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ASSESSMENT OF THE FUTURE SUSTAINABILITY OF FOOD SUPPLY AND FOOD SECURITY

JEL classification: : Q51, Q56, C53

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Abstract. *The agro-ecosystem is a complex system, with various parameters that can impact on its productivity.*

Over time, human beings have put the sector under stress due to their demands for food and other agricultural products from it. The proposed Ecological-Footprint Agro-Ecosystem Model (EFAM) has shown that the increasing ecological footprint (i.e. demands on the agro-ecosystem) has a negative relationship with the efficiency of productive arable lands. Agricultural lands are extremely scarce. Additionally, in the present study, data on land used for agriculture have been converted into global calories received from the sun which are stored in agricultural products; this shows that land is only marginally producing the calories that human beings need for food security globally. This will lead to economic insta-

bility around the world. The policies for agro-ecosystems should monitor the condition of agriculture in the world from climate change to land productivity and good distribution of food throughout the world. This may be done by subsidizing world food production through United Nation programs. In this respect, the UN or governments should have funds reserved to support subsidizing food production in the impacted areas of lower production but without changing the policy for market commodities. This fund is to be used not for emergencies but to support farmers in producing agricultural commodities and to ensure food security.

Keywords: *Agro-ecosystem – Ecological Footprint – Food Security-EFAM Model System – Ecological Footprint Agro-ecosystem Scheme (EFAES)*

Introduction

The agro-ecosystem is a complex system (Millennium Ecosystem Assessment (MA), 2005). The system has many input parameters that may impact on its productivity and the possibility of guaranteeing its continuation. The sustainability of the agro-ecosystem depends on the maintenance of the economic, biological and physical components that make up the system (Belcher et al., 2004). Furthermore, the agro-ecosystem is made up of integrated stocks of man-made, human and natural capital corresponding to the standard factors of production, capital, labor and land (Costanza and Daly, 1992).

Currently, the ecological footprint (Rees, 2001, 2013) has become the new trend for assess-

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ing ecosystems to provide a measure of how much human beings are using natural resources, including the greater part of agro-ecosystems. Ecological footprint analysis (EFA) quantifies the ecosystem area required to support a specified human population (H_p) (Rees, 2013). The human population has increased, and its eco-impact on the earth seems to be irreversible due to the high consumption of natural resources (Shakir-Hanna and Osborne-Lee, 2011). The agro-ecosystems of the world account for more than 36% of the total natural resources of the world. As the intensity of agricultural production increases, as a consequence of the increase in the human population and increasing demand for agricultural crops, the emerging sustainability issue of maintaining the agro-ecosystems becomes vital. The continuation of agro-ecosystems in providing the increasing number of human beings with their needs for food, agricultural products transformed from the agro-products, is very important in supporting current and future generations.

Ecological footprint is used as a tool for measuring sustainability and accountability towards our natural heritage. However, the first author is introducing a new concept related to ecological footprint and naming a new measure which is considering the “**Ecological Human Imprint.**” This new terminology is more comprehensive, covering every aspect of human demands from the earth, the human activities that produce products and the value added to the resources. Using this concept we include the human impacts on resources when measuring and adding economic value to resources (this terminology will be discussed in detail in a separate paper that will cover the issues and concerns about the ecological footprint).

The present paper will assess the impacts of the ecological footprint on the global agro-ecosystems (i.e. the demands of humans and the bio-capacity of this ecosystem) of the earth in order to predict the future of the global agricultural sector in supporting and securing the current and future generations. Additionally, the suggested Ecological-Footprint Agro-ecosystem Model (EFAM) that will be presented in this paper will help to measure the important issues of sustainability of food security issues.

An overview of ecological footprint

Ecological Footprint is an instrument that measures the demands of human beings from the earth (Rees, 2001, Venetoulis, J and Talberth, J, 2010). It also provides assessment of global bio-capacity of the earth (Rees, 2001, Rees and Wackernagel, 1994, Shakir Hanna and Osborne-Lee, 2011, 2012, Shakir Hanna, *et al.*, 2013 a, Shakir Hanna *et al.*, 2013 b in press). At the same time, the ecological footprint is a largely heuristic tool that has been widely used in sustainability analyses for over a decade (Venetoulis, J. and Talberth, J., 2010). According to Wackernagel *et al.* (2002), the ecological footprint is “a measure of how much productive land and water an individual, a city, a country, or humanity requires to produce the resources it consumes and to absorb the waste it generates, using prevailing technology.” In this regard, there is an important element that must be taken into account for calculating the ecological footprint and for this the first author has suggested the term of “**Ecological Human Imprints (E_H)**”. This new terminology, that will be discussed in the coming paper by the first author, has a new dimension with respect to the term of Ecological Footprint. The new dimension is to add the value of human activities that have an imprint on ecosystems and, in particular the agro-ecosystems, negatively or positively and the impact values that the ecological footprint did not consider. One of the added values of human imprint on the ecosystem is the social dimension, which is not accounted for in the ecological footprint. Social dimensions of agro-ecosystems are very important to villages and

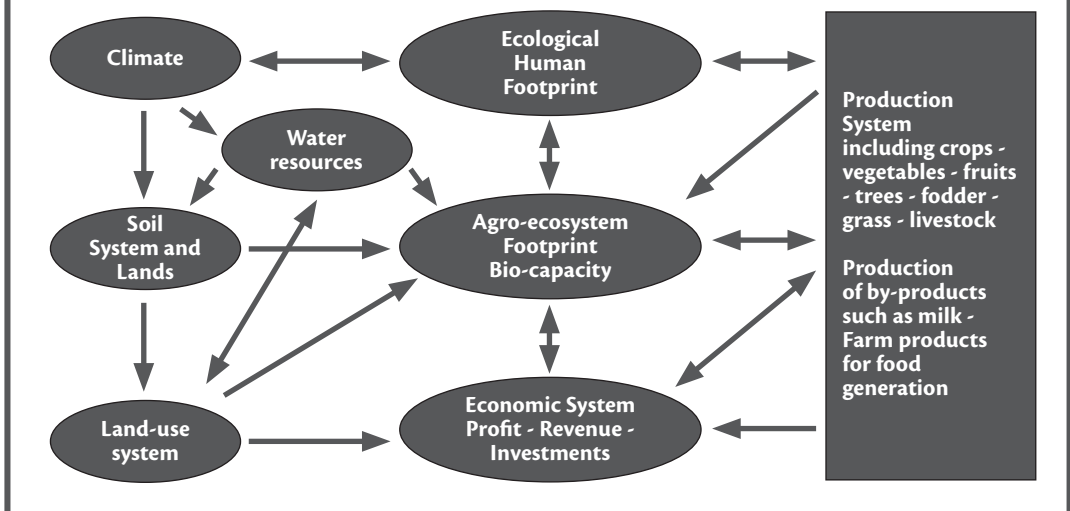
farmers in many countries in the world. For example, eco-tourism of the agro-ecosystem, which has a dimension in the analysis, has not been assessed in the Ecological Footprint. This aspect is adding value to the agro-ecosystems and, at the same time, has a consumption value for the ecosystem. Additionally, the agro-ecosystems added more employment values to these ecosystems and this has not been assessed from the point of view of consumption from these systems.

