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IMPROVING FOOD SECURITY IN SUB-SAHARAN AFRICA WHILE LIMITING PRODUCTION IMPACTS ON CLIMATE

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15 Credits

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June, 2011

ABSTRACT

Climate change is one of the biggest global challenges in the twenty-first century and has been discussed on several platforms with anthropogenic contributions to the phenomenon widely acknowledged. Agriculture has been one of the main contributors to climate change being a major source of all the three prominent green house gases (GHGs); CO_2, N_2O and CH_4 mainly due to intensification. The sub-Sahara African region faces a precarious food situation which looks to deteriorate through the years and the suggested intensification practices to improve on productivity are likely to worsen the impacts on climate. This paper makes a compilation from literature to address how food security in the region can be improved while reducing the negative impacts of agriculture on climate. Adoption of best management practices (BMPs) can reduce the global warming potential (GWP) of agricultural practices by increasing carbon sequestration and efficiency in fertilizer application to improve productivity. Enhancing the adaptive capacity of rain-fed agriculture to climate change through employment of scientific tools to map rainfall patterns coupled with strengthening the resource base of agriculture communities will be necessary to ensure food security in the sub-Saharan region. Continuous in-country assessments will be necessary to fit methods and approaches identified into specific local conditions of different countries.

ACKNOWLEDGEMENT

First of all, I am grateful to God for His protection and guidance throughout the study year.

For keeping her head up to ensure our dreams become a reality even during the seemingly impossible times, I want to say, God bless my mother. We will continue to keep the dream alive.

I owe sincere and earnest thankfulness to my supervisor, Göran Sahlén for his kind supervision without which this project would not have been successful. All the great comments have been very much appreciated.

I would like to show my gratitude to Stefan Weisner, Marie Mattsson, Siegfried Fleischer and Sylvia Waara their precious times they expended in my aid during the study period.

I am obliged to my colleagues and friends especially Benjamin Osei-Karikari for his role in helping out with this project.

I am truly indebted to Anna Larsson and Angela Bäckström for their support and contributions to my study period in Halmstad.

Special thanks go to Finn Poulsen, Miikka Vuorinnen and the Salvation Army of Halmstad for the wonderful gesture shown.

To my family and friends, I appreciate all the help and efforts.

MAY GOD BLESS US ALL!

CONTENTS

FIGURES

TABLES

1. INTRODUCTION

Climate change phenomenon is one of the most discussed issues around the globe in recent decades mainly because its consequences have been glaring in local, regional and global perspectives. There is no doubt that human activities have substantially increased green house gas (GHG) emissions in the atmosphere and for that reason, anthropogenic footprints on this phenomenon have been acknowledged whenever the issue has been discussed (Cooper et al., 2008; Gorte and Sheikh, 2009; Pitesky and Stackhouse, 2009; Tinker et al., 1995). Burning of fossil fuels is the leading cause of GHG emissions into the atmosphere basically in the form of CO_2 (Tinker et al., 1995) but agriculture has been identified as one of the few anthropogenic activities that produce substantial amounts of all the three major Green House Gases; CO_2, N_2O and CH_4 (Johnson et al, 2007) with proportion of each gas emitted by different activities represented in figure 1.

