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THE EVOLUTION OF MINIMUM ARABLE LAND AND FOOD CONSUMPTION FROM 1961 TO 2013

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Abstract

Food security continues to be a vital subject for every country, while the main mean of supply remains agriculture. In order to evaluate the situation and to discover the tendencies, we track the main production and distribution parameters; arable land, productivity, population and food consumption from 1961 to 2013, and we explore the minimum arable land per person, a way of estimating the necessary area of productive land according to consumption levels, while also taking note of relevant dietary shifts regarding the sources of calories and proteins. Our results show a trend of significant decrease of arable land per person, but also a similar decrease of minimum arable land per person. At the dietary level, we also found increases in consumption, along with a shift towards animal based energy in developing countries, while some developed countries plateaued. In line with the field's literature, our results describe an increased consumption based on ecologically unsustainable large yield increases.

Key words: *arable land, food security, sustainability, food consumption, food footprint.*

INTRODUCTION

The 20th century has been witness to one of the best investments in international research people have made, in the form of the Green Revolution. This continuous revolution has increased food security by raising productivity and lowering prices (Evenson, 2003), making better use of arable land. Land is one of the most relevant limited resource in human history, and we can treat it as a constant to which a variable population is connected. Arable land per capita is a function that allows us to see the total amount of arable land at the disposal of a population. Minimum arable land is a more abstract function that shows us the size of arable land currently used by that population or land that will be used by a population in the future, an arable land footprint. To have food security, minimum arable land per capita must stay well below arable land per capita, and this has happened over the last half-century thanks to big increases in yields. The sustainability of productivity remains a challenge (Ray et al., 2013), but not necessarily an unexpected hurdle, as this is not the first time when a leap in efficiency in the production sector is met with Jevon's paradox – a counter-intuitive theory which predicts that gains in efficiency of use of a resource become consumed by increased demand of that resource, instead of easing the pressure on that resource (Jevons, 1865; Alcott, 2005; Sorrell, 2009). In this paper we expand on the ideas of Puia and Soran, "*Agroecosystems and human food supply*" (translation), 1981, on agricultural productivity, supply, and relative differences between dietary patterns in terms of impact on land use. These authors have observed, as others continue to do today, that the most efficient diet tends to be plant based, and adding animal components increases inefficiency and minimum arable land and decreases ecological and economical sustainability (Springmann et al., 2016; Peters et al., 2016; Shepon et al.; 2018).

MATERIALS AND METHODS

In order to explore consumption patterns, land and population we extended the methodology of Puia and Soran to cover not just a snapshots of the situation, but a timeline based on data provided by FAOSTAT ranging from 1961 to 2013. Population numbers were also provided by FAOSTAT. We used PostgresSQL and open-source software tools to manage the tables and queries. The first round of results centralized all the data into one table, including all the parameters we explored: per capita calories, protein, plant based calories and protein, animal based calories and protein, arable land and yield. Yield is an important variable here and in the previously mentioned book the authors used a fixed value for all calculations. In our formula, we used yield relative to the actual region for increased accuracy.

$$A_m = \frac{(E_P + m * E_A) * 365}{Y * E_c}$$

A_m – minimum arable land;
Y – yield of the crop, average for cereals in this case;
E – calories: from plants, from animals, from crops; for cereals, the average value was 367.9 kcal/kg;
m – multiplier to control for inefficiency of production for animals. In this case m = 7, as suggested by Puia and Soran, to control for inefficiency of production of animals. In future studies, this multiplier could be more dynamic and fine-tuned.

These results were used for the World's situation in which the year 1961 was also added to encompass more data. For other countries and regions, further results were extracted by averaging a new set of values for each of the 5 decades inside the time line, providing a more condensed.

RESULTS AND DISCUSSIONS

The World's average situation, from 1961 to 2013, has changed consistently in a linear trend on all investigated parameters. Arable land per capita has decreased from 452 m^2 to 225 m^2, a change of -227 m^2 or -50.30%. Minimum arable land per capita has also decreased from 309 m^2 to 154 m^2, a change of -155 m^2 or -50.11%. This minimum land is dependent on the cereal yield which has grown from 1353.2 kg/ha to 3832.1 kg/ha, an increase of 2478.9 kg/ha or 183.19% (Figure 2).

In terms of energy supply, total kcal/cap/day has grown from 2196 kcal to 2884 kcal, a 688 kcal difference, 31.33% (Figure 3). Primary energy supply, measured in kcal/cap/day, has increased from 4424 kcal to 5968 kcal, an increase of 1744 kcal or 41.29%. Plant based energy supply has grown from 1858 kcal/cap/day to 2370 kcal/cap/day, an increase of 512 kcal or 27.56%. Animal based energy supply has grown from 338 kcal/cap/day to 514 kcal/cap/day, a difference of 176 kcal or 52.07%.

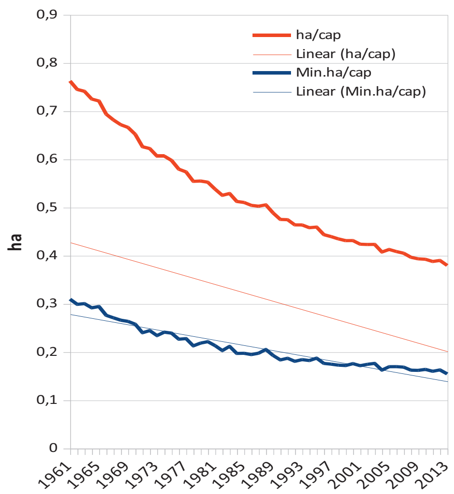

Figure 1. World average arable land per person and minimum arable land per person

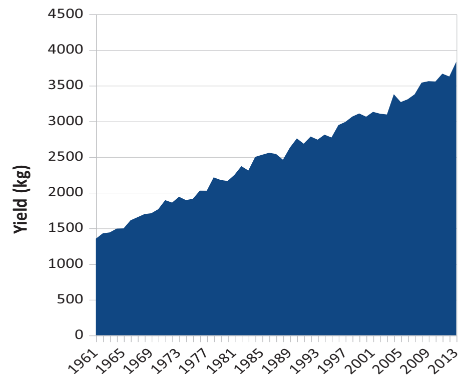

Figure 2. World average yield for cereals

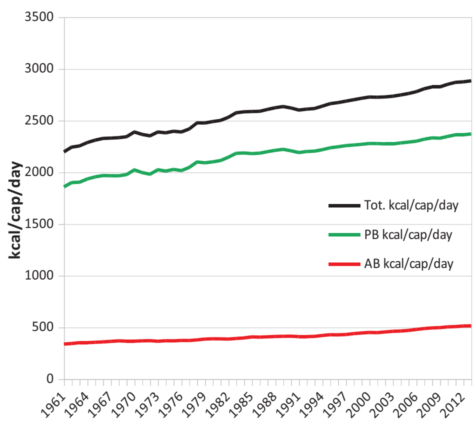

Figure 3. World average energy supply: total (black), plant based (green), animal based (red)

Protein intake has also increased, total protein in g/cap/day growing from 61.45 g to 81.23 g, an increase of 19.77 g or 32.17% (Figure 4). Plant based protein intake, in g/cap/day, has increased from 41.79 g to 49.1 g, a change of 7.3 g or 17.46%. Animal based protein intake, in g/cap/day, has grown from 19.66 g to 32.13 g, a difference of 12.47 g or 63.43%.

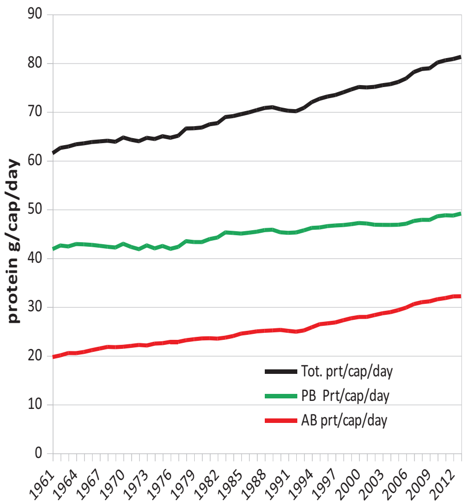

Figure 4. World average protein supply: total (black), plant based (green), animal based (red)

Linear regression (Figure 1) of the evolution of the minimum arable land per person parameter points to 2057 as the intercept with the year axis, with R^2 = 0.90 and Standard Error = 4.84. For the linear regression of the arable land per person parameter, the year axis intercept is also 2057, with R^2 = 0.97 and SE = 2.75.