The Ecological Human Imprints (E_{HV}), terminology has another dimension which is the amount of calories that can come from the sun to enter all the activities of human beings, organisms and plants above ground and organisms below ground and all other species, live or not, on the earth, in addition to considering what human beings release of energy wasted. This gives a broader sense to the ecological footprint and in consequence to the “**Ecological Human Imprints**”. The ultimate process of the calories absorbed from the sun in any live and non-living organism is the motor function of all processes on the earth. The ultimate goal for these scenarios is the survival of human beings and it increases the functionality of our planet.

1. The Ecological Footprint of Agro-ecosystems Scheme (EFAES)

The concept of agro-ecosystems is that of a system that has complex parameters that interact with each other to form the direct products of crops such as wheat, rice, vegetables, fruits, fodder crops and intermediate products coming from these such as meat, milk and other products and perhaps secondary products that can return to the soil. Furthermore, sustainable food production is inextricably linked to environmental stewardship. In order to sustain food security, it is mandatory to improve access to culturally appropriate, health-promoting foods for food insecure families by impacting on food availability, food access, food quality, and food use. Figure. 1 shows the Ecological Footprint Agro-ecosystem Scheme (EFAES) that includes the Ecological Human Footprint in the agro-ecosystem which comprises the activities that provide human-beings with their needs, and the products consumed. The system includes the economic and the natural resource components that participate in food production and ultimately the food security of the world.

Fig. 1 - The Ecological Footprint of Agro-ecosystem Scheme (EFAES)



These important values give many dimensions to be assessed in agro-ecosystems.

2. Measuring the Ecological Footprint of Agro-ecosystems

To measure the footprint of the agro-ecosystem, many procedures have been adopted by scientists and researchers [(Rees 1992, 2000, 2006, 2008, 2010), Rees and Wackernagel, 1994, and Borucke, *et al.*, 2013)]. However, the most important aspects of measuring the footprint of agro-ecosystems are to use a global hectare measurement for commodities produced from the farms locally, regionally and globally and exported and imported (Borucke, *et al.*, 2013 and Kissinger and Gottlieb, 2012).

3. The Impacts of Ecological Footprint on Global Agriculture Policies and Food Security

The World Food Summit of 1996 defined food security as existing “when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life”. Commonly, the concept of food security is defined as including both physical and economic access to food that meets people’s dietary needs as well as their food preferences (WHO, 2013). In our discussion here, we need to stress that food security is related to the availability of food and the availability of food is concentrated on the availability of arable lands that produce food most efficiently. In this respect, arable land and agricultural land need good quality soil, water resources, less pests and plant diseases and important climatic factors¹ These factors will participate in producing good quality and yields of crops for humans. One of the major concerns of food security is the sufficiency and affordability of food to support the growing global human population

The question now is: is our global ecological footprint and, in consequence, the ecological cropping system (i.e. the demands for crops and the earth’s cropping system bio-capacity), on the sustainable path for food security for humanity or not? Let us discuss some scenarios of food requirements for humanity in terms of the minimum required calories needed to support the population. USDA indicated that the required average number of calories per day for human survival is 2000 calories per day. This means that the total need for all human beings is 2000 times 7.2 billion people on Earth and continues to grow (i.e. 14000.4 billion calories per day and 5110146.0 billion calories per year). In other words we need about 14 trillion calories per day to feed the whole of humanity. From that scenario we can ask ourselves where we can get all these calories to feed our human population The obvious answer is from our global productive lands that produce the crops and by-products that support human beings. Additionally, the question is: is our earth producing these calories transformed from the energy that the sun emits to the earth? We need to ask ourselves if the conversion factor from energy emitted from the sun to produce food, is sufficient, with other parameters in soil and climate, to generate the commodities that we need to support our existence and food security. Accordingly, Krenz (1976) has estimated that reflectivity and emissivity constants are averaged to values that depend on cloud coverage and atmospheric composition at 227 Watts/m² of the earth. From the conversion of the earth watts of energy per m² to calories, the earth will receive and emit in the range of 26.1- 28.0 million trillion calories annually (Shakir and

¹ [i.e. drought poses a problem to agriculture, especially in US: the lack of rain has already contributed to devastating wildfire in the West, which created more than \$450 million worth of damage in Colorado alone. Additionally, the most apparent, immediate impact of the drought has been a reduction in crop yields across the 29 states in the affected area. Estimated U.S. corn yields have dropped steadily as the drought has worsened. Reduced yields and the threat of outright crop failure have severe and immediate impacts that stretch beyond farmers and the communities who rely on their crops for their livelihoods. Ranchers faced with increased feed prices are also affected. (WRI, 2012 by Robert Kimball)].

Osborne-Lee 2012). From the earth's agricultural lands (36% of earth's total surface, World Bank Data Group 2012), it can produce 10.0 million trillion calories per year. Therefore, the earth is providing about 20 times the requirements of the earth's current population in absolute number of calories. However, the real maximum number of calories that we are able to use from the Sun to produce agricultural products and food is in the range of about 30%. On this assumption, therefore, the earth's maximum ability to produce is 6,600,000.0 billion calories per year for feeding the whole population. Accordingly, from this scenario, with the increasing human population and the increasing demands for agricultural products, we are in a very dangerous zone of shortage of food and food security will be in question.