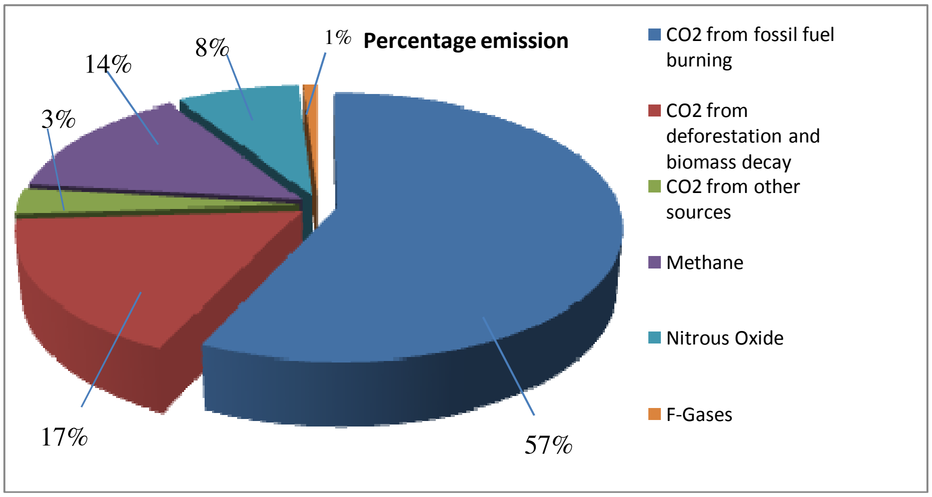

Figure 1: Assessment of Global Anthropogenic GHG emissions by the year 2004 ***(Redrawn from IPCC, 2007)***

The rate of CH_4 emissions into the atmosphere is said to have doubled over the last 25 years due to human activities (Synder et al., 2009) and said to have increased at a rate of 1% per year with 70-90% coming from biotic sources (Bouwman, 1990) while atmospheric concentrations of N_2O concentrations is reported to have increased from 270 parts per billion (ppb) during the pre-industrial era to 319 ppb in 2005 (Synder et al., 2009). Global land characteristics including physical and physiological characteristics have been significantly altered by humans through agricultural activities. On the global scale, agriculture is said to account for 13% of radiative forcing related to GHGs (Desjardins, 2010). At the local, regional and global scale, agriculture is considered to be the largest source of anthropogenic N_2O and CH_4 (Pitesky and Stackhouse, 2009) contributing 52% of global methane and 84% of global nitrous oxide emissions from agricultural sources such as animal husbandry, manure management and agricultural soils (Desjardins, 2010) while transportation still accounts for the highest CO_2 emission (Pitesky and Stackhouse, 2009).

Globally, agriculture is recognized to have undergone tremendous changes in the past four decades and these changes have been influenced mainly by population pressure, technological changes, public policies and economic growth (Smith et al., 2007). These changes in agriculture has kept the production of food and fiber in pace with sharp increase in food demand by a constantly rising world population even though there are notable regional exceptions. Agricultural growth has however occurred to the detriment of the environment while it has not been successful in solving the problems of child malnutrition and food insecurity in very poor countries (Smith et al., 2007).

The demand for agricultural products is rapidly on the increase in the world due to a constantly growing population and shifts in consumption patterns. The increase in production in the agri-food sector is highly desired in countries where agricultural productivity has been relatively low at present levels (van Beek et al., 2010; Verge et al., 2006). These countries are mainly identified as developing countries and countries in transition which are non-Annex 1 countries of the United Nations Framework Convention on Climate Change (UNFCCC) (van Beek et al., 2010). Asia is the largest food consumer of the world and will remain so for the next three decades while contributing about 50% of global GHGs from agriculture. The growth of food demand will however be highest in Africa (Verge et al., 2006).

Agriculture is said to account for 20-30% of gross domestic product (GDP) of the sub-Saharan region and 55% of total value of exports from Africa (O'Brien and Leichenko, 2000). The sub-Saharan region has been relatively left out of globalization process (O'Brien and Leichenko, 2000) and is the only region of the world where food production has been on the decline despite a general increase in the world (Pitesky and Stackhouse, 2009) as the green revolution responsible for increase in agricultural production and reduction of poverty in Latin America and Asia has largely by-passed it (Cooper et al., 2008). This declining trend can be linked closely to issues regarding low and declining soil fertility and inadequate fertilizer inputs as well (Smith et al., 2007).

An estimated substantial increase of up to 127% in agricultural GHGs is likely to result from the growing food demand in Africa unless improved management systems are introduced and adopted (Verge et al., 2006). This is because the intensification of agricultural systems is closely linked to the high level emissions in the form of N_2O and CH_4 (van Beek et al., 2010). As stated in van Beek et al. (2010), although the current increase in GHG emissions in non-Annex countries is mainly as a result of the increasing level of fossil fuel use, future agricultural emissions also requires much attention regarding how the economic development of most of these countries is rooted in agriculture. The changes associated with agricultural production, transport and systems of processing will have a massive impact on their emissions.

The importance of addressing limitation of GHG emissions from agriculture in the African continent especially in the sub-Saharan region is further highlighted by studies which consider the potential effects of climate change on agricultural productivity (Parry et al., 1999). It is estimated that about 80 million additional people to the currently estimated half of a billion worldwide will be at the risk of hunger due to climate change by 2080 (Parry et al., 1999) and the African region will be one of the most adversely affected as it is expected to experience marked reductions in yield and could have 70 million of the total projected (Parry et al, 1999; Ramankutty et al., 2005).

The necessity of examining the links between mitigation and adaptation; and sustainable development drive and potential for mitigating GHG emissions from agriculture in the future cannot be over stated. As Synder et al. (2009) states, agriculture has the potential to reduce GHG emissions and increase C sinks.

2. METHODOLOGY AND OBJECTIVE

My project is a desktop study which focuses on sub-Sahara Africa (figure 2) and makes a review from various scientific articles, reports, books and other related materials to address my objectives which are;

- Identify some of the best management practices (BMPs) from around the world with the potential of improving agricultural productivity of the region while mitigating GHG emissions usually associated with agriculture intensification.
- The current agricultural systems in the region is highly reliable on rainfall as the sole source of moisture and the success or failure of a growing season is associated with seasonal rainfall variability (Cooper et al., 2008). The project therefore seeks to identify means of enhancing the ability of agriculture communities and various stakeholders involved in agriculture in sub-Sahara Africa to adapt to climate change that may already be underway to help reduce the projected negative impacts, while taking advantage of any possible opportunities.

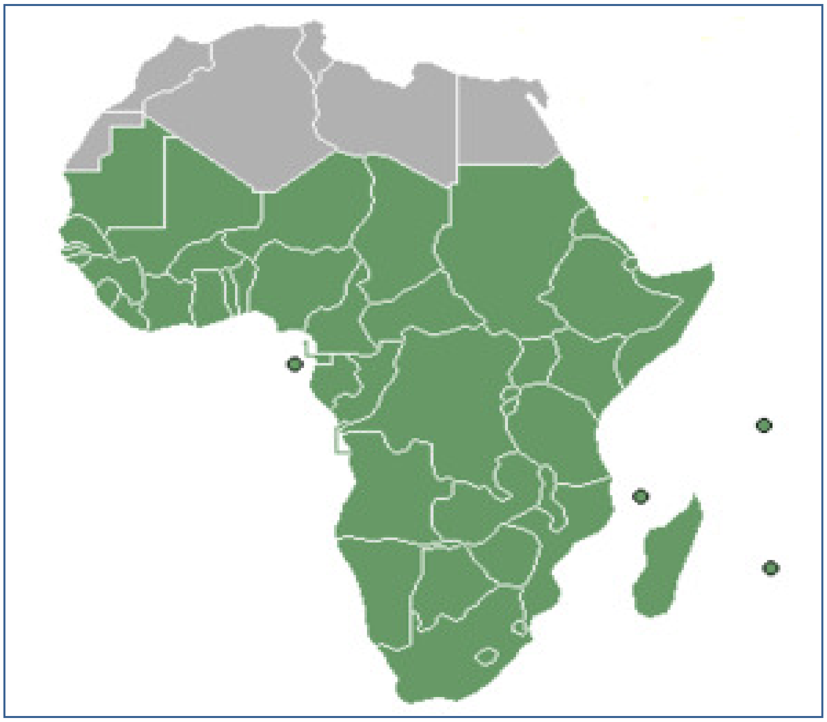

Figure 2: Sub-Saharan Africa indicated by green part of the map ***(Obtained from Wikipedia)***

3. RESULTS AND DISCUSSION

3.1. GLOBAL AGRICULTURE- Overview of its dynamics over the years

The development and improvement in agricultural practices have occurred for thousands of years through the history of man. Many changes have occurred in the global agricultural sector but these changes cannot be said to be uniform, as different forms of advancements are made in different regions around the world. However, common factors such as increase in the demand for food, increased technological intervention and an improved understanding of the ecosystem have formed the basis to these changes of agriculture (Desjardins, 2010). There is a hypothesis of early agricultural development being few forest clearings which occurred in Europe and China about 8,000 years ago, a period when hunting and gathering was still the basic means of accessing food for consumption. Climate was least affected by this early form of agriculture but impacts on climate have increased through the years from agriculture improvement through the Asian adoption of paddy rice system through the slash and burn system to the highly mechanized forms of agriculture currently practiced in many parts of the world (Desjardins, 2010).

Global landscape has been changed to a very large extent by the improvements in agricultural system as there is a high rate of substitution of natural vegetation for agricultural lands. There is currently a total of about 1.4 billion hectares of farm land on which agricultural activities are undertaken of which 18 million km^2 are croplands (Ramankutty et al., 2005). The study of Desjardins (2010) further sheds more light on how much agriculture has altered the global landscape through the years by stating that the size of cropland area increased to 1,471 million hectares in 1990 from 265 million hectares in 1700. Desjardins (2010) also stated that in the same period, 1700-1990, livestock grazing areas increased to 3,451 million hectares from 524 million hectares. These major changes have had significant impacts on climate due to resultant degradation of land in many areas around the globe.

Carbon and nitrogen fluxes were effectively balanced in the early systems of agriculture such as the traditional slash and burn system which was practiced on small scales and allowed re-establishment of natural vegetation through long fallow periods. This reduced annual build-up of GHGs in the atmosphere as emissions were limited (Desjardins, 2010; Tinker et al., 1995). Desjardins (2010) however identifies that changes in the physical and physiological land characteristics of the globe has been largely contributed by activities such as tillage, irrigation, fertilizer application and others which are carried out extensively by humans due to development in the agricultural sector.

Despite the general expansion of agricultural systems around the globe due to a constantly increase in production demand, there exist a conspicuous difference in agricultural footprints on different areas around the world in the present times as far as adopted methods and production systems are concerned. Smith et al. (2007) stated that technological changes, population pressure, economic growth and price squeeze have been some of the main factors driving a drastic change in agriculture in the past four decades. Verge et al. (2006) cited FAO (2003) which stated that since the 1960s, crop production increase has been as a result of yield improvement with 78% of the growth; 15% arising out of arable land expansion and responsible for the remainder 7% being crop intensity increase. The study projected a likely continuing trend through the year 2030 with about 70% accounted for by improvement in yield, 20% by land expansion and 10% by increase in cropping intensity.

Green revolution was a coordinated international effort which was instituted to pursue the goal of eliminating hunger and this is seen to have accounted for increase in food production around the world. This plan came with intensification of practices such as fertilizer and pesticide application, irrigation and mechanization of farms to pursue its goal (Smith et al., 2007; Verge et al., 2006). The green revolution is said to have been successful in keeping the pace of food and fiber production with the steep increase in food demand from a constantly growing global population but has not been completely successful in solving child malnutrition and food security problems since there are still challenges in some regions to contend with. Meanwhile, it has been noted that the intensification practices which accompanied this effort has been very detrimental to the quality of the environment (Smith et al., 2007; Verge et al., 2006).

As with the details presented in table 1, there has been a decrease in agricultural lands in developed countries while an increase has been observed in the developing countries. This is attributed to the fact of land use efficiency in the developed countries through the employment of very advanced agricultural systems (Smith et al., 2007) while the subsistence form of agriculture still practiced in most rainforest areas coupled with expansion of pasture lands has been responsible for the increased clearance of natural vegetation for agricultural lands (Desjardins, 2010).

Production of livestock is presently the biggest user of all agricultural lands around the globe both in direct terms for pasture and indirectly for feed and forage. According to Ramankutty et al. (2005), lands under permanent pastures are more than twice those dedicated to food crop cultivation around the globe. Over 40% of current food production in the world stems from livestock production and its contribution is observed to still be on the rise.

There is no doubt that food demand will continually increase due to a constantly rising global population. This, accompanied by a general worldwide phenomenon of carbon-credit market emergence and high demand for biofuels will only not likely result in mounting pressure on agricultural lands but also an enhancement of agricultural productivity through intensification since incentives exist for producers (Desjardins, 2010).

Table 1: Different uses of agricultural land in the past four decades in global and regional contexts *(Redrawn from Smith et al, 2007)*

	Area in Million ha (Mha)					Change (2000s-1960s)	
	1961-1970	1971-1980	1981-1990	1991-2000	2001-2002	%	Mha
World							
Agricultural land	4562	4484	4832	4985	5023	+10	461
Arable land	1297	1331	1376	1393	1405	+8	107
Permanent crops	82	92	104	123	130	+59	49
Permanent pasture	3128	3261	3353	3469	3488	+10	306
Developed countries							
Agricultural land	1879	1883	1877	1866	1838	-2	-41
Arable land	648	649	652	633	613	-5	-35
Permanent crops	23	24	24	24	24	+4	1
Permanent pasture	1209	1210	1201	1209	1202	-1	-7
Developing countries							
Agricultural land	2682	2801	2955	3119	3184	+19	502
Arable land	650	682	724	760	792	+22	142
Permanent crops	59	68	80	99	106	+81	48
Permanent pasture	1973	2051	2152	2260	2286	+16	313

3.2. MECHANISMS OF EMISSIONS AND EFFECTS- How Agriculture impacts on Climate

The study of mechanisms through which anthropogenic activities impact on GHG emissions in atmosphere and affect global climate have existed for over 100 years as John Tyndall in 1861 stated that CO_2 in the atmosphere could effectively trap heat (Johnson et al., 2007). Agriculture impacts on climate through two processes; the biogeochemical which constitutes the release and sequestration of GHGs that modifies the absorption of terrestrial long-wave radiation from the atmosphere and the biophysical which modifies surface energy budget and water balance through land cover change (Desjardins, 2010; Seguin et al., 2007).

Agriculture can influence climate through land-use changes which has the capacity to modify albedo (how much incident sunlight is reflected back) of earth surface. Climate can also be affected directly or indirectly by the radiative and non-radiative forcing agents impacted by agricultural activities. Approximately one-fifth of the annual increase in radiating forcing, or one-third with land-use considered is accounted for by the emissions of CO_2, CH_4 and N_2O on global scale (Desjardins 2010; Verge et al., 2006). Aerosols existing in the environment as dust particles from bare soil and plant residues or burning of crops can also have a significant cooling effect. Directly, they affect radiation budget by scattering and absorbing both short-wave and long-wave radiation while they indirectly possess a radiative effect of influencing the formation of clouds which lead changes of incoming radiation. Hydrological cycle change as a result of different crop and soil conditions is an example of non-radiative forcing effect. Both radiative and non-radiative effects can change heat and moisture fluxes on the surface which changes the lower boundary conditions of the atmosphere thereby influencing weather and climate (Desjardins, 2010; Verge et al., 2006).

Agricultural development has contributed enormously to the release of GHGs into the atmosphere. It is estimated that a total of about 310 gigatons of carbon (GtC) was accumulated at an average rate of 0.04 GtC yr^{-1} between 8000 years and 200 years ago from land clearance but this contribution has increased to an average of 0.8 GtC per year since the beginning of industrial revolution accumulating an estimated 160 GtC in the period (Desjardins, 2010). It is estimated that CO_2 emissions from fossil fuels only surpassed that of agriculture after the 1970's.

More than 50% of the world's crops are routinely fertilized stemming from the Green Revolution. Increasing use of nitrogen fertilizers has prompted concerns of the impact of their N_2O releases on the environment. Studies show that more than 50% of nitrogen fertilizers are not taken up by crops and are lost either through leaching or released into the atmosphere in the form of N_2O (Desjardins, 2010; Smith et al., 2007; Verge et al., 2006). According to Snyder et al. (2009), N_2O emissions are through two microbial processes; nitrification and denitrification and these processes release small amounts relative to the total soil N supply. Denitrification occurs when NO_3^- is transformed to dinitrogen (N_2) gas described in the pathway, NO_3^- - NO_2^- – NO - N2O - N2. The process of converting NO_3^- to N_2 is usually completed with a small and variable portion of the N emitted as N_2O gas. Emissions occur sporadically before, during and after a growing season. Moistening or saturation from precipitation or irrigation of soils which were previously well-aerated can also cause flushes of N_2O (Synder et al., 2009).

Several GHGs including carbon dioxide (CO_2), methane (CH_4), ozone (O_3), nitrous oxide (N_2O) and water vapour trap heat. CO_2, CH_4 and N_2O are however recognized as major contributors to positive increases in radiative forces as they are long lived in the atmosphere (Johnson et al, 2007). Therefore, high increases in their atmospheric concentrations have the capacity to cause elevated mean global temperatures and changes in precipitation (Tinker et al., 1995).

3.3. ATTRIBUTES AND STATE OF SUB-SAHARAN AGRICULTURE

The targeted economic growth of most sub-Sahara African countries still has agriculture as the main engine of their drive contributing about 30% of the GDP and being the source of employment of about half of its labour forces (Barrios et al., 2008; O'Brien and Leichenko, 2000). The systems of agriculture in this region of the world remain basically rain-fed. Even though rain-fed agricultural systems is a major contributor of global food (about 60%), it is exceptionally significant in the sub-Saharan region as it contributes to about 90% of its staple food production. Rain-fed agriculture therefore forms the basis for food security and forms the foundation of the livelihood of many rural communities (Barrios et al, 2008; Cooper et al, 2008).

Agriculture, despite its economic importance in the sub-Saharan region has had a relatively poor performance in relation to other developing regions of the world (Barrios et al., 2008). Institutional failures, pre-colonial slave trade and poor policies in the post-colonial era including economic ones such as focusing on cash crops and minerals as the main source of government revenue and foreign exchange have been pinpointed as having played negative key roles in sub-Saharan agricultural performance (Barrios et al., 2008; Mohammed-Saleem, 1995). Intensification of agriculture in many developing regions of the world has taken place gradually over some decades but will have to occur in a very short period in the sub-Saharan region due its rapid population. As Mohammed-Saleem (1995) stated, the process of agricultural intensification in the sub-Saharan region has been sabotaged by the many economic distortions in the region since independence.

Although basically dependent on rain as the source of moisture for agriculture in the sub-Saharan region, it is worthy to note that availability of water in the region widely differs as a consequence of a very large diversity of geographic conditions across the continent (Barrios et al, 2008). The tropics around the equator being parts of both the West and western part of Central Africa are humid throughout the year. There is almost no rain in dry seasons in the sub-humid regions located to the south and the north of the tropics though substantial rainfall occurs in the wet seasons. Located further towards the poles from the sub-humid regions are the arid and semi-arid climates. As can be inferred from the names, these areas suffer from unreliable rainfall in extