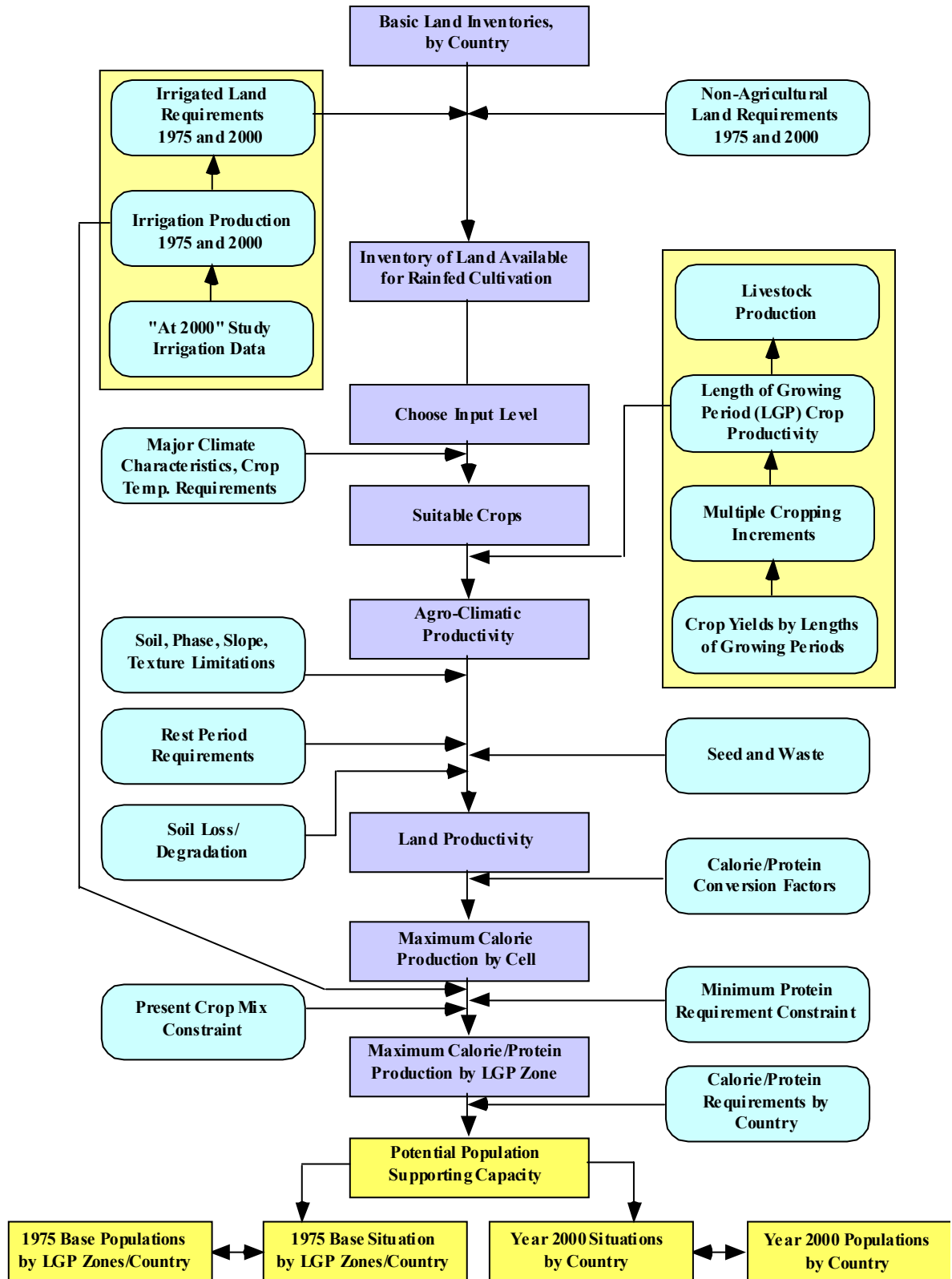
The crop production is converted into calorie and protein equivalent using the international calorie and protein composition factors of crops.

The production in terms of calorie equivalent makes easier the aggregation of different crops and provides a mean for the estimation of the potential population that can be supported.

Finally, the computed rainfed calorie production potentials, for each length of growing period zone, are combined with appropriate calorie production data on irrigate land and converted into potential population supporting capacities by application of country specific per-capita calorie requirements.

We can examine this completed methodology with the help of the following scheme:

Figure 6.2.:Methodology



The carrying capacity potential is then calculated for three alternative levels of agricultural inputs:

- **Low** level of inputs, assuming only land labor, no fertilizer and pesticide applications, no soil conservation measures and with productivity losses arising from land degradation. Cultivation of the presently grown mixture of crops on all potentially cultivable rainfed lands is assumed.
- **Intermediate** level of inputs, assuming the use of improved hand tools and/or draught implements, some fertilizer and pesticide application, some simple soil conservation measures lessening productivity losses from land degradation, and cultivation of a combination of the presently grown mixture of crops and the most calorie (protein) productive crops, on all potentially cultivable rainfed lands is assumed.
- **High** level of inputs, assuming complete mechanization, full use of optimum genetic material, necessary farm chemicals and soil conservation measures. Cultivation of only the most calorie and (protein) productive crops on all potentially cultivable rainfed lands is assumed.

In the following figure 6.3. we have the summary of these levels of inputs:

Figure 6.3.

