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Manuscript title: Deforestation and land farming as regulators of population size and climate
Short Title: Deforestation

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Abstract

This work reveals that deforestation and farming of the cleared land may be considered as regulators of the size of world population and climate. When the green matter is cleared, it decomposes, oxidizes, and releases to the climate the heat of carbon conversion to carbon dioxide. The farmed land provides carrying capacity that sustains population growth. As world population grows, energy consumption increases. Most of this energy has been fossil fuel based, and the heat released is gained by the climate. Warming of the surface and population growth are thus processes that depend on land clearing and conversion into farmland. If deforestation increases, the size of the farmland increases, population size increases, and the surface accumulates heat and vice versa. Therefore, analyses of the correlation between deforestation, population growth, and climate change may have merit for research and society. Through 1990, deforestation has contributed at least 36% of the total heat added to the surface. Therefore, deforestation contribution to climate change is substantial. At the current rate of deforestation, the world population may approach 14.5 billion by the year 2100. Should deforestation decrease and approach zero by then, the world population may steady at nearly 10.3 billion instead.

Keywords: Deforestation; Photosynthesis; World Population Growth; Energy Production; Climate Change

1. Introduction

Food and Agriculture Organization of the United Nations (FAO 2016a) reveals that from early human history the area of land covered by forests has decreased by nearly 50%. “There has been a relationship between population growth, increased demand for agricultural land, and forest loss dates back thousands of years. Forests have sometimes re-established naturally as deforestation pressures have eased. Archeological and historical records reveal that the decrease in forest size is associated to population growth and demand for crops and grazing land. In locations of the world that had experienced severe disease and population decline, forests re-grew again.” The historical and archeological records potentially correlate deforestation with population growth. Deforestation and farming of the cleared land provide resources that sustain world population. When the world population increases in size, demand for energy increases as well (EIA 2016). Therefore, investigating drivers and regulators of population growth at the global level are important for the objectives of this manuscript.

Statistical models to calculate and project populations have been successfully used. Jones and Tertilt (2006) summarize the history of fertility in the U.S.A. since 1826, its relationship with economy and social factors, as well as statistical models used to calculate population size. Similar statistical methodologies have been adopted by United Nations UN (2019) for world populations. These methodologies appear to assume human factors as regulators of human population, and human population is thus an independent variable. Conversely, this work reveals that world population may be calculated and projected reasonably by considering only deforestation and farming of the cleared land as a variable. The applicable laws of population growth to plants and organisms appear to be applicable to humans as well. They all need nutrients to multiply and human population is therefore a dependent variable instead.

Deforestation is the opposite process of photosynthesis, in that the chemical energy stored in plants' tissues is converted into climate heat. It raises surface temperature. Farming of the cleared land increases the carrying capacity of the farmland available and world population grows. This growth requires energy to be maintained, and most of this energy has been fossil fuel based. Deforestation and fossil fuel burning produce heat and carbon dioxide that interact with the climate in accordance with the laws of thermodynamics. The outcome of this interaction is that all of the heat of deforestation and fossil fuel burning accumulates in the surface (Swedan 2019). Also, the methodology presented in (IPCC 2013) uses the total variation in the concentration of carbon dioxide in the atmosphere as the basis to calculate changes in the climate. The methodology utilizes the Radiative Forcing concept, discussed in Chapter 8 of this reference, and the resulting radiative forcings are reported in W m^{-2}. There appears to be no direct mathematical relationship that calculates the heat of deforestation at this time. It is thus derived in this manuscript. In addition, the radiative methodology used in the Intergovernmental Panel on Climate Change reports assumes that climate agents impose radiative imbalance at the top of the atmosphere. Such a methodology may only provide an overall anthropogenic forcing, and biosphere thermodynamic interactions may not be captured by this methodology. Limited information may thus be obtained by the radiative model. The manuscript on the other hand discusses biosphere thermodynamic and heat exchange interactions as a result of human development and civilized structure. The information that may be obtained by the proposed methodology are many including but not limited to world population growth, deforestation, energy production, efficiency of photosynthesis, and surface greening.

This work reveals that there exist relationships between deforestation and farming of the cleared land, heat of deforestation, population size, energy production, and surface warming. The independent variable is deforestation and farming of the cleared land. Dedicated mathematical relationships to calculate the heat of deforestation and size of world population, are, therefore, derived and validated in this manuscript. They are found to be in agreement with observations. Because of the breadth and multidisciplinary nature of this work, a section "Symbols and Abbreviations" is appended to the end of this paper. The intended meanings of parameters and symbols are explained in this section.

2. Background Information

Long before the Industrial Revolution, deforestation was minimal and population size was relatively small based on information provided by (FAO 2016a; FAO 2016b). Deforestation then increased by nearly 0.2% annually through the first half of the twentieth century to nearly 50% at the present time. The world population increased as well. In the nineties, deforestation began to decrease, and population growth rate has decreased. By 2010, deforestation was estimated at 0.08% annually and it is expected to decrease with time. So is population growth projection by (UN 2019).

The United Nations (UN 2019) analysis attributes the observed and projected decrease in population growth rate to reduced levels of fertility. Population projection utilizes demographic and statistical methodologies. The decrease in fertility is attributed to "human development factors such as reduction in child mortality, increased level of education particularly for women and girls, increased urbanization, expanded access to reproductive health care, women's empowerment and growing labor force participation," and other similar human and social factors. The observed decrease in deforestation and size of farmland trends are not mentioned as causes of the observed reduction in world population growth rate.