The world average situation can be described as a relentless increase in overall consumption due to population growth, but also due to individual consumption increases in intensity, with rising levels across both calories and proteins. This total increase is more resource intensive due to the faster growth of consumption of animal based calories and protein, compared to the plant based increase, yet plant based nutrients still dominate the average diet. All these aspects of growth are inversely tied to arable land per person, a resource that is usually very limited and fixed. Arable land can grow, but it does so usually at the expense of grasslands, forests and wetlands, areas which are important parts of the biosphere. Arable land per person has been halved over the course of a half-century. Minimum arable land per capita also evolves, as the minimum changes to match the new total, it should increase, but, instead, it has decreased similarly to arable land per capita: by half in a half-century. This decrease has been supported by a much faster growth in yield: an almost tripling of yield for cereals, an average rate of 47 kg more per year, the negative consequences of which are not discussed in this paper, but are important to ecological sustainability and climate change (Peters, Christian J. et al., 2016; Eshel, Gidon et al., 2017). Both arable land and minimum arable land are decreasing towards 0 (ha), converging concurrently around the year 2057. While it is difficult to simulate what agricultural systems will look like then, we can notice that, as the two parameters come closer to each other and to 0, there's an increase in vulnerability to anything that might shrink the harvest, as such changes may become points of intersection in the trend lines. Yield is the most malleable factor in this equation and yield increases need to be at least 2.4% per year in order to keep up with the projected demand by 2050, but recent gains are only between 0.9% and 1.6% (Ray et al., 2013).

The following results are shown in charts. Each region shows the decade average for the period of 1962-2013. Decades are ordered new to old, while regions are ordered by the value of the most recent decade (V) descending from the biggest values to smallest values.

We can see (Figures 5, 6) how arable land per capita has decreased in most places; sharp decreases for top regions and dwindling changes for the lowest regions where the pressure was already more intense.

Concerning minimum arable land per capita (Figures 7, 8), the overall trend of decreasing values is clear, but, unlike the arable land progression, there are outliers who have had some increases along the way.

Important factors to look at in such cases would be changes in technology and related infrastructure, changes in demand for animal based foods, and more dramatic events such as conflicts that hamper, discourage, or block agricultural production.

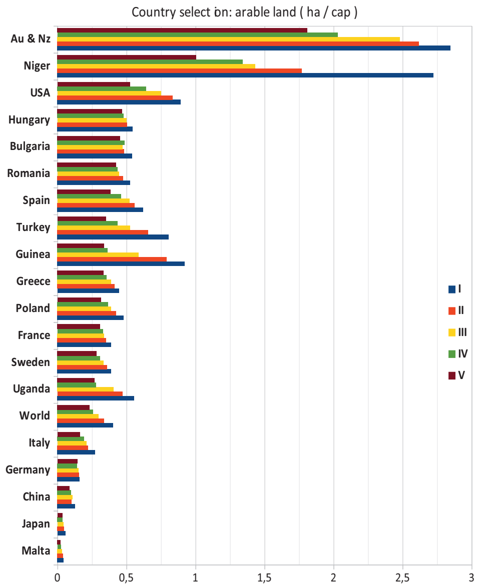

Figure 5. Change in arable land over 5 decades for a set of countries

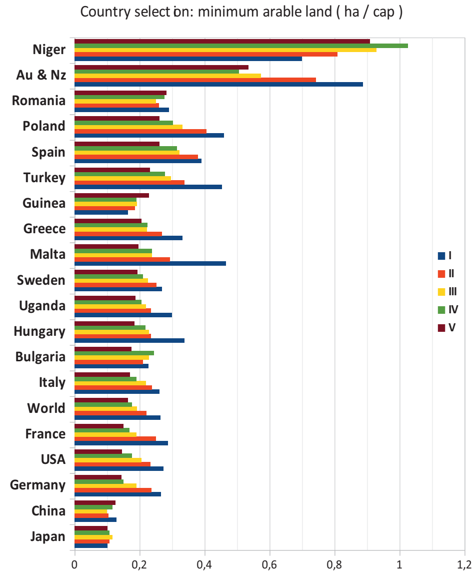

Figure 7. Change in minimum arable land over 5 decades for a set of countries

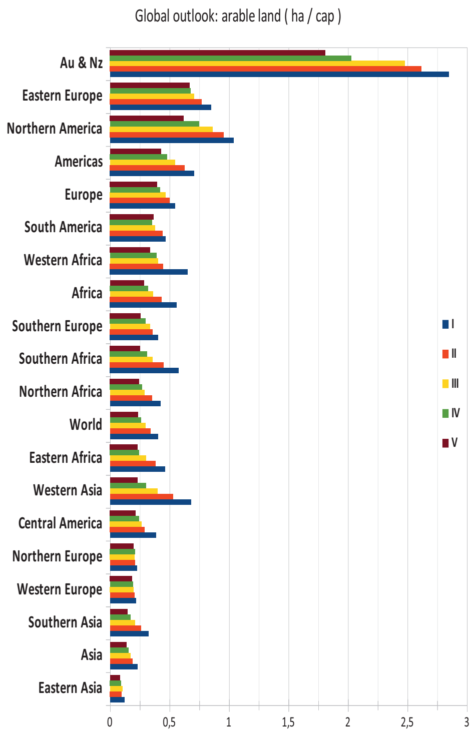

Figure 6. Change in arable land over 5 decades for global regions

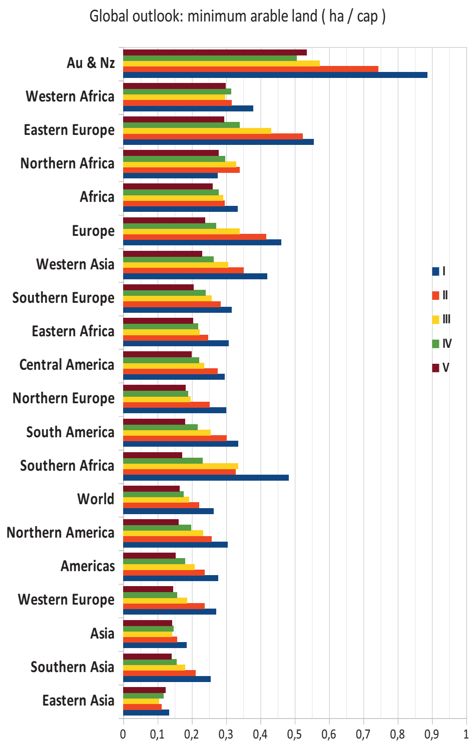

Figure 8. Change in minimum arable land over 5 decades for global regions

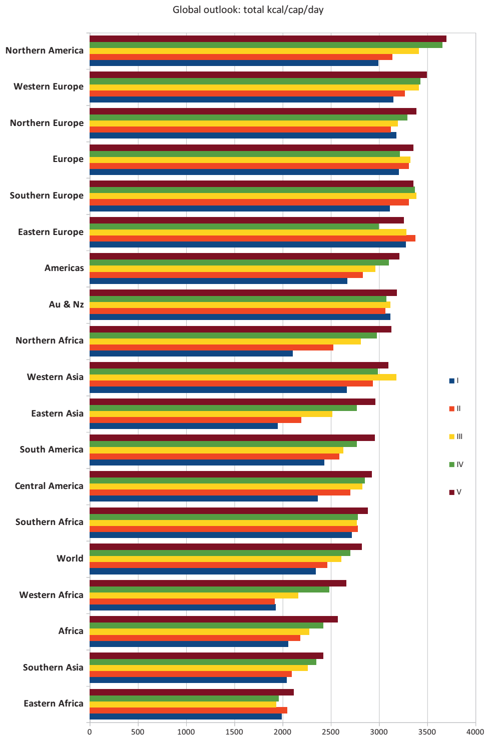

Figure 9. Change in total kcal/cap/day over 5 decades for global regions

For total calories per person, the regional changes around the world continue to support the trend of growth, even among developed regions. Not all regions have constant growth and we can see even a decrease in Southern Europe.

These averages are limited in their power to describe the level of adequate or inadequate nutrition around world, since recommended caloric intake is not a "one size fits all" parameter (FAO/WHO/UNU, 2004).

Next, we calculated the range from the starting decade to the ending decade based on their averages, illustrating the change in primary kcal/cap/day across the 5 decades. The chart (Figure 9) includes all regions and selected countries together.

The trend (Figure 10) shows an increase in the consumption of primary calories across the World, demonstrating that even if total caloric gains decelerate or plateau, there can still be increases in primary calories due to dietary shifts. However, there can be decreases too, as seen in Northern Europe, Poland, Australia and New Zealand.

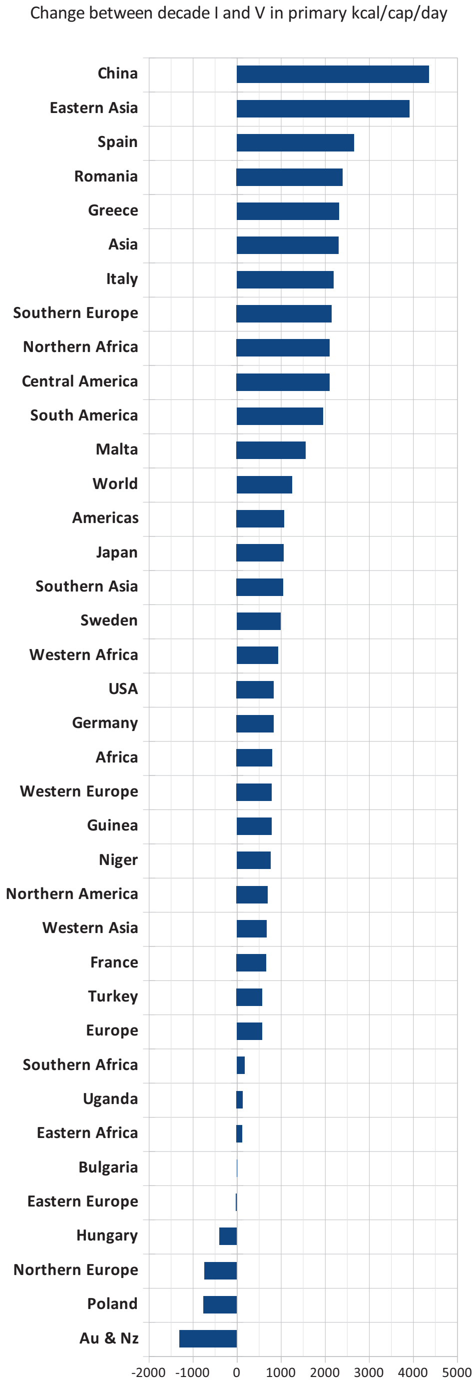

Figure 10. Change in primary kcal/cap/day from the average of decade I to the average of decade V

We also measured, from decade I to V, the shift in dietary energy supply from plant based calories to animal based calories.
The following charts (Figures 11, 12) show the change that happened with plant based calories as a percentage of the total, negative meaning a decrease in plant based and an increase animal based calories.

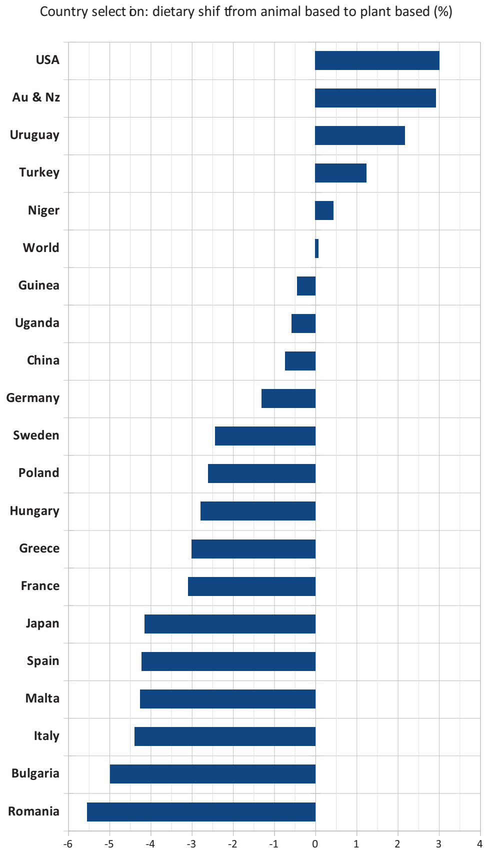

Figure 11. Changes in plant based caloric supply between the 1st decade average and the 5th decade average for a selection of countries

We can now see that a significant number of developed and developing regions (Figures 9, 10, 11, and 12) have reduced their total caloric intake and/or have replaced animal based calories with plant based calories.
We can also see that developing countries are getting closer to developed-country levels by increasing animal based calories.
The global average leans slightly towards more plant based calories and the positive trend is probably based on economic forces that promote the cheaper and more efficient plant-based ingredients, rather than on ethical forces such as environmental awareness or vegetarian movements. In some situations, this shift could be related to economic distress that makes animal products more unaffordable.

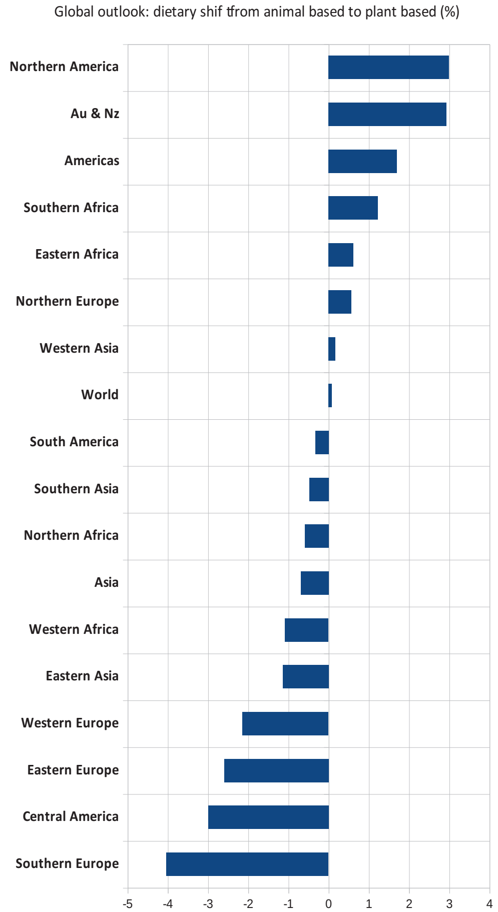

Figure 12. Changes in plant based caloric supply between the 1st decade average and the 5th decade average for global regions

CONCLUSIONS

Arable land per person has decreased continuously and consistently in the period between 1961 and 2013; someone in 1961 would have had assigned a unit of arable land twice the size of someone in 2013.
Minimum arable land has also decreased at a similar pace; a unit of arable land used by a

single person in 1961 can support two persons with greater consumption in 2013.

During this period, consumption has increased, reducing nutritional deficiencies all over World. Consumption has also become more resource intensive, with developing countries adopting a more Western diet that is rich in animal-based foods, while some developed countries have shifted slightly in the opposite direction.

The general improvement in consumption and minimum arable land that has happened is directly dependent on large gains in yield, a development that is already failing to keep up the necessary increases to match future needs 3 decades from now and is leading to a future of less food security by the middle of the 21st century.

If yield cannot keep up, other factors must change: increase available arable land, but this comes at further cost to sustainability, biodiversity, carbon sinks; decrease minimum arable land by shifting to more plant based diets.

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