ATTRIBUTE	LOW INPUT LEVEL	INTERMEDIATE INPUT LEVEL	HIGH INPUT LEVEL
Production System	Rainfed cultivation of presently grown mixture of crops	Rainfed cultivation with part change to optimum mixture of crops	Rainfed cultivation of optimum mixture of crops
Technology employed	Local cultivars. No fertilizer or chemical pest, disease and weed control. Rest (fallow) periods. No long-term soil conservation measures.	Improved cultivars as available. Limited fertilizer application. Simple extension packages including some chemical pest, disease and weed control. Some rest (fallow) periods. Some long-term conservation measures	High yielding cultivars. Optimum fertilizer application. Chemical pest, disease and weed control. Minimum rest (fallow) periods. Complete conservation measures.
Power Sources	Manual labor with hand tools	Manual labor with hand tools and/or animal traction with improved implements	Complete mechanization including harvesting
Labour intensity	High, including uncosted family labour	High, including part costed family labour	Low, family labour costed if used
Capital intensity	Low	Intermediate with credit on accessible terms	High

Market orientation	Subsistence production	Subsistence production plus commercial sale of surplus	Commercial production
Infrastructure requirements	Market accessibility not necessary. Inadequate advisory services	Some market accessibility necessary with access to demonstration plots and services	Market accessibility essential. High level of advisory services and application or research findings
Land holdings	Fragmented	Sometimes consolidated	Consolidated

6.2.2. THE FAO/IIASA/UN ASSESSMENT RESULTS FOR THE CASE STUDY REGION

And in the following figure 6.4. we can see the data, from the FAO/IIASA/UN report, for the countries that we are studying.

Figure 6.4.

REGION	LAND, He	CRCP Low (L)	CRCP Int. (I)	CRCP High (H)
AFRICA	2878100	0.44	1.56	4.47
ETHIOPIA	120800	0.17	0.59	2.56
SOMALIA	63600	0.03	0.05	0.12
KENYA	57000	0.1	0.24	0.93
UGANDA	20000	0.56	2.2	7.72
RWANDA	2495	0.29	1.42	3.22
BURUNDI	2600	0.33	1.78	4.05

6.3. THREE FIRST REFERENCE SCENARIOS

The FAO/IIASA/UN assessments, jointly with our carrying capacity first level model, allows us to draw the three first big reference scenarios about the carrying capacity “situation/scale-evolution” in our countries and region.

Logically we would like to see: what will happen in the region if low (**L**), or intermediate (**I**), or higher (**H**) conditions (level of inputs) **are achieved and maintained on time**, while the population follows the trends that we have seen in the chapter before?

So assuming in each case a zero growth rate for the carrying capacity variable, we will have the subsequently theoretical future scenarios: **LL, II, HH**.

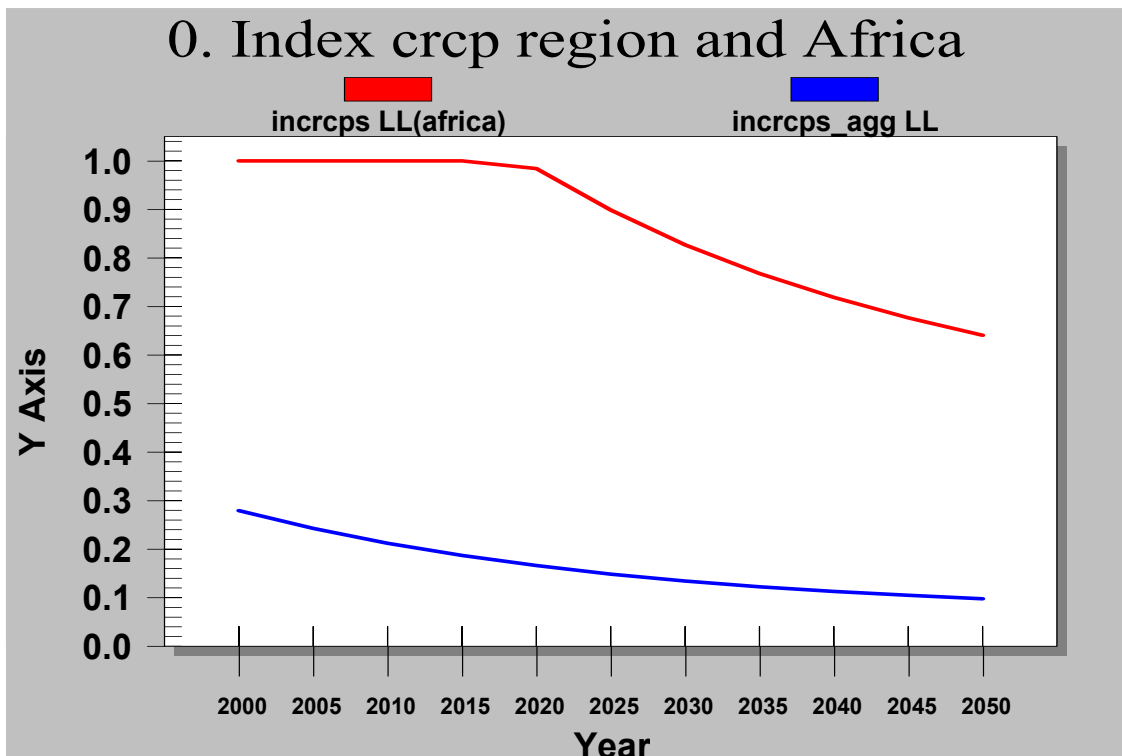
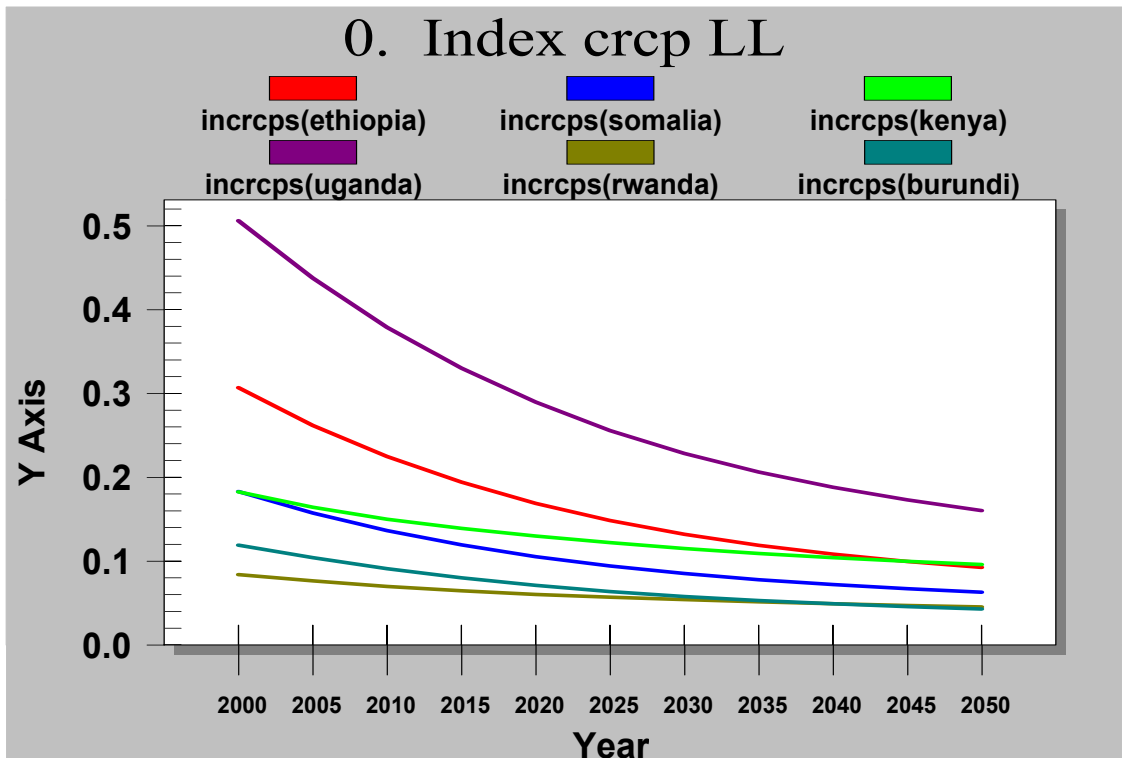
We will represent the results only in terms of the carrying capacity index because the index allows us to be more concise and direct in seeing and understanding what will happen in the region. We should remember here that the meaning of this index, by its definition as a quotient between the population capacity and the population real, is that if it is less than 1, then the land does not have enough capacity to support the population. The farther the index is to 1, the more problematic will occur in the region.

For each scenario we will represent two graphs by the following order: one for all the separate countries, another for the aggregate case study region and for Africa.

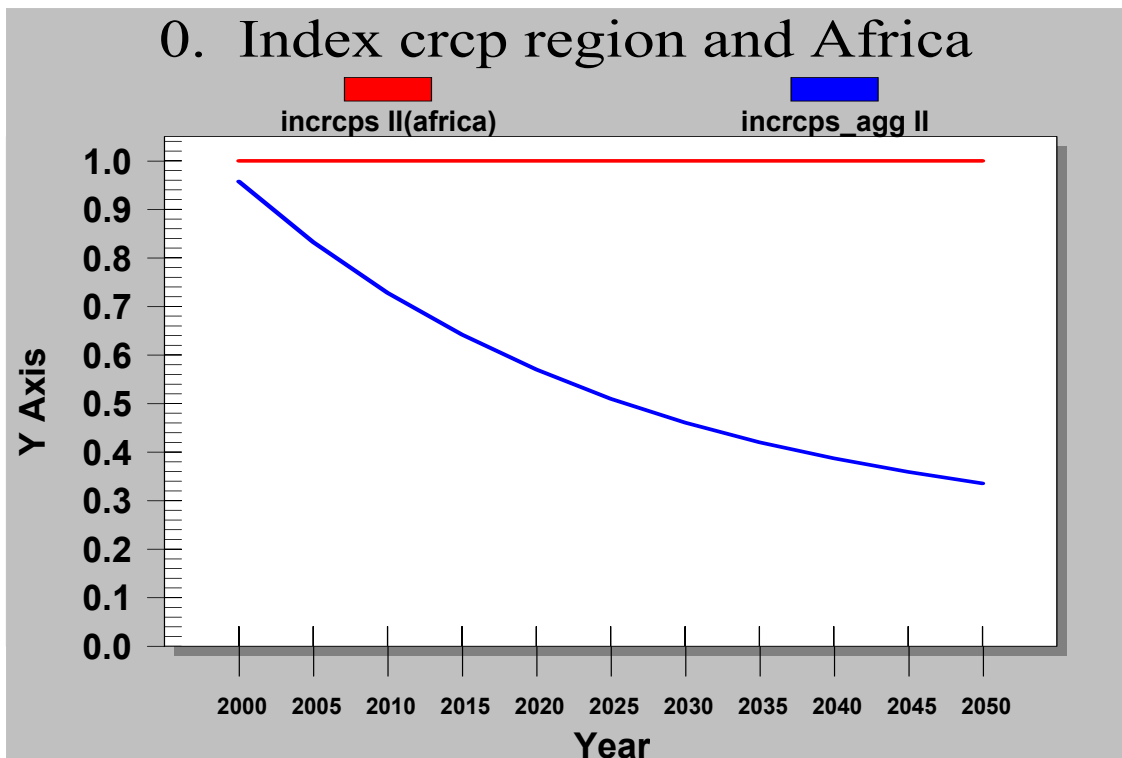
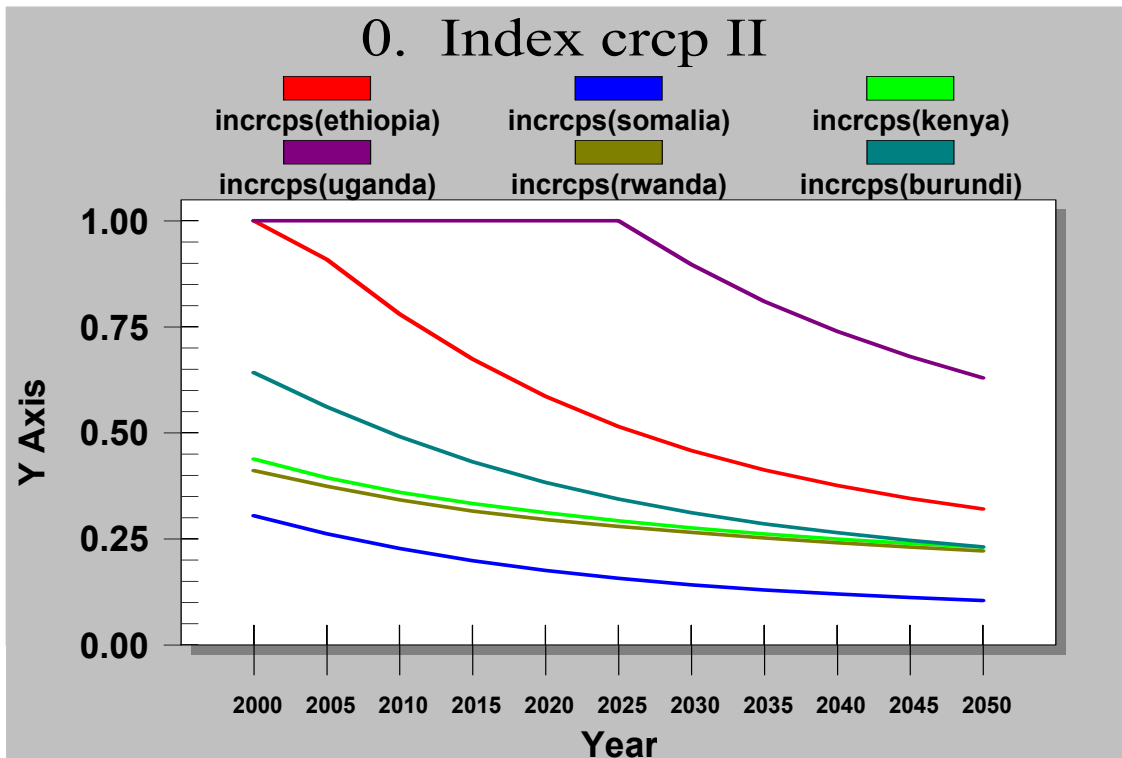
We will proceed from the first scenario as our “worst-case” scenario where the region has a low constant level of inputs of carrying capacity (low constant level of inputs of the potential population supporting capacities of the lands), to our “best-case” scenario corresponding to a high level of inputs of carrying capacity, through an intermediate scenario.

The time period in our study is between 2000 and 2050. It is large enough a time scale to see the trends and implications on the population evolution of these extreme situations (worst-case, intermediate and best-case scenarios) to the regions.

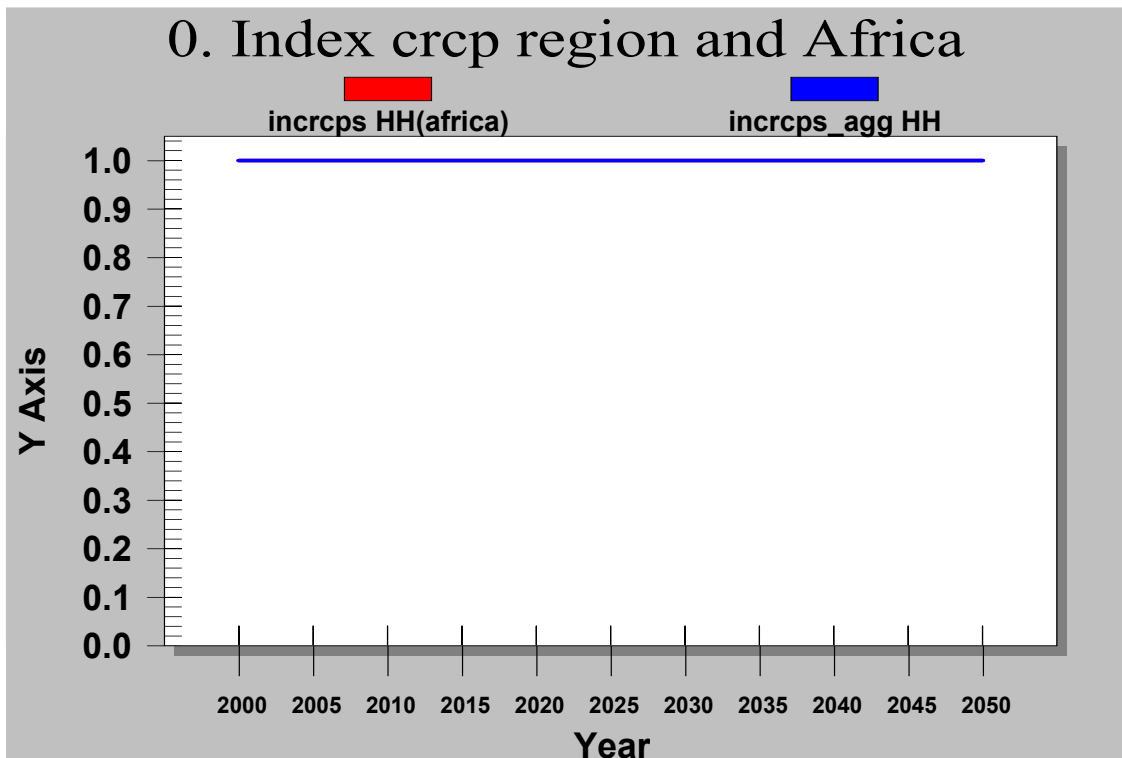
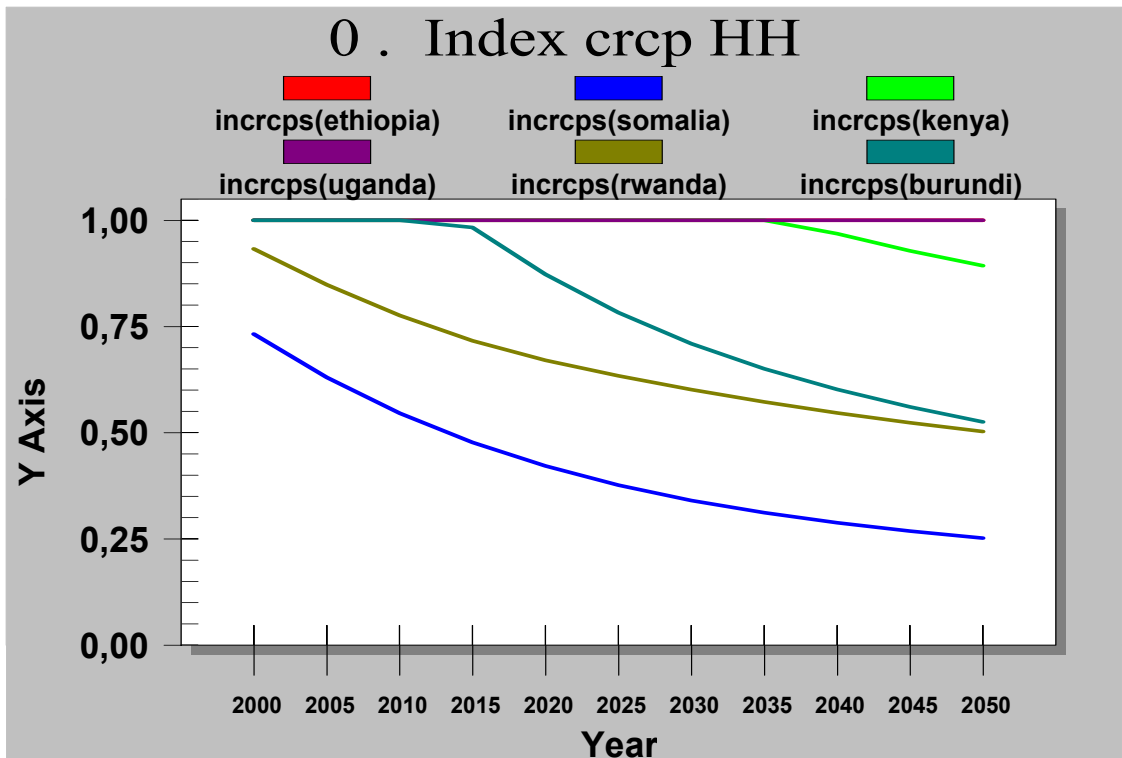
Figures 6.5.: Scenario LL



Figures 6.6.: Scenario II



Figures 6.7.: Scenario HH



6.3.1. FIRST REMARKS AND CONCLUSIONS

Before we proceed, it is necessary to mention here that the remarks and conclusions that appear in this section is not final, simply because its validity can only be justified after we do, for example, the analysis of the more detailed second level carrying capacity model (see chapter 8). This is in accordance with our multilevel hierarchical integrated approach as described at length in chapter 4. At the second level, for example, we take into account that not all the countries ought to be at the same level of inputs, and that, obviously, the levels of inputs not should be constant on time. At the moment but, the qualitative aspects of the region are taken into account as explained in chapter 2.

If we look at Figures 6.7. of the previous **HH** scenario, we can see two main results:

- Africa and indeed our case study region will not have problems if this high level of inputs assumptions is achieved and maintained. This assumption leads us to a maximum although unrealistic situation, or in other words a utopia. If we again read carefully the hypothesis behind this assumption, we can see how far we are from this high “agricultural technology”, and how farther we are from the economic and political conditions necessary to achieve them, according to chapter 2. The trends that we currently see in Africa, unfortunately, goes more indeed in the opposite direction. But many authors blindly cited this scenario, in which they argue that the earth can not really have food problems from the point of view of physical constraints. This is a controversial point. But anyway, for our analysis at this moment we will include this as the most optimistic or a utopia reference.
- The second main conclusion is that indeed under this utopia assumption, there are some countries in our case study region that will still have many problems. Namely: Somalia, Rwanda, Burundi (after 2010) and Kenya (after 2035). We will analyze this, in a certain way, in the final part of this chapter. It is important to realize this because indeed the problems in our region still persist in this utopia!

According now to Figures 6.6. in the **II** scenario we also have two main results:

- Africa has no problems. The conditions are weaker than previous scenario, but the same line of reasoning can be followed.

- Except for Uganda (in which we will have problems only after 2025), we will have problems in all other countries in our case study region starting from the year 2000. This intermediate level of inputs is probably the nearest to reality right now in some of the countries in the region and in Africa in general. We will see. At least we expect to be probably a little bit better than low level input in practically all of the countries. But again, we can see that indeed if we arrive at this intermediate level of inputs, but if there are not any new strong policies in order to improve the situation immediately we will have problems. It is such important problems that will have a suddenly effect in practically all of the countries in the region and in the region itself as a whole. Again by order, the more important problems will be in Somalia, Rwanda, Kenya, Burundi and Ethiopia.

Finally according to Figures 6.5. in the scenario **LL**, we have again two main results:

- Despite the fact that initially Africa will not encounter problems, all countries in the region and also the region itself as a whole we have tremendous problems. So we would like to emphasize again that, since and basically in the most potential pessimistic point of view, the case study region is really one of the most stressful regions in the world in terms of food self security aspect.
- From the Africa point of view, depending on the real situation between the low and intermediate level of inputs as mentioned before, the growth of population in general can not be supported to the near future, by not significant improvement in potential capacity to provide food for itself. This scenario acts as an alert signal of the “worst” things that can happen to Africa in general if we have a passive negative “Business as Usual, BaU,” scenario, that starts with really bad conditions or if not, unfortunately, very close to them.

Thus the general and important remarks and conclusions can be summarized in two parts:

- The case study region is really the most stressful region of Africa and perhaps of the world at the beginning of the next century. (We must insist here again that we are saying this under the light of the general qualitative information that we have about the region from chapter 2, and after this first high level analysis of possible different levels of inputs in carrying capacity).
- The analysis suggests us, it was absolutely clear, to think of some active policies in order to improve the situation in the region. If the intermediate level of inputs is agreed to be the acceptable “level of inputs” to start (probably not

achieved until), we should also accept the existence of the policy through which we can go towards H/2 -the high level of inputs divide by two- level of inputs (probably optimistic but may be a possible goal) and to analyze again the situation at that time.

We would like to qualify this new scenario as one example of a desirable and probably feasible scenario for the case study region.

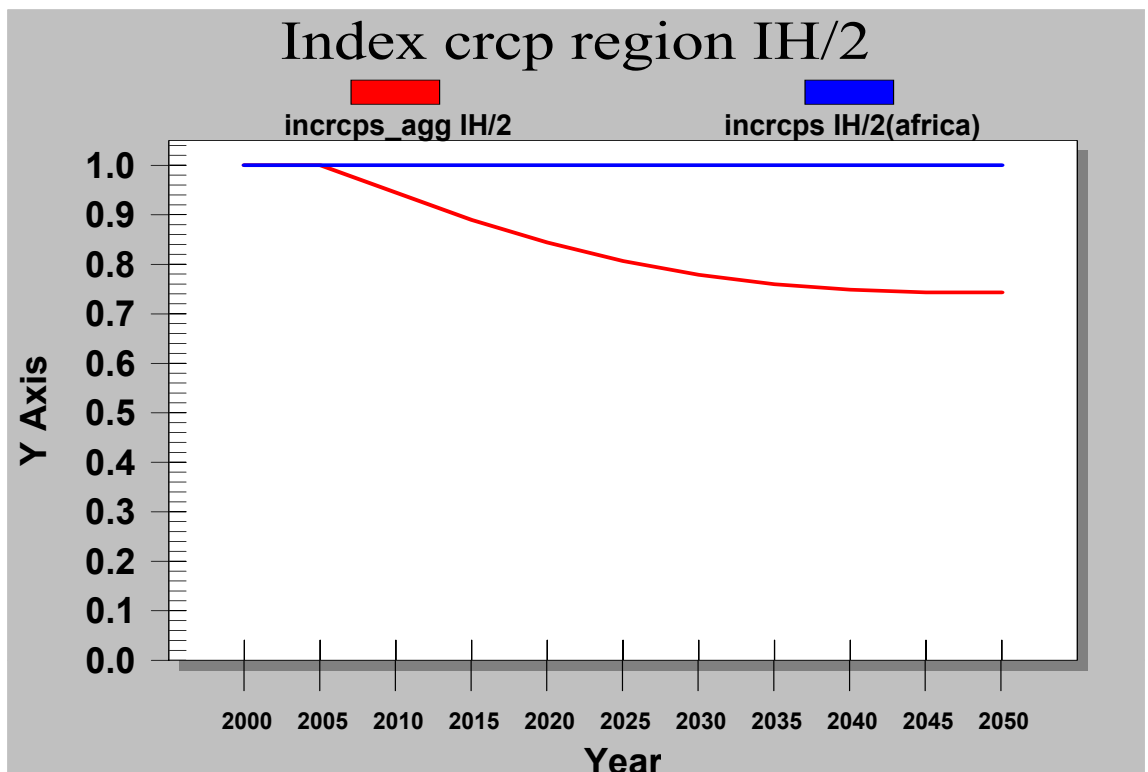
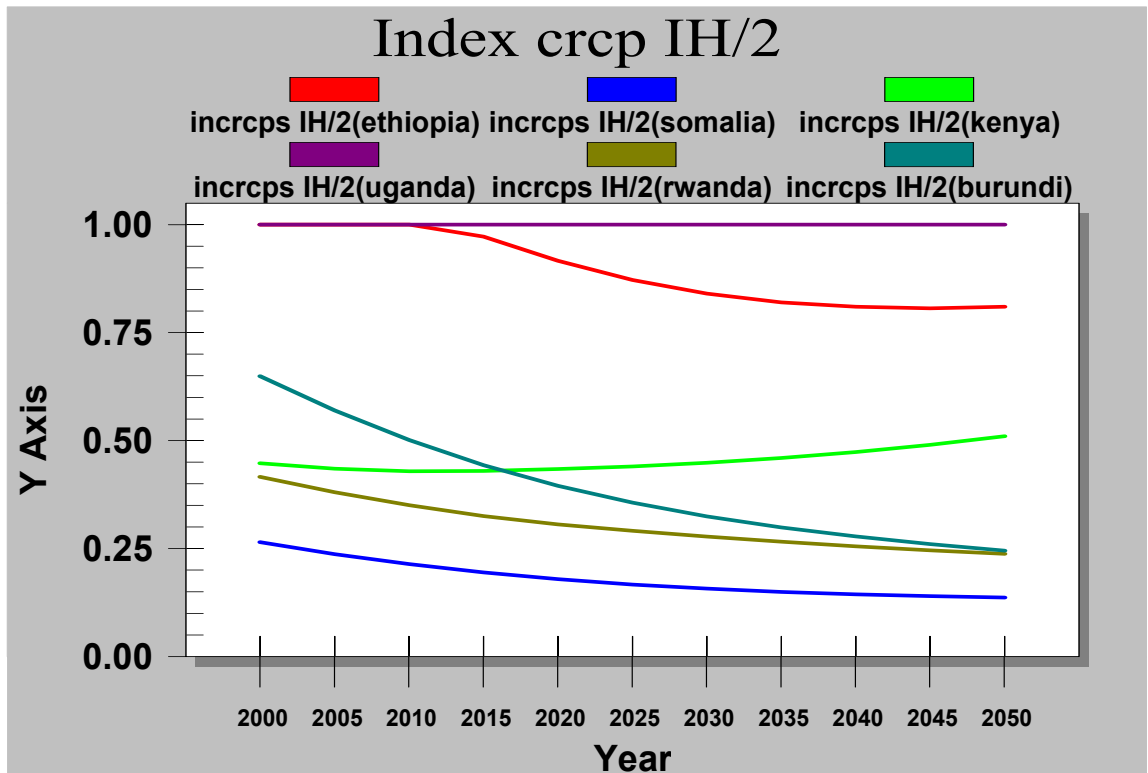
6.4. ONE EXAMPLE OF A DESIRABLE AND COULD BE FEASIBLE HIGH LEVEL INPUT SCENARIO TO THE CASE STUDY REGION

We decide to define this scenario, as one that starts by assuming the initial level of inputs of carrying capacity variable in the region is the intermediate level of inputs of the FAO/IIASA/UN report. And we will achieve the level of inputs H/2 of the report, assuming that the constant growth rate, during the next half-century, is (coherently with the observations done about the characteristics of the more general equations used in our methodological approach -see chapter 4):

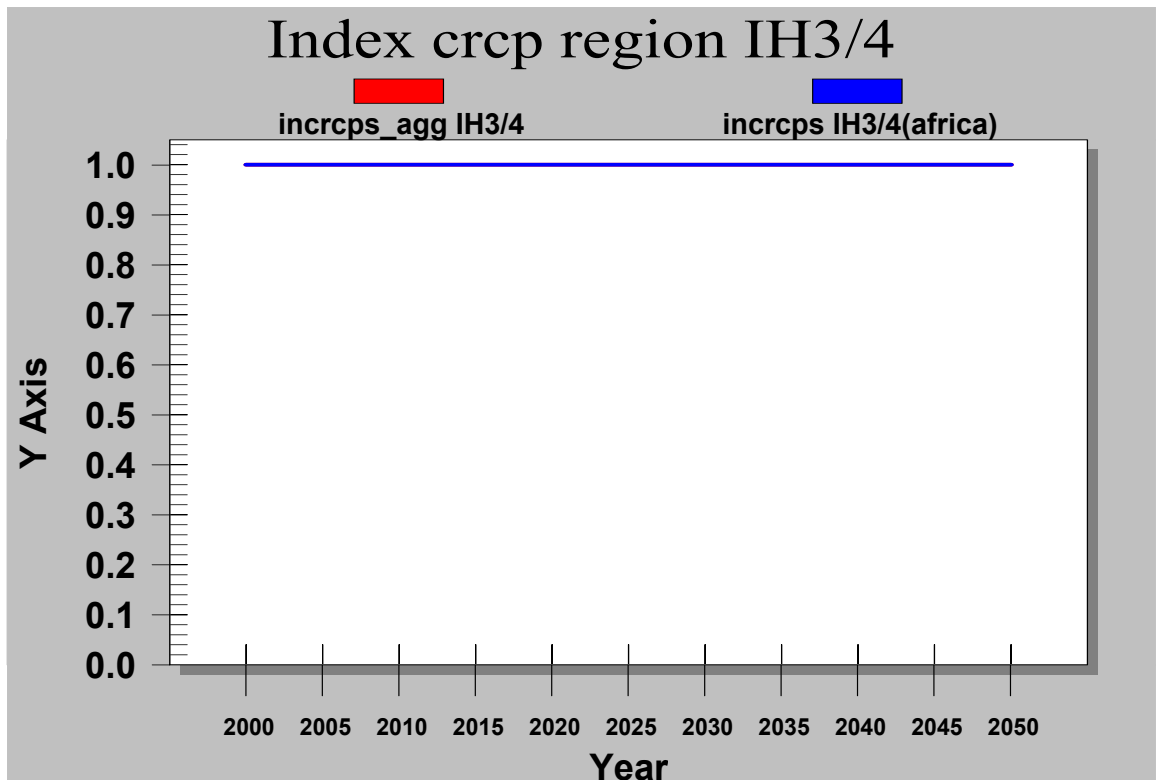
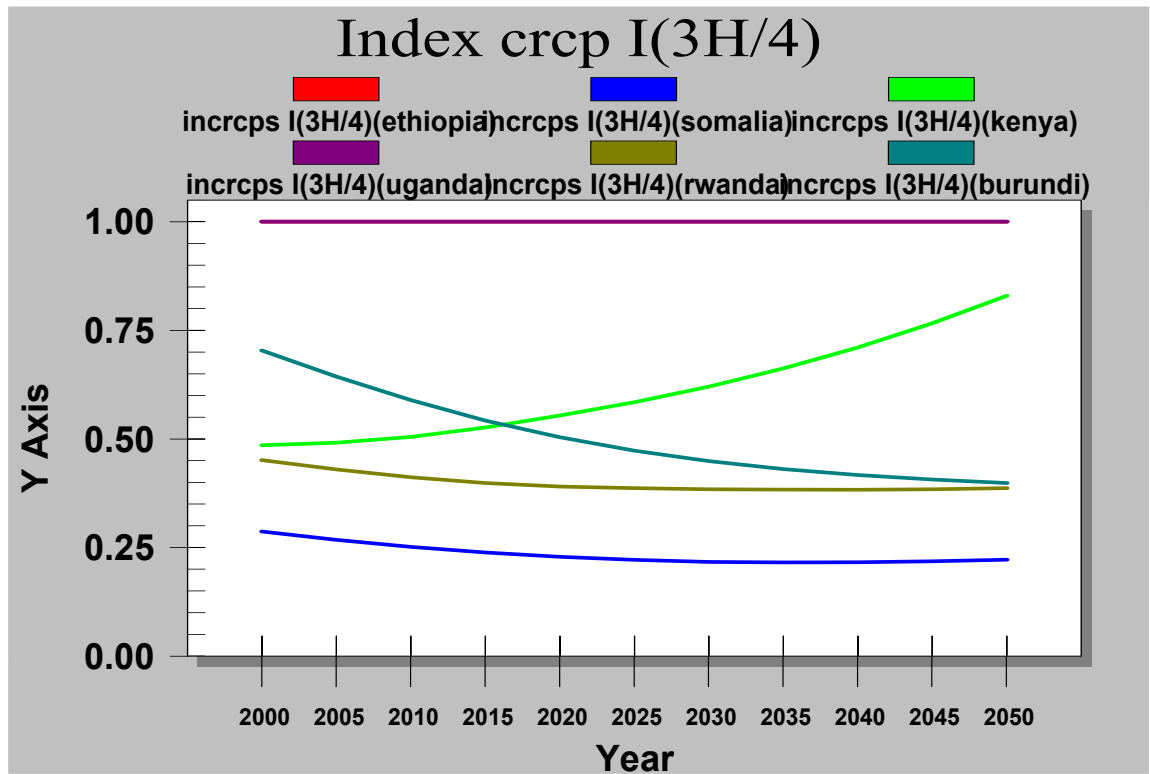
$$rcrcp = \{[(crcp(t+\Delta t)/crcp(t))^{(1/\Delta t)}] - 1\} * 100$$

In the next Figures 6.9. we can see the main foresights of this scenario, and also for a similar more optimistic scenario assuming a final level of inputs 3H/4 (see also Figures 6.10). The conclusion of this comparison is that there are not substantial differences between the countries of the region. The difference is only in the region as a whole, where a final level of 3H/4 of the countries drives the whole region out of the carrying capacity problem. In fact, it is Ethiopia that has the biggest impact in the whole region, simply because at this level the potential capacity to support its population will be enough to support the population deficit of other countries.

Figures 6.9.: Scenario IH/2



Figures 6.10.: Scenario I(3H/4)



6.5. WHAT HAPPENED IN RWANDA-BURUNDI?

We have already seen that there are some countries in the case study region that are potential focus of important problems of food self-security. Especially, in order of calamity, Somalia, Rwanda, and Burundi and Kenya interchanging the third position in time, because the population growth in Kenya “is more under control” at long time perspective.

We knew this. Rwanda-Burundi, South Sudan and Somalia have been the headlines in the newspapers and TV news during this decade.

But, why this was especially dramatic in Rwanda-Burundi and not, for example, in Somalia.

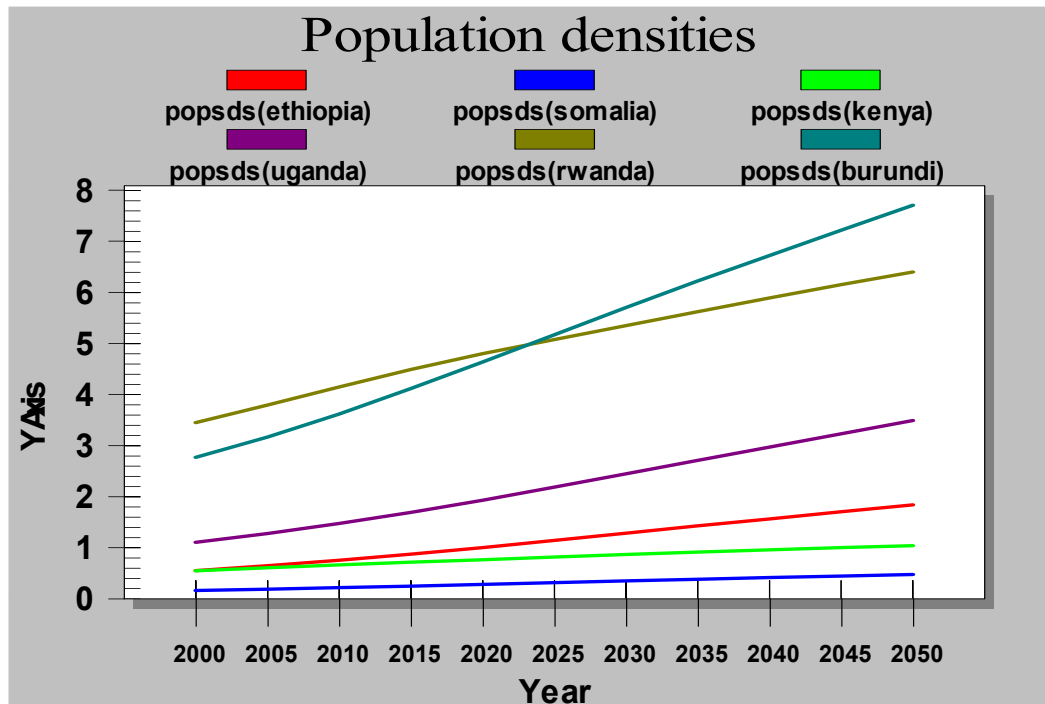
Figure 6.11. is the last step to explain this. We have anticipated detailed comments around this explanation and the political ulterior causes in chapters 0 and 1. Thus we can see now that, certainly, the main cause is absolutely related with the discussion in this chapter but, seen the Figure 6.11., taken into account another, explicitly, complementary dimension: population density. Rwanda-Burundi was and is a country "outside" of all orders of magnitude. And this is also true in all the scenarios that we have seen until here. Because indeed in the "best-case" scenario, in which Rwanda-Burundi is not the poorest potential land country (see Figures 6.4.), the scale effect around the density of the population in a very small country is, with all the probabilities, the additional step in explaining this exceptional situation.

Effectively, it is clear that the conjunction of the two elements (population density and carrying capacity) is the definite explanation of the deeper dimensions of the problem. If we refer to Figures 6.12., for the scenarios LL, II and HH, we can see that the population density deficit (that includes both, population density and carrying capacity, aspects) in Rwanda-Burundi is, and basically was in the 90's, the worst, compare to other countries in the region.

And following this dissertation we should have taken into account that meanwhile the land is constant and the population in the countries is increasing a lot, the future density problems will be added to the food self-security problems and news similar to Rwanda-Burundi can appear.

The units for the densities, in all the following figures, are per hectare (remember only that you must to multiply by 100 in order to have the densities per square kilometer -see Figure 5.16.).

Figure 6.11.



Figures 6.12.