Material and methods

This paper has used series of published data from United States Department of Agriculture (USDA Data web site, 2005, 2006, 2007, 2008, 2009, and 2012), Food and Agriculture Organization (FAO, 1960-2008, 2008), World Bank Data Group (1960-2008, 1960-2012), WRI- Earth-Trends (1960-2005, 2000, 2012), United National Environmental Program (UNEP, 2009), World Wildlife Fund (WWF, 2002, 2004, 2006, 2008, 2012), Global Footprint (2008), EPA (2012), UNFPA (2001) and National Oceanic and Atmospheric Administration (NOAA, 2012, www.noaa.gov - Blunden and Arnd, 2012). These data were transformed to units of global hectares of the agro-ecosystem data. The global ecological footprint was calculated by using the data from cropland, grazing lands and energy lands. The data were analysed by regression, correlation, and statistical methodologies using Sigma Plot Soft, 2D software (SPSSSCIENC, 2008) and SAS (2010). The following indices were calculated to explore the Agro-ecological Footprint on earth and its relationships to food security issues that are of great importance to all human beings living on this earth.

- $MI\ Index = G_{BC} / G_{BD} * 100$ (1)
- $G_{BC} = C_F + G_{LF} + F_{GF} + F_F + T_{EF} + B_L$ (2)
- $G_{BD} = C_F + G_{LF} + F_{GF} + F_F + T_{EF} + B_L\ consumed$ (3)
- $G_{DC} = G_{BC} - G_{BD}$ (4)
- $G_{EAgLI} = (C_F\ Bio-capacity / Total\ Agriculture\ lands)$ (5)
- $G_{EALI} = (C_F\ Bio-capacity / Total\ Arable\ Lands)$ (6)
- $Ratio\ of\ Global\ Bio-capacity\ of\ the\ Earth\ to\ Global\ Agriculture\ Land\ G_{BC} / G_{AL}$ (7)

Where (G_{BC}) is the total Global Biological Capacity and defined as the ability of the Earth to produce renewable natural resources in term of global hectare/capita, (G_{BD}) is the total Global Biological Demand and defined as the resource consumption of human beings in term of global hectare/capita; (C_F) is Cropland Footprint in million global hectares; (G_{LF}) is Grazing Land Footprint in million global hectares, F_{GF} is Forest Ground Footprint excluding fuel wood in million global hectares, (F_F) is Fish Ground Footprint in million global hectares, T_{EF} is the Total Energy Footprint in million global hectares, (B_L) is Built-up Land in million global hectares, Global Deficit Capacity (G_{DC}) in million hectares, G_{EAgLI} is the Global Efficiency of Agriculture lands Index, G_{EALI} is Global Efficiency of Arable Lands Index, and Maintenance Index (MI) or Maintenance Sustainability index is a percentage of the total Global Biological Capacity (G_{BC}) (i.e. total availability or supply of natural Resources) in global hectares to the total Global Biological Demand (G_{BD}) (i.e. consumption or demand) in global hectares from the earth. In this respect, the index of MI explains the ability of the earth to regenerate biological capacity from the prospective of natural

resource availability. In other words, the MI index explains the status of our Global land (i.e. the earth) in providing natural resources for the production of goods and services for the needs of the human population. Additionally, the predictions from year 2011 to 2100 were made on the basis of annual data from the time series of years 1960 to 2010, almost 50 years of published data.

Results

1. Analysis of Ecological Footprint of Agro-ecosystems

The global agro-ecosystem is a very important sector in the global economy. It provides the essential products that support human beings' existence, present and future for the process of the global economic cycle. In other words, the agro-ecosystem provides the major energy for the economic cycle by feeding the human population (H_p) to work and produce the major products that are used throughout the world.

Figures (2-9) provide the essential picture of what is happening in the agro-ecosystem and its ecological footprint, global demands on it and the bio-capacity of the system. Figure 2 shows that the relationship between the global croplands' footprint (i.e. demand for cropland products) and the global croplands' bio-capacity (i.e. the products available from croplands). The regression line shows a significant negative relationship ($r^2=0.93$) indicating that there is a shortfall between the products available from the agro-ecosystems and the demand from these systems. However, the most positive relationship is between the agro-ecosystem bio-capacity (i.e. arable lands) and the global bio-capacity of the earth. This trend is most important because the maintenance of the earth's bio-capacity depends on the agro-ecosystems (Fig. 3). Furthermore, the human population (H_p) in billion people is growing and crop production in the form of crop production index, shows a similar trend ($r^2 = 0.97$). However, the trend has shifted to a slight reduction in recent years, as indicated by the regression line in (Fig. 4). This is a concern for the food security issue because the regression line shows a tendency towards increase in human population rather than an increase in the crop production index.

On the other hand, the agro-ecosystem trend shows a significant negative relationship between global ecological footprint and the efficiency of arable lands (Fig. 5). This is shown in the regression line where the correlation coefficient is negative ($r^2 = 0.83$). This indicates the reduction in efficiency of agricultural lands and it is not on the same trend as the demands of humans from this system. Further, the agro-ecosystem shows a significant and sharp negative relationship between the human population in billions and the efficiency of agricultural lands (i.e. $r^2 = 0.93$, $r^2 = 0.97$, $r^2 = 0.96$, and $r^2 = 0.65$ Fig. 6, Fig. 7 and Fig. 8). This indicates that food security for the human population is in danger and a very alarming situation for world food security and the possibility of achieving less hunger and famine. It is a serious issue for world leaders to avoid this condition which has many implications and ramifications. This can be seen from Fig. 8 which explains the negative relationship between total ecological footprint and the ratio between biological capacity and arable lands available for producing agricultural products. It indicates that productive agricultural land is approaching exhaustion and a dangerous depletion of the renewability of its productivity.

Considering all these aspects, it is important that the United Nation Food and Agriculture Organization (FAO), United Nation Development Program (UNDP), United Nation Environmental Program (UNEP), and all governmental and non-governmental agencies, should take this matter seriously, otherwise the globe will be in chaos.

Fig. 2 - Relationship between global cropped land footprint and the global cropped land biocapacity

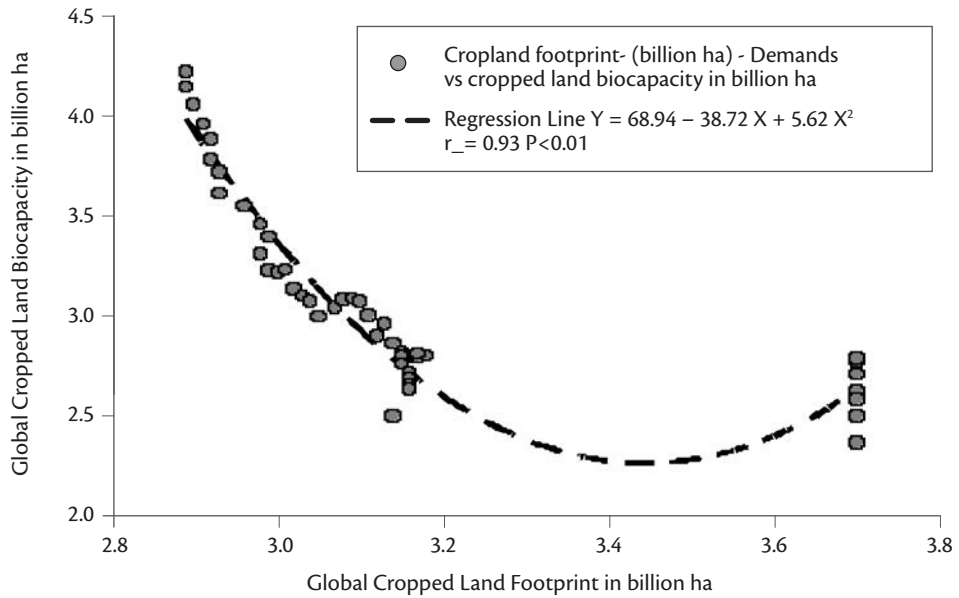


Fig. 3 - Relationship between the global available arable lands and global biocapacity of the earth

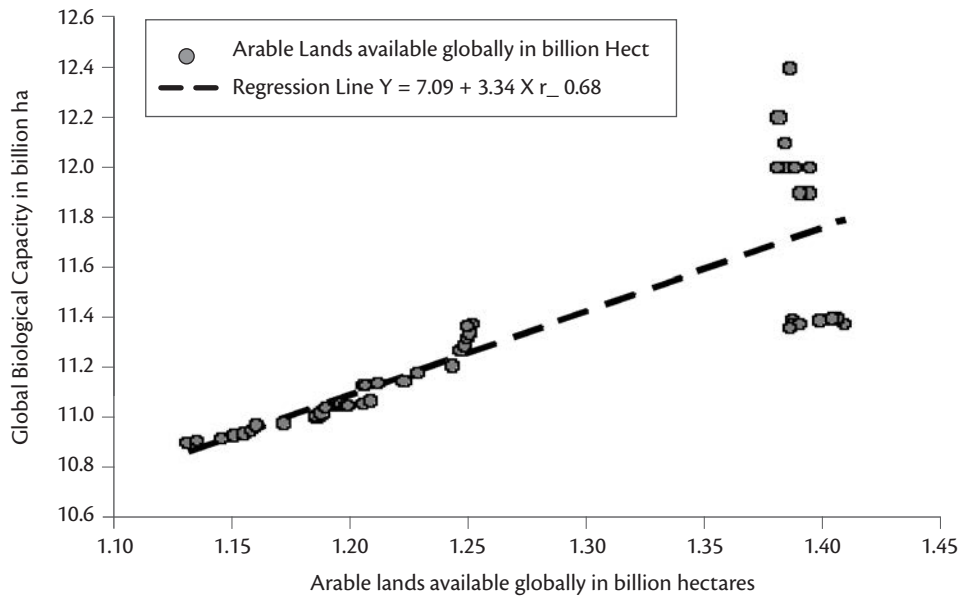


Fig. 4 - Relationship between world human population and global crop production index

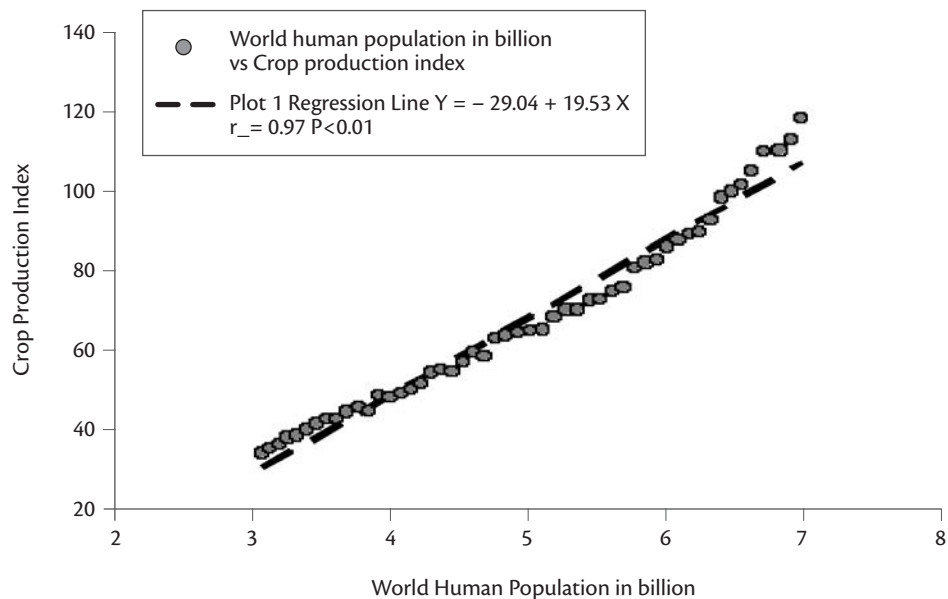


Fig. 5 - Relationship between global ecological footprint and the efficiency of arable lands

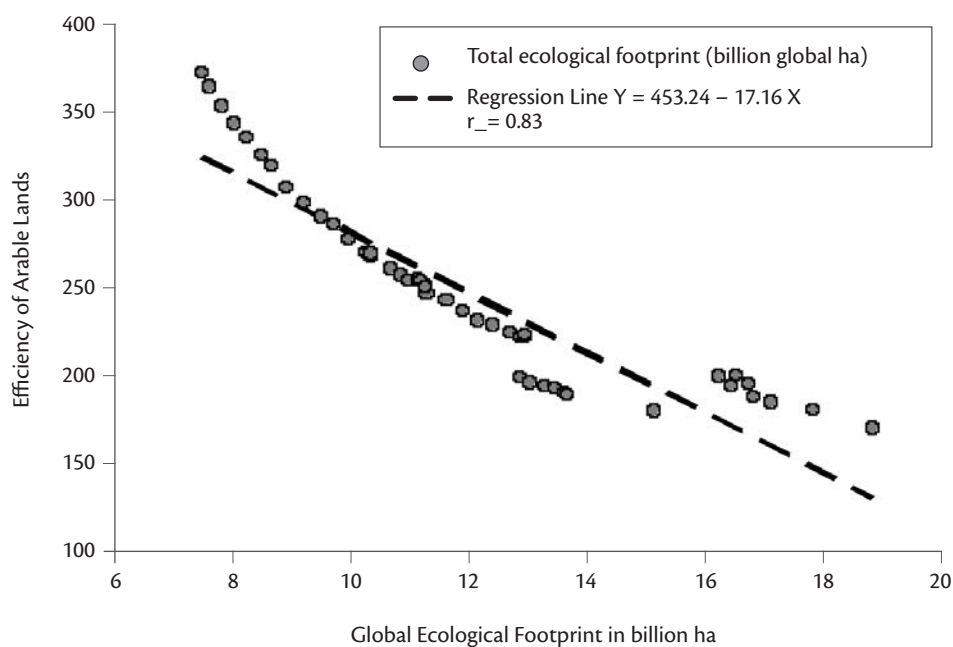


Fig. 6 - Relationship between world human population in billion and efficiency of cropped land as %

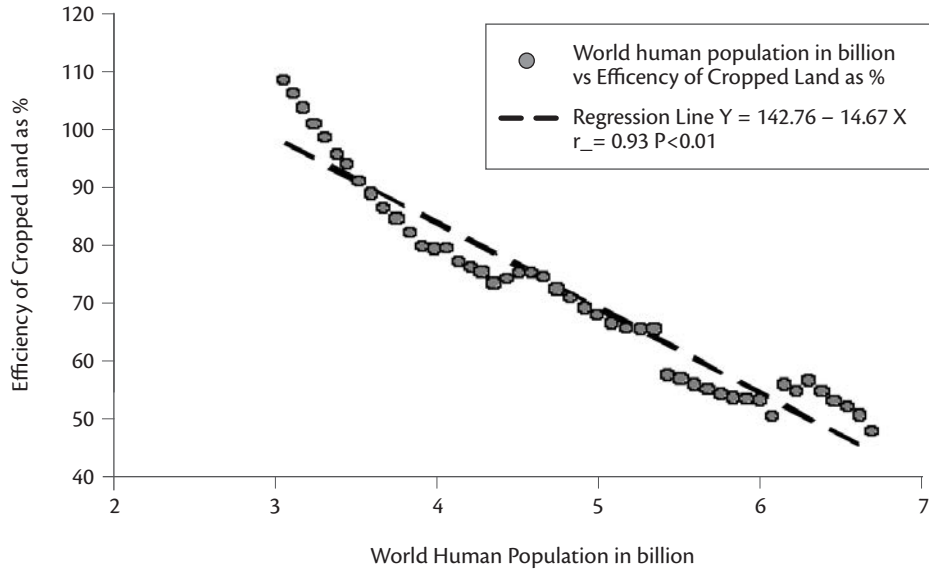


Fig. 7 - Relationship between world human population and cropped land biocapacity

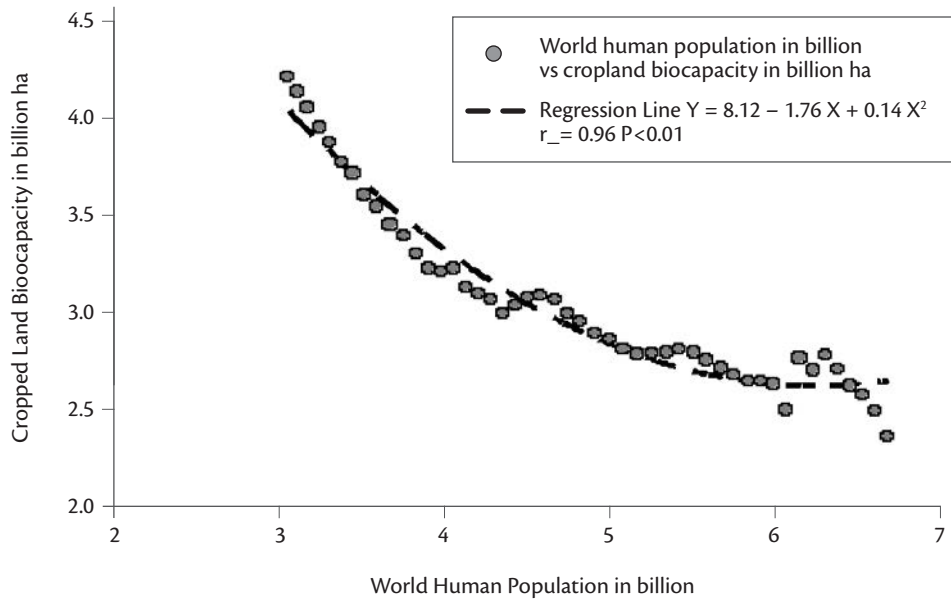


Fig. 8 - Relationship between global human population in billions and efficiency of available arable lands in producing global biocapacity for the Earth

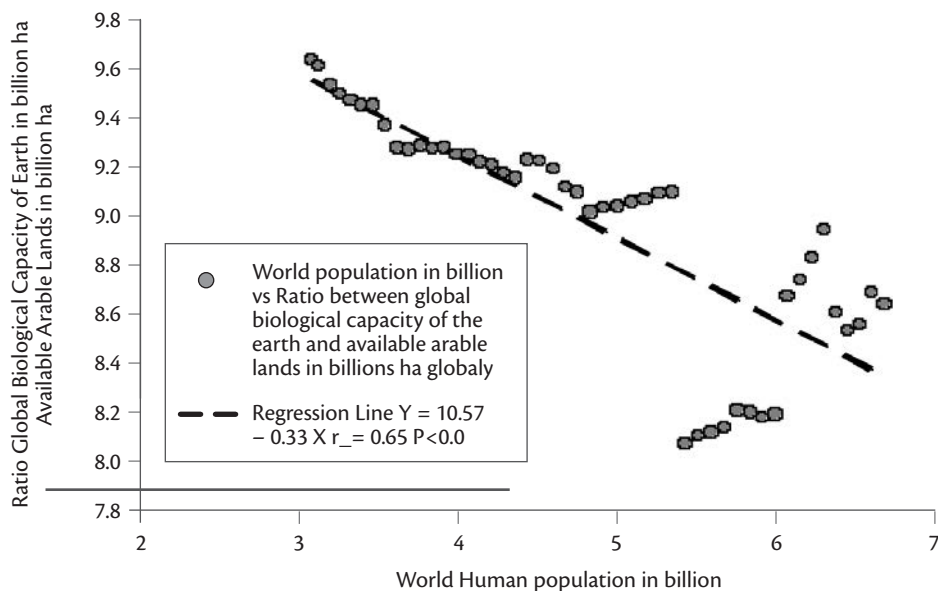
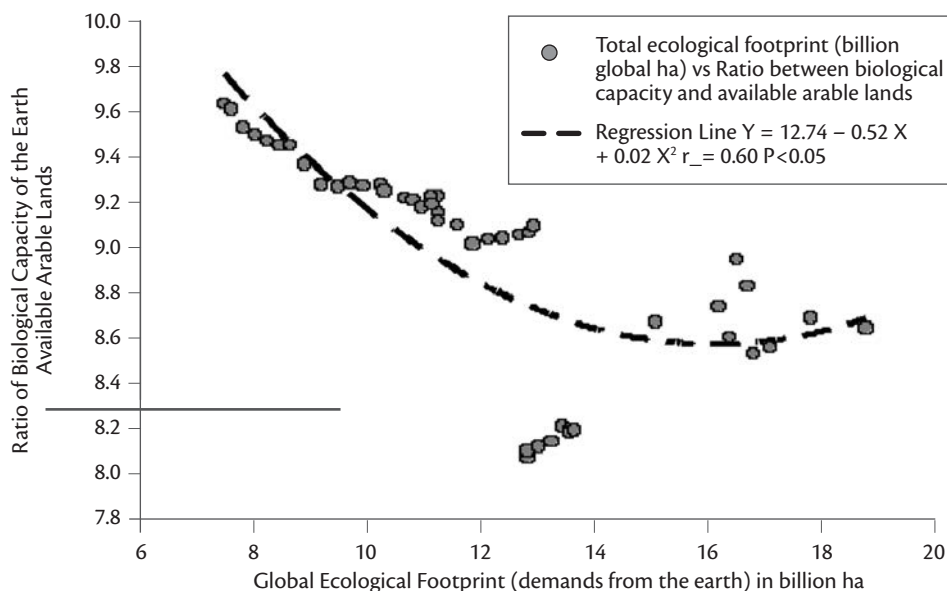


Fig. 9 - Relationship between total ecological footprint and ratio between biological capacity and available arable lands



2. The Ecological-Footprint Agro-ecosystem Model (EFAM)

A) Description of the Model

The Ecological- Footprint Agro-ecosystem Model (EFAM) is designed to predict the impact of human consumption of agricultural products, to predict the future of the global agro-ecosystem for providing the goods and services to support food security, and to assess the human need for food products. The model will be a tool to measure the changes in the parameters that will impact on agro-ecosystems as regards their ability to regenerate bio-capacities which support the planet in sustaining the human population (H_p) globally. This model was written using STELLA modeling software package (2001) – and the version is number 8.0. The model used an annual time step with the fourth Runge–Kutta integration method (Ouyang, 2008). The EFAM model predicts the condition of the agro-ecosystem globally, and determines the future needs for agricultural bio-capacity from the earth for the period 1960 to 2050, almost one hundred years. The simulation period can be from one year to several years and be for a short time period of simulation. Background data and literature parameters were used to initialize the model and short-term data was collected from different sources and data sets of series available on the web sites of World Research Institute (WRI)-Earth-Trends, World Bank, Food and Agricultural Organization (FAO), United States Department of Agriculture (USDA), United Nation Development Program, World Wildlife Fund (WWF) and Global Footprint Network. Table (1) shows the list of variables and parameters in the Model and its interpretation.

Tab. 1 - List of variables and parameters that are used in the Global Ecological Footprint and Climate Change (GEF-CH) Model and its interpretation.

Variables	Interpretation	Unit used in the model
H_p	World Population Series	In billion individuals
E_F	Total Ecological Foot Print	In billion global hectares
G_{BC}	Global Biological Capacity of the Earth	In billion global hectares that generate the biological capacity of the earth
G_{BD}	Global Biological Demand from the Earth	In billion global hectares that consumed from biological capacity by human beings from the earth
C_F	Cropland Footprint	In billion global hectares of croplands
G_{LF}	Grazing Land Footprint	In billion global hectares of grazed lands
F_{GF}	Forest Ground Footprint	In billion global hectares of forest lands excluding fuel wood
F_F	Fish Ground Footprint	In billion global hectares of fish farming
B_L	Built-up Land	In billion global hectares
G_{DC}	Global Deficit Capacity	In billion hectares
G_{EAgLI}	Global Efficiency of Agricultural Lands Index	As a ratio
G_{EALI}	Global Efficiency of Arable Lands Index	As a ratio

The model used parameters such as world human population series (H_p) from year 1961 to 2009, Ecological Foot Prints, Maintenance Index (MI) In addition, other terms such as the G_{BC} which is the Global Biological Capacity and G_{BD} which is Global Biological Demand, Cropland Footprint (C_F) in billion global hectares, Grazing Land Footprint (G_{LF}) in billion global hectares, Forest Ground Footprint (F_{GF}) excluding fuel wood in billion global hectares, fish ground footprint (F_F) in billion global hectares, Built-up Land (B_L) in billion global hectares, Global Deficit Capacity (G_{DC}) in billion hectares, are used in calculations, G_{EAgLI} is the Global Efficiency of Agriculture lands Index, G_{EALI} Global Efficiency of Arable Lands Index and Ratio of Global Bio-capacity of the Earth to Global Agriculture Land G_{BC}/G_{AL}

B) Model Formulas

The following are the formulae that the model used in the prediction of what will happen beyond the period for which data is available.

- 1) The relationship between global cropland footprint and the global cropland bio-capacity is $Y = 68.94 - 38.72 X + 5.62 X^2$.
- 2) The relationship between global available arable lands and global bio-capacity of the earth is $Y = 7.09 + 3.34 X$.
- 3) The relationship between global human population (H_p) and global crop production index is $Y = -29.04 + 19.53 X$.
- 4) The Relationship between global ecological footprint and the efficiency of arable lands is $Y = 453.24 - 17.16 X$.
- 5) The relationship between global human population (H_p) and the efficiency of cropped lands as % is $Y = 142.76 - 14.67 X$.
- 6) The relationship between world population and efficiency of available arable lands in producing global bio-capacity for the earth is $Y = 10.57 - 0.33 X$.
- 7) The relationship between total ecological footprint and the ratio between biological capacity and available arable lands is $Y = 12.74 - 0.52 X + 0.02 X^2$.
- 8) The relationship between world populations and cropland bio-capacity is $Y = 8.12 - 1.76X + 0.14X^2$.

3. Model Simulation and Analysis

In the application of the EFAM model and the simulation analysis the data used for the model are the year, human population (H_p), according to the assumption of a growth rate of human population and according to the calculated global bio-capacity produced per global hectare. The model output (Tables 2 & 3), (Figures 10 and 11) showed that there is a trend of decreasing efficiency in the arable lands available, decrease in the efficiency of croplands and alongside is the increasing human population (H_p) (i.e. in the range 9.0 – 9.5 billion people by year 2050 at growth rate of 1.0%). Furthermore, the model predicted that croplands' biological capacity may be increasing because of heavy machinery, fertilizers and cropping systems which occupy land several times during the year in specific areas. However, global available arable land may increase towards the period 2030-2040. This could be due to the extensive use of agricultural lands, biotechnologies of which now there is an extensive use, i.e. of genetic materials to produce and enhance the crop yields. This will lead to the fullest use of agricultural land.

The model, further, predicts that global available arable lands will start decreasing around the period 2040- 2050. This may be due to the increasing human needs for arable lands and also the demands from an increasing ecological footprint from the earth's resources in the form of goods and services. This is alarming for our global agricultural system. The trend will continue beyond 2050 unless other measures are taken.

These scenarios and predictions, give an opportunity to governments and international agencies and other non-governmental agencies to think of an approach to help support nature in order for it to regenerate itself without degrading resources, and to keep providing them for the coming generations. Interestingly, from Fig. 10 and Fig. 11, we can see that with the increase in the growth rate of human population (H_p) from a 1.0% annual increase to 1.5%, there is still a gap between the growth of cropland biological capacity and human

population. This will lead to a shortage of food supply to support the growing human population.

Tab. 2 - Global Population, Global Biological Capacity (G_{BC}), Global Biological Demand (G_{BD}) and Maintenance Index of Our Planet Earth from Year 1961 to Year 2008 - Data are in 10 year intervals*

	1961	1970	1980	1990	2000	2008
Global Population in billion	3.08	3.70	4.44	5.27	6.10	6.69
Total Global Biological Demand (G_{BD}) (billion global ha)	7.47	9.50	11.25	12.93	15.1	18.8
Total Global Biological Capacity (G_{BC}) (billion global ha)	10.90	11.00	11.13	11.38	12.00	12.00
Deficit in global biological capacity billion hectare = $G_{BC}-G_{BD}$	+2.43	+2.50	+0.12	+0.55	-3.10	-6.80
Maintenance Index = G_{BC}/G_{BD}	1.46	1.15	0.98	0.88	0.79	0.68
Cropland Biological Capacity (in billion global ha)	4.21	3.45	3.03	2.79	2.49	2.36
Global Available Arable Lands in billion global ha	1.13	1.18	1.21	1.25	1.38	1.39
Efficiency of arable lands Index = total cropped bio-capacity/ total arable lands	3.72	2.91	2.51	2.22	1.80	1.70
Efficiency of Cropland Index = Cropland Biological Capacity/ Total Agriculture lands	1.08	8.86	0.74	0.65	0.51	0.48

* Data Sources are World Bank- FAO – WWF – Ecological Footprint Network – WRI-Earth Trends - US Estimates,

Tab. 3 - Predicted Values calculated for Global Population, Global Biological Capacity (GBC), Global Biological Demand (GBD) and Maintenance Index of Our Planet Earth from Year 2009 to Year 2050. The data presented are in 10 year intervals on the basis of current trend of estimate of population growth rate and other parameters

	2009	2010	2020	2030	2040	2050
Global Population in billion	6.74	6.79	8.83	9.17	9.51	9.84
Total Global Biological Demand (G_{BD}) (billion global ha)	16.98	17.11	22.46	28.62	31.30	33.36
Total Global Biological Capacity (G_{BC}) (billion global ha)	11.94	11.95	12.13	12.31	12.52	12.73
Deficit in global billion hectare = $G_{BC}-G_{BD}$	-5.04	-5.16	-10.33	-16.31	-18.79	-20.73
Maintenance Index = G_{BC}/G_{BD}	0.65	0.64	0.54	0.43	0.40	0.38
Cropland Biological Capacity (in billion global ha as predicted from the model)	2.59	2.59	2.67	2.87	3.19	3.62
Global Available Arable Lands in billion global ha as predicted by the model	1.02	1.03	1.08	1.11	1.10	1.06
Efficiency of arable lands Index as calculated from the model	8.47	8.45	8.24	8.03	7.81	7.60
Efficiency of Cropland Index as calculated from the model	0.49	0.49	0.39	0.30	0.20	0.11

Climate change ($G_{EF}-C_{H}$) Model and its interpretation.

Fig. 10 - Simulation analysis of the EFAM Model showing the prediction of 1) Cropland biological capacity, 2) Efficiency of arable lands, 3) Global available arable lands, 4) Efficiency of croplands and 5) Population accumulated on the basis of human population growth rate at 1.0% and the availability of global bio-capacity

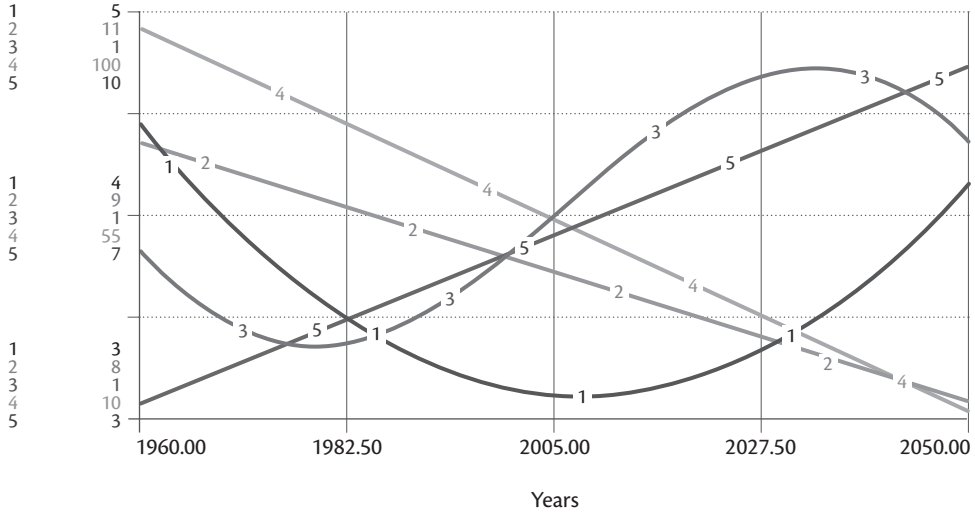


Fig. 11 - Simulation analysis of the EFAM Model showing the prediction of 1) Cropland biological Capacity, 2) Efficiency of arable lands, 3) Global available arable lands, 4) Efficiency of croplands and 5) Population accumulated on the basis of human population growth rate at 1.5% and the availability of global Earth bio-capacity



Discussion

The agro-ecosystem is one of the productive systems around the world and, together with the forest ecosystem, is that able to store the energy from the sun in its vegetative components. The sustainability of the agro-ecosystem depends on the maintenance of its economic, biological and physical elements. In addition, this system must be given the time completely to regenerate itself, otherwise it will be depleted in an alarming and irreversible manner. Once it is degraded, this ecosystem will take too much time to recover, especially the soil properties of the system. In this respect, we must consider all the aspects and components of the system. Furthermore, the agro-ecosystem can be defined as indicated by Wood *et al.*, 2000, as “*a biological and natural resource system managed by humans for the primary purpose of producing food as well as other socially valuable non-food goods and environmental services.*”

In the present study, the ecological footprint bio-capacity of agro-ecosystem (i.e. the productivity of the system) and ecological footprint demands from this system have been assessed in several ways that can be of importance to human food security. As indicated in this study, the ecological footprint demands from the agro-ecosystem have a declining relationship with efficiency of productive arable lands. In this respect, Wood *et al.*, 2000 indicated that cropland and managed pasture detected by satellite interpretation cover some 28 percent of global land surface. This is supported by the World Bank Data Group. Overall, 31 percent of agricultural areas are occupied by crops, and the remaining 69 percent are under pasture. Annual cropland is relatively stable at around 1.38 billion hectares, while permanent crops occupy around 131 million hectares and show a net growth of almost 2 percent per year. Pasture areas are estimated to be increasing at around 0.3 percent per year. These data have been converted into global calories received from the sun which are stored in agricultural products and show that land is marginally producing the calories that the human beings are in need of. However, the increasing population will impact on the globally required calories from the stored energy in the agro-ecosystems; this will result in shortage of these products, and an inability of the agro-ecosystems to provide the essential food security to all the global population.

Another concern, as indicated by Wood *et al.*, 2000, is that irrigated areas occupy 270 Mha, around 5.4 percent of global agricultural land and 17.5 percent of all cropland. Irrigated area continues to expand, but at a slowing rate, now around 1.6 percent (about 3.3 Mha) per year. This net amount is presumed to allow for irrigated area losses estimated at up to 1.5 Mha per year from salinization. Our recent results have supported this statement, as indicated in the reduction of efficiency of agriculture lands, and it is not in line with trends in the demands of humans from this system. Additionally, Wood *et al.*, 2000 showed the following results: data on production systems and resource management aspects of land use are extremely scarce at regional and global levels. This is an alarming fact that has been indicated about thirteen years ago and, our results continue to produce an alarm bell regarding the status of the global agro-ecosystem which depends on the ecological footprint of the agro-ecosystem's ability to produce products that can support food security to all human beings. Additionally, our new analysis of trend of as presented here, using the earth's agro-ecosystem calorie production to provide the number of calories to support human existence and survival, gives another dimension to the ecological footprint, which is the “**Ecological Human Imprint (E_{HI})**”.

The policies for agro-ecosystems should monitor the agricultural condition in the world, from climate change to land productivity and distribution of food around the world. This may be by subsidizing world food production through United Nation programs or governments. In

this respect, the UN or governments should have reserve funds to support subsidizing food production in the impacted areas of lower production but without changing policy for the market commodities. This fund should be used not for emergencies but to support farmers in producing agricultural commodities and to ensure food security.

Conclusions

The EFAM model has predicted the status of the ecological footprint of global agriculture worldwide. It predicts that cropland efficiency will decline. Furthermore, the model predicts that cropland's biological capacity may be increasing due to powerful machinery, use of more fertilizers and the use of multiple cropping during the year in specific areas. However, global available arable land may be increasing until around the year 2030. This could be due to the extensive use of agricultural biotechnologies employing genetic materials to enhance crop yields which would lead to the use of agricultural land to its fullest capacity. The model further predicted that the global available arable lands will start decreasing from 2030 to 2050. This may be due to the increasing human pressure on arable lands and also the increasing demands of ecological footprint on the earth's resources in the form of goods and services. This is alarming for our global agricultural system. The trend will continue beyond 2050 unless other measures are taken. Continuous assessments of the status of global agro-ecosystems should be taken seriously and be monitored to avoid a disastrous condition that may be leading to unsustainable agricultural systems, instability in the world economy and instability in political conditions. These scenarios would lead to chaos worldwide. Agricultural policies should monitor the conditions in the world from climate change to land productivity to good distribution of food around the world. Further, the United Nation Agencies should work with all governments to ensure food security and policies that must be directed to massive food production for ensuring food security globally.

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