Apparently, the methodologies adopted assume growth of human population to be an independent variable, strictly driven by human related factors. This is likely to be true and may continue to be applicable for specific geographic locations or regions of the world. However, at the global level population growth resembles growth of other organisms and plants as this work reveals. The basic natural laws applicable to organisms and plants appear to apply to humans as well. Textbooks of ecology, for example (Cain et al. 2014), reveal that populations can grow when conditions are favorable. When environmental conditions are ideal, populations grow exponentially; however, the growth cannot continue indefinitely. There is a limited carrying capacity for each ecosystem that population size may not exceed. Population growth increases population density and species have to compete for space, nutrients, and other ecological and environmental parameters. The environmental conditions become less favorable with time and population growth deviates from that of exponential growth. It tends asymptotically to the carrying capacity, defined as the maximum population size an ecosystem can sustain. This growth pattern is typically referred to as logistic growth. For this growth, population density may be considered as a population regulator. Logistic growth curve fits have been used to calculate specie populations and human populations of geographic locations (Pearl and Reed 1920).

Until the twentieth century, most humans lived in rural areas (UNESCO 2019) where population density was not a major factor. Presently, the majority of the world lives in cities based on this reference, and the urbanization trend is projected to continue. Population density may thus be a factor in the observed decrease in population growth rate. However, humans have the ability to relocate and emigrate for better environmental conditions. While urban population density may have a role in the observed decrease in population growth rate, it may not be as definitive as for plants or organisms. For these, the carrying capacity of their immediate ecosystem is a limiting factor. For humans, the entire biosphere is their ecosystem. Manufactured and food products may be shipped around the world, and humans can leave a poor immediate ecosystem for a better one. Human population is ultimately dictated by how much farmland is available in the biosphere. The farmland supplies nutrients and provides carrying capacity. Consequently, population size is assumed to be a dependent parameter, mainly on the available farmland and population function is derived. The calculated populations are compared with observations and (UN 2019) projections and found to be in agreement.

Energy consumption is associated with population size, and this energy has been provided mostly by burning fossil fuels. Therefore, it is reasonable to associate an increase in energy consumption to deforestation and farming of the cleared land. Deforestation on the other hand is the opposite process of photosynthesis; the green matter oxidizes, decomposes, and combusts, and the heat of carbon conversion to carbon dioxide is released to the surroundings. Based on this understanding, the total heat of deforestation and energy consumption is dependent on deforestation. Deforestation is thus the independent parameter and regulator of world population and climate. Accordingly, mathematical relationships between deforestation, world population, and climate exist; they are derived in this manuscript. The significance of the derived equations is discussed and their applications illustrated. The calculated heat added to the surface is compared with observations and found to be in agreement as well.

3. Data

The data used for this work are available in the public domain, accessible by the links provided under references. Required for this work are green matter growth relationships and efficiency of seasonal photosynthesis. They are calculated from available seasonal variations of carbon dioxide in a report prepared by U.S. Environmental Protection Agency (EPA 2012). In order to produce Table 1 and figures 1 through 4, past and present history of deforestation is summarized in reports prepared by Food and Agriculture Organization of the United Nations (FAO 2016a; FAO 2016b). For comparison with the calculations, observed world populations are obtained from United Nations report (UN 2019). The Intergovernmental Panel on Climate Change (IPCC) summarizes changes in the climate and provides a historical record of the changes as well as forcings for comparison with the calculated heat added to the surface. Their most recent report (IPCC 2013) is used as a source of data. Energy consumption of the world population is an integral part of this work; it is compiled since 1990 by the Energy Information Administration (EIA 2016). Reference and textbooks such as Perry and Green (1984) and Jørgensen and Svirezhev (2004) are used to obtain heat of decay, combustion, and oxidization of the green matter and compare calculated photosynthesis efficiency with those calculated by others.

4. Method

The geological record reveals that changes in climate occurred long before humans became influential in the biosphere. Warming and cooling cycles existed several hundred thousand years ago (Petite et al. 1999). Causes of these changes are attributed to the inherent tendency of green matter to multiply and the resulting variations in its size (Swedan 2019). The size of plants and vegetation has been variable with human development in the forms of deforestation, and apparently, surface greening (FAO 2016b; Zaichun et al. 2016). Variation in the size of green matter induces thermodynamic transformations in the biosphere and human activities are thus an integral part of biosphere thermodynamics. Therefore, the model used in this work assumes that humans and their surrounding biosphere are an ecosystem. Unlike primitive forms of life, humans can travel and ship manufactured and food products around the ecosystem. They are not limited by space or time. For example, farm products in developing countries find their way to consumers in industrialized countries. Similarly, manufactured products in industrialized countries are sold in developing countries. Shipping time of goods has so much decreased to the point that it is reasonable to assume that changes in the biosphere due to humans are global in nature and practically immediate. At the center of these goods are basic forest and agricultural products. Kissinger et al. (2012) reveal that most of these goods produced in the cleared lands are for export. Farmland may thus be considered to belong to the world population, and deforestation and its conversion into farmland increase biosphere carrying capacity.

Therefore, population size is assumed to be proportional to the total size of farmland available in the biosphere. The forests converted into farmland support additional world population. In turn, the population requires more energy for heating and air conditioning, lighting, appliances, infrastructure, transportation, recreation, and others. Most of this energy has been provided by burning fossil fuels since the Industrial Revolution, assumed 1750 by (IPCC 2013). This energy produces heat and carbon dioxide. Deforestation produces heat and carbon dioxide as well.

Together, deforestation and energy consumption add heat and carbon dioxide to the climate. The surface gains this heat as a result.

Based on this understanding, equations of heat of deforestation and world population size are derived and reduced to simple formulas so that the entire work may be reproduced by others. Basic calculation tools thus suffice. In this presentation a calculation spreadsheet, Microsoft Excel, is used to prepare Table 1 and figures 1 through 4. Given that the independent variables of the formulas may change with time as explained in the conclusion section, programming using a higher level language may be recommended for more accuracy.

5. Theory and Model

5.1 Heat of Deforestation

Equation (20) of Swedan (2019) will be used as the basis to derive equations of seasonal efficiency of photosynthesis, plant growth, and heat of deforestation. The equation follows:

$$dn_{G'}/n_G=(dppmv_{CO2}/2)/ppmv_{CO2} \quad (1)$$

Where

$dn_{G'}$ = Average variation in the number of moles of the green matter, mol.
n_G =Number of moles of the green matter in the biosphere, mol.
$dppmv_{CO2}$ =Variation in the concentration of carbon dioxide in the atmosphere in parts per million by volume, ppmv.
$ppmv_{CO2}$ =Concentration of carbon dioxide in the atmosphere in parts per million by volume, ppmv.

Plants grow annually and during the warming season. Their growth reaches maximum value toward the end of this season. Therefore, the maximum variation in the number of moles of the green matter dn_G, which is equal to 2 x $dn_{G'}$ is required for this analysis. The term dn_G/n_G may be thought of as the maximum value of seasonal efficiency of photosynthesis, which is equal to $dppmv_{CO2}/ppmv_{CO2}$. Consequently

$$dn_G/n_G=\eta max \quad (2)$$
$$\eta max=(dppmv_{CO2})/ppmv_{CO2} \quad (3)$$

Where

dn_G =Maximum annual increase in the number of moles of the green matter, mol.
ηmax=Maximum value of seasonal or annual efficiency of photosynthesis, dimensionless.

Every year, a new green matter, dn_G, is added. Therefore, the total size of the green matter may be obtained by integration of Eq. (2) with time

$$\int_{n_{G0}}^{n_G} dn_G/n_G=\int_{t_0}^{t} \eta max\ dt \qquad (4)$$

$$n_G=n_{G0}\, e^{[\eta max\ (t-t0)]} \qquad (5)$$

Where

n_G =Number of moles of the green matter at age, t, mol.
n_{G0} = Number of moles of the green matter at a reference age, t_0, mol.
t =Age of the green matter, years.
t_0 =Reference age of the green matter at which its size is equal to n_{G0} moles, years.

Equation (5) gives the size of the green matter and vegetation as they age. However, plants do not grow in size indefinitely; they die when they reach the end of their life. The dead wood decays and decomposes, and this represents a reduction in carbon stock of forests. The report (EPA 2012) reveals that if not for anthropogenic emission of carbon dioxide, variation in the content of carbon dioxide in the atmosphere in a full year may be negligible. Or, natural decay of biomasses is nearly equal to natural seasonal photosynthesis for small periods of time. This, however, may not be true for extended periods of time, because green matter inherently tends to increase in size when environmental conditions are favorable as discussed in the background section. Therefore, if average efficiency of seasonal photosynthesis is equal to η, the annual natural decay of the green matter is nearly equal to $\eta \times n_{G0}$. Consequently, the net size of the green matter after subtracting natural wood decay follows

$$n_{Gnet} = n_{G0}\, e^{[\eta max\ (t-t0)]}-n_{G0}\, \eta\ (t-t_0) \qquad (6)$$

Where n_{Gnet} is the net size of the green matter, measured in moles, after the time $t-t_0$ has elapsed. The parameter, η, is average efficiency of photosynthesis. Deforestation is assumed to decrease this net size of the green matter with time. The ratio between the annual size of the cleared green matter and the total original size is equal to the annual deforestation fraction, d. Therefore $d=-dn_D/n_{Gnet}$. Where dn_D is equal to the number of moles of the cleared green matter annually. The minus sign is a convention to denote deforestation. Multiplying both sides of Eq. (6) by d

$$dn_D=-d[n_{G0}\, e^{\{\eta max\ (t-t0)\}}-n_{G0}\, \eta\ (t-t_0)] \qquad (7)$$

Where d is average annual deforestation fraction and, dn_D, is equal to the number of moles of the green matter removed annually by deforestation. The removal decreases the chemical energy of the green matter in the biosphere, and this decrease is equal to the heat of deforestation. The heat of deforestation may be obtained by multiplying the number of moles of the green matter removed by the heat of combustion of the green matter. For simplicity, this heat may be assumed to be equal to that of carbon combustion. Multiplying both sides of Eq. (7) by the heat of carbon combustion ΔH_c

$$dQ_G=-\Delta H_c\ d\ [n_{G0}\ e^{\{\eta max\ (t-t0)\}}-n_{G0}\ \eta\ (t-t_0)] \quad (8)$$

The term dQ_G represents the annual heat of deforestation. Integration both sides of Eq. (8) between an initial year n_0 and an arbitrary year n.

$$\int_{Q_{G0}}^{Q_G} dQ_G=-\int_{n_0}^{n} \Delta H_c\ d\ [n_{G0}\ e^{\{\eta max\ (t-t0)\}}-n_{G0}\ \eta\ (t-t_0)]\ \ dt \quad (9)$$

Where the quantity Q_{G0} represents the amount of chemical energy available in the green matter at the initial year n_0. Q_G is the available chemical energy in the green matter after, n, years of deforestation. Q_{G0} is greater than Q_G. Assuming that the reference age of the green matter, t_0, and the initial year, n_0, to be the same and equal to zero, the heat of deforestation follows

$$Q_D=Q_G-Q_{G0}=-\Delta H_c\ d\ n_{G0}\ [(1/(\eta max)e^{\{\eta max\ (n)\}}-\eta\ n^2/2-1/(\eta max)] \quad (10)$$

Where Q_D is equal to the total heat of deforestation after, n, years of deforestation. The value of the heat of carbon combustion, ΔH_c, is 3.93 x 10^5 J mol^{-1} (Perry and Green 1984). The original number of moles of the green matter, n_{G0}, before any deforestation, before 1750, may be approximately estimated: Major deforestation may be assumed to have been initiated at about the beginning of the Industrial Revolution. FAO (2016b) indicates that primary forests presently cover approximately 30% of the land and average carbon content is nearly 74 tons per hectare. Therefore, present inventory of green matter is 1.11 x 10^{22} J. At 50% total deforestation and heat of carbon combustion of 3.93 x 10^5 J mol^{-1}, n_{G0} is nearly equal to 5.64 x 10^{16} moles. Equation (10) simplifies

$$Q_D=-2.22 \times 10^{22}\ d\ [(1/(\eta max)\ e^{\{\eta max\ (n)\}}-\eta\ n^2/2-1/(\eta max)] \quad (11)$$

Where Q_D is the total heat of deforestation in Joules after, n, years of deforestation at average annual deforestation fraction d. The minus sign is a convention to indicate a decrease in the chemical energy of the green matter. The surface gains the absolute value of Q_D.

5.2 Population Size

As discussed in the method section, the size of the world population is assumed to be proportional to the total size of farmland available in the biosphere. The farmland provides the carrying capacity. When new farmland is added, population grows exponentially until the carrying capacity is satisfied. If the available size of farmland is equal to F, then

$$dN/N=dF/F \quad (12)$$

$r_F \quad =dF/dt \qquad (13)$

$r \quad =(1/N)dN/dt \qquad (14)$

Where

N =Population size, number of people.
F =Size of the farmland, m^2.
r_F =Rate of increase in the size of the farmland, $m^2\ t^{-1}$.
r =Population exponential growth rate, t^{-1}.

Equation (14) is available in typical textbooks of ecology, for example (Cain et al. 2014). Equations (12) and (13) give

$$dN/N=(r_F/F)\ dt \qquad (15)$$

Referring to Eq. (13), for dt equal to one, or one year, r_F is equal to the annual increase in the size of farm land. From Eq. (13), the ratio (r_F/F) is thus equal to the fraction of the farmland added annually, dF/F, which has been increasing. This fraction is not necessarily equal to the annual deforestation fraction. However, because the current deforestation is at 50% of the original forest size and deforestation data are reported with respect to this current deforestation, then they are equal. The increase in the annual farmland fraction is equal to the increase in annual deforestation fraction. The annual deforestation fraction is nearly equal to two times the average annual deforestation fraction. Therefore, (r_F/F)=2d, where d is average annual deforestation fraction. Equation (15) and its integration yield

$$dN/N=2d\ dt \qquad (16)$$

$$N=N_0\ e^{[2d\ (t-t0)]} \qquad (17)$$

Where, t, is an arbitrary time and, t_0, is an initial reference time. N is population size at the time t and N_0 is population size at the initial time t_0. The values of N may be thought of as theoretical population that can be supported by the total farmland available at the time t. Also, it may be thought of as the carrying capacity of the total land available at the time t. Within the time, $t-t_0$, the total population available P(t) may be assumed to increase exponentially, and the exponential rate of increase is equal to r. Referring to equations (14) and (15), for dt=1, or one year, r=dN/N and Eq. (16) gives r=2d. Therefore, the actual annual increase in population follows

$$dP(t)=rN=2d\ N_0\ e^{[2d\ (t-t0)]} \qquad (18)$$

Where P(t) is the population function. The world population in any given year is the cumulative sum of annual population increases, coordinated with farmland increases and carrying capacities. For the first year, n=1, the change in population is dP(t). For the second year, n=2, the total change is 2dP(t), and so forth because the carrying capacities of new farmlands add cumulatively. Therefore

$$\int_{P_0}^{P(n)} dP(t)=\int_{n_0}^{n} 2d\ N_0\ e^{[2d\ (t-t0)]}\ t\ dt \qquad (19)$$

Where P(n) is population size at an arbitrary year n and P_0 is population size at a reference initial year n_0. Assuming $n_0=t_0=0$, then $P_0=N_0$ and population function P(n) follows

$$P(n)=P_0[1+n\ e^{(2\ d\ n)}-(1/2\ d)\ e^{(2d\ n)}+(1/2\ d)] \qquad (20)$$

Where P(n) is population size calculated after n years have elapsed at average annual deforestation fraction of d.

6. Significance and Application of the Derived Equations

Referring to Eq. (11), the average and maximum efficiencies of seasonal photosynthesis may be assumed to be the same every year. Therefore, average annual deforestation, d, is the only variable required to calculate the heat of deforestation. The equation reveals that this heat is time dependent. Plants grow with time, equations (5) and (6). Therefore, for equal areas of forest lands cleared in two different years n_1 and n_2, where n_2 is greater than n1, the heat of deforestation produced in n_2 is greater than the heat of deforestation produced in n_1. The reason is that plants grow in size in the time between n_1 and n_2. Also, population size, Eq. (20), has only deforestation as an independent parameter. Because energy consumption is a function of population size, the total heat produced by deforestation and energy consumption is a function of deforestation and farming of the cleared land.

Caution must be exercised when using equations (17) and (20) for world population. Unlike organism or plant ecosystems, deforestation does not provide readily digestible nutrients to people. As a result, the equations may not be used as traditional continuous functions to calculate world population. Population size, Eq. (20), has to be applied for discrete and equal periods of time having constant duration of years, n. The period of time cannot be selected arbitrarily, it must be equal to the period of time of the life cycle of the processes comprising deforestation and land clearing, land preparation for farming, farming of the prepared land; harvesting, storing, and shipping of agricultural products, incorporation of the products in the food chain, family planning and fertility decisions, and newborn registrations. The life cycle varies with agricultural products such as grains, nuts, produce, or fruits, and may be estimated as the sum of the periods of time required for each process of the life cycle. Alternatively, the duration of the life cycle, n, may be determined mathematically by using Eq. (20) and simple trial and error iterations to match a narrow sample of observed world populations.

The life cycle and its duration do not appear to be addressed in the literature. It is thus estimated to be between eight and 13 years, and ten years may be used as an average. Therefore, n=10=constant should be used for all of the discrete periods of time. Selecting discrete periods of time smaller or greater than ten for the same initial reference population will be incorrect. For illustration, assuming the world population of 1960 is used as a reference, P_0, at which $t_0=n_0=0$. Using n=10, Eq. (20) correctly calculates world population every ten years in either direction. For population growth between 1960 and 1970, deforestation of the previous decade, 1950-1960, provides the carrying capacity, because deforestation between 1960 and 1970 has not yet provided carrying capacity. It takes nearly ten years for deforestation in 1960 to contribute to population growth. Using the reference year, 1960, to calculate population in 1969, will be incorrect, in that it does not account for the contribution of the resources of 1959. For 1969, the correct reference population has to be that of 1959. The same is true for longer periods than that of the life cycle: using population of 1960 as a reference to calculate population of 1971 will be incorrect as well, in that it assumes deforestation of 1961 has reached carrying capacity when in fact it has not. Therefore, by using known world populations in the record for any decade as reference years, past, present, and future populations may be calculated by knowing only average annual deforestation fractions. Accordingly, Table 1 and figures 3 and 4 are produced for evaluation and discussion.

To calculate the heat of deforestation using Eq. (11), the maximum value of annual seasonal efficiency of photosynthesis, ηmax, is required. EPA (2012) provides for 2011 average carbon dioxide content in the atmosphere of 391.67 ppmv and five (5) ppmv for seasonal carbon dioxide variation. Using Eq. (3), where $ppmv_{CO2}$=391.67 and $dppmv_{CO2}$=5, the value of ηmax=0.013. The average value of seasonal efficiency of photosynthesis η=ηmax/2=0.007.

The observed anthropogenic forcings of the current warming trend are available in (IPCC 2013). Figure 8.18 of Chapter 8 of this reference presents time evolution of anthropogenic forcing between 1750 and present time. Between 1750 and 1850, the forcing was small and negligible. Therefore, 1850 may be used as a representative reference year for comparison with the calculations. Because world energy consumption is unavailable before 1990, it is assumed to be linear through that year for simplicity. For 1990, Fig. 1-2 of EIA (2016) reveals that the world consumed nearly 350 quadrillion British Thermal Units (BTU), which is equal to the sum of energy consumed by OECD and Non-OECD countries. This is equivalent to 3.70×10^{20} J. Assuming world energy consumption in 1850 to be negligible, the total energy consumed between 1850 and 1990 is about 2.59×10^{22} J. Also, present total deforestation is nearly 50% of the original covered land, and annual average deforestation was approximately equal to 0.2% through 1990. For the period of time 1850-1990 and average annual deforestation of 0.2%, Eq. (11) yields heat of deforestation, Q_D, of nearly 1.45×10^{22} J. The total heat added to the surface by deforestation and energy consumption between 1850 and 1990 is thus equal to 4.04×10^{22} J. In Radiative Forcing terms, it is equal to 2.52 Wm^{-2}. The observed anthropogenic forcing for 1990 is unavailable; however, it is 1.25[0.64 to 1.86] for 1980 and 2.29[1.13 to 3.33] for 2011 based on Fig. 8.18 of (IPCC 2013). As a result, the observed forcing for 1990 must be between 1.86 Wm^{-2} and 3.33 Wm^{-2}.

7. Discussion

Kant and Berry (2005) suggest that deforestation and farming of the cleared land has increased the size of world population since farming was invented some 12 000 years ago. Generally, land farming followed small-scale and large-scale deforestations. Traditional small-scale farm products may be considered for local consumption that have increased and maintained local population size. However, this type of farming presently feeds a steadily decreasing rural population size as discussed in the background section. Therefore, it is reasonable to assume that at least some of the agricultural products produced by traditional farming compete with commercial agricultural products intended for global market. In addition, most of the deforestation for this type of farming has already contributed to population growth. Consequently, any present type of deforestation and farming of the cleared land in the biosphere should be factored in the calculations.

Deforestation and life cycle duration, n, are required for Eq. (20). The values of average annual deforestation fractions are available in (FAO 2016b). However, the values used in the calculations must lag the observed values by the duration of the life cycle of agricultural products produced as discussed in Section 6. The cycle begins with deforestation and ends with the incorporation of agricultural products in the food chain and birth of newborns. Accordingly, the values of average annual deforestation fractions used in the calculations are presented graphically in Fig. 1.

As mentioned in Section 6, field data to estimate the life cycle do not appear to be available in the literature at this time. The life cycle may be between eight and 13 years. Also, the value of n may be estimated from observed population growth, because this growth must reflect logistics of the life cycle. Therefore, Fig. 2 is prepared to summarize results of trial and error iterations to calculate life cycle duration n. The figure is related to observed populations sample between 1970, reference year number zero, and 1980, year number ten. For 1971, year number one, the value of the iterated, n, so that the calculated population by equation (20) converges to the observed population is 3.1. For 1975, year number five, n is equal to 7.14. For 1980, year number ten, n=10. This pattern shown in Fig. 2 is repeatable every ten years for any human populations sample; apparently, it is characteristic of human population growth. Therefore, the value of n is nearly equal to ten and it is a constant. The world population may be calculated reasonably accurately every ten years measured from any given reference year using Eq. (20).

On these bases, Table 1 is prepared. The population of the year 1950 is used as a reference year for Eq. (20) and ten-year periods are used for n. The observed populations are obtained from (UN 2019). Populations are assumed to lag deforestations by ten years as explained in Section (6). For example, present average annual deforestation is nearly 0.08%. However, it is not shown or used in the calculations because its carrying capacity accrues in the future. The tabulated values of this Table 1 are graphically illustrated in Fig. 3. The figure reveals that the observed and calculated populations are practically in agreement. The maximum difference between calculated and observed populations is -1.27% or less as Table 1 indicates. Equation (20) is therefore assumed to represent population growth reasonably well. Consequently, Fig. 4 is produced to project population growth for two scenarios. In the first scenario, average annual deforestation is assumed to remain steady at its present rate of 0.08% annually. In the second scenario, deforestation is assumed to continue its decreasing trend linearly to negligible in 2100.

8. Summary of Results and Conclusions

The application part of Section 6 reveals that for climate calculations, the calculated forcing through 1990 is nearly 2.52 Wm^{-2}. It falls well within the observed forcing between 1.86 Wm^{-2} and 3.33 Wm^{-2}. The heat of deforestation contributed nearly 36% of the total heat added to the surface, assuming energy production between 1850 and 1990 to be linear with time. Clearly, the heat of deforestation is large and substantial. The calculated maximum and average values of seasonal efficiency of photosynthesis are 0.013 and 0.007 respectively, Section 6. Jørgensen and Svirezhev (2004) compiled average values of photosynthesis efficiency available in the literature. The green leaf machine model yielded 0.016 and the radiative models yielded values between 0.005 and 0.007. The calculated seasonal efficiency of photosynthesis is in agreement with the work of others. Table 1, figures 3 and 4, and the discussion section show good agreement between calculated and observed world populations. At the present decreasing trend of deforestation, world population projections are 8.4 billion in 2030; 9.4 billion in 2050; and practically steady at 10.3 billion in 2100. For comparison, UN (2019) projections are 8.5 billion in 2030; 9.7 billion in 2050; and steady at 10.9 billion in 2100. Should deforestation remain at its current value of 0.08% annually, the world population is expected to reach 14.5 billion instead. Based on these agreements between calculations and observed heat added to the surface, population size, and photosynthesis efficiency, equations (11) and (20) may be used to calculate the heat of deforestation and the size of world population. The only variable required for these equations is the average annual deforestation fraction.

The population function, Eq. (20), is derived on the basis that population size is proportional to the size of the farmland available that provides carrying capacity of the biosphere. The equation is in essence a logistic growth applicable to organisms and plants as well. The carrying capacity, N of Eq. (17), would be available after land has been cleared and converted into productive farmland. Population then grows exponentially, Eq. (18), until the carrying capacity of the biosphere has been satisfied, and the process repeats again with the addition of new farmland. Apparently, there is a similarity between human population growth and growth of other species. The difference is that the cleared land does not provide readily digestible nutrients. It takes years for the cleared land to be converted into productive farmland and increase land carrying capacity. The logistics associated with this process appear to be embedded in human population growth as discussed in the discussion section. Population size lags new land carrying capacity by nearly ten years. It is thus reasonable to conclude that world population growth is a dependent parameter; it depends on the cleared and farmed land. So is energy production because it is a function of population size. Therefore, deforestation and farming of the cleared land may be considered as regulators of population size and climate.

The errors in the calculated heat of deforestation and population size variation by equations (11) and (20) are nearly equal to the errors in deforestation measurements. The data sources do not provide error margins of average annual deforestation fractions. As a result, calculation errors are not presented. Lack of data relative to energy consumption prior to 1990 necessitated the assumption of linearity of energy consumption with time. In reality the energy consumption curve lies below the assumed line. This is evident from the world population trend before 1990 (Cain et al. 2014, UN 2019) and population Eq. (20). Therefore, the contribution of deforestation to surface warming is greater than the calculated 36%, and it may well approach 50%.

Finally, there is room for improvement and research relative to the fundamental three variables required for equations (11) and (20). These are seasonal efficiency of photosynthesis, η; duration of the life cycle, n; and average annual deforestation fraction, d. Climate change is presently increasing surface temperature and the content of carbon dioxide in the atmosphere. Therefore, seasonal efficiency of photosynthesis is incrementally increasing and this increase should be accounted for in the calculations, given the exponential nature of the equations. Also, duration of the life cycle may be variable with technological advancement and may assume values other than ten years in the future. The reason is that communication and information transfer have become practically immediate thus affecting business transaction times and delivery schedule of agricultural products. Moreover, advancement in technology and improvement in agriculture practices may impact cycle duration as well. Deforestation is a variable required for calculating population size and heat of deforestation. Consequently, determining deforestation values with accuracy is important for representative projection of these climate parameters.

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11. Tables

Table 1. The observed and calculated world populations. The observed populations are obtained from UN (2019).

Year	Average deforestation fraction	Observed population	Calculated population	Difference Percent
1950	0.0020	2.536E+09	2.536E+09	0.00
1960	0.0020	3.035E+09	3.057E+09	0.72
1970	0.0020	3.700E+09	3.684E+09	-0.42
1980	0.0020	4.458E+09	4.441E+09	-0.38
1990	0.0018	5.327E+09	5.260E+09	-1.27
2000	0.0016	6.144E+09	6.119E+09	-0.41
2010	0.0014	6.957E+09	6.991E+09	0.49
2020	0.0011	7.795E+09	7.771E+09	-0.30

12. Figures

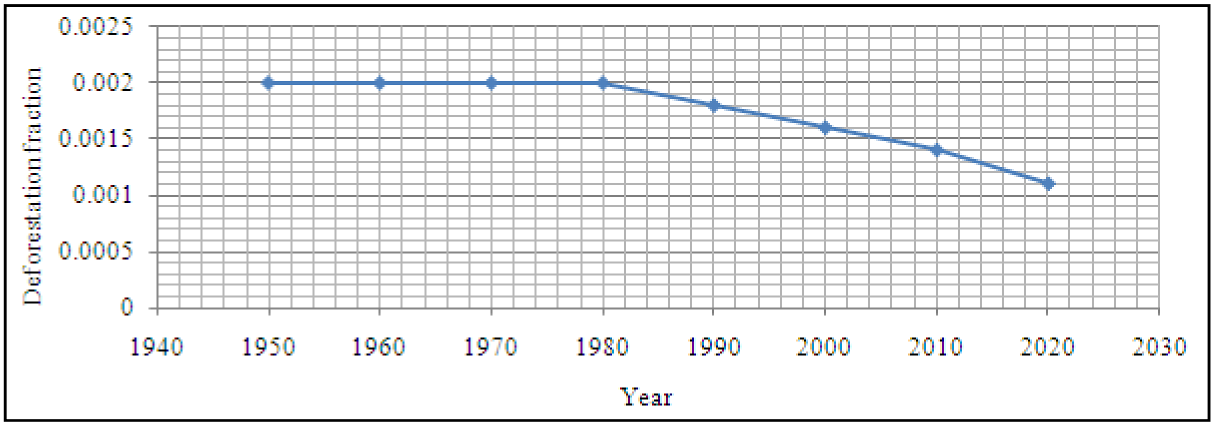

Fig. 1. The observed average annual deforestation fractions used in the calculations, obtained from FAO (2016b).

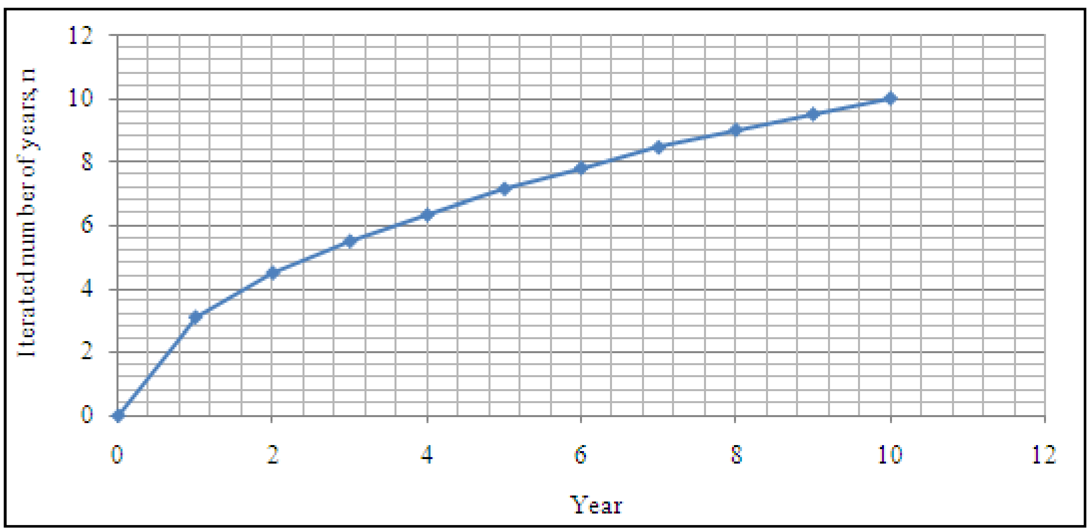

Fig. 2. Values of the iterated number of years, n, at which the calculated populations by Eq. (20) converge to the observed populations. The sample used is for world populations between 1970 and 1980. The population of 1970 is assumed to be a reference population, P_0, when year=0. Only for, n, nearly equal to ten do the years assume the same value. This is typical for any human population sample.

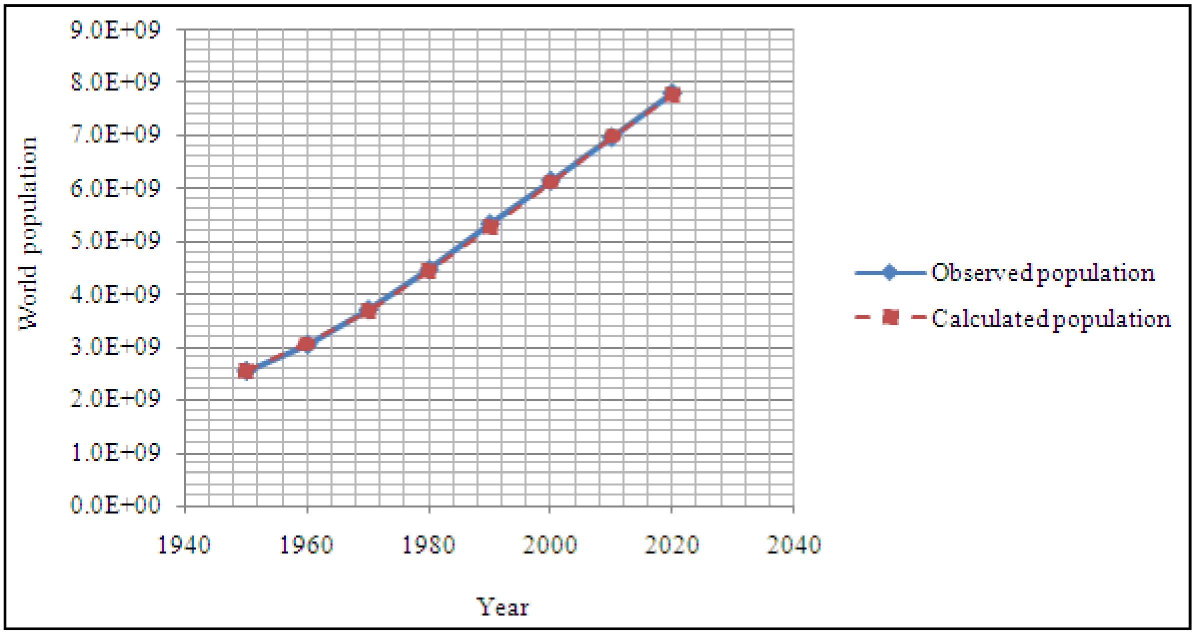

Fig. 3. Observed and calculated world populations, produced from Table 1.

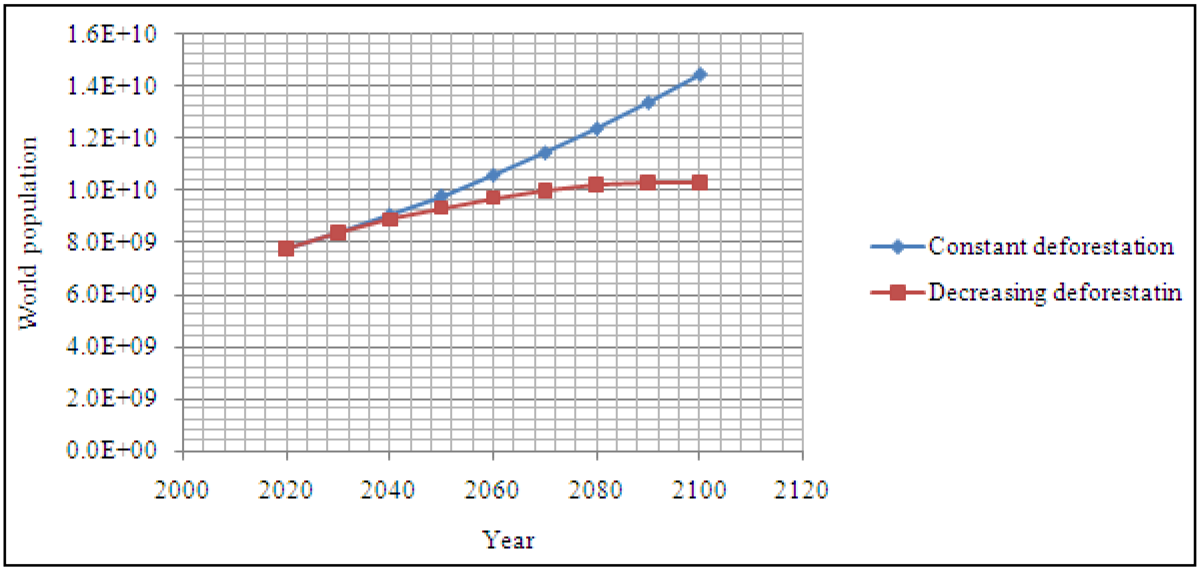

Fig. 4. World population projections at constant deforestation rate of 0.08% annually and decreasing deforestation. The decreasing trend is assumed to be linear with time, from its present value of 0.08 % annually to negligible in 2100.

13. Symbols and Abbreviations

d	Average annual deforestation fraction, equal to the ratio between the size of the green matter cleared annually and the size of the available green matter, dimensionless.
$dn_{G'}$	Average change in the number of moles of the green matter in a period of time, mol
dn_G	Maximum change in the number of moles of the green matter in a period of time, mol
dn_D	Maximum number of moles of the green matter cleared annually, mol
n_{Gnet}	Net increase in the number of moles of the green matter after subtracting natural biomass decay, mol
$dppmv_{CO2}$	Variation in the concentration of carbon dioxide in the atmosphere in parts per million by volume, ppmv
e	Natural logarithm base number, equals to 2.7183
F	Size of the farmland available in the biosphere, m^2
mol	Molar concentration
η	Average value of the efficiency of seasonal photosynthesis, equal to the ratio between variation in the size of the green matter and total size of the green matter in the biosphere, dimensionless
η_{max}	Maximum value assumed by the efficiency of photosynthesis in a complete seasonal cycle, dimensionless
N	The maximum population size an ecosystem can sustain, number of species
N_0	The maximum population size of an ecosystem at a given reference time, number of species
n	Number of years, years
n_G	Number of moles of the green matter in the biosphere, mol
$ppmv_{CO2}$	Number of moles of carbon dioxide in the atmosphere in parts per million by volume, ppmv
P_0	Population size at reference year n_0, number of species
P(n)	Population size at an arbitrary year n, number of species
ppmv	Concentration of carbon dioxide in the atmosphere in parts per million by volume
Q_G	The chemical energy stored in the green matter, Joule
Q_D	The heat of decay, combustion, or oxidization resulting from clearing green matter, Joule
r	Population exponential growth rate, t^{-1}
r_F	Variation in the size of farmland with time, $m^2\ t^{-1}$
t	Age of the green matter or time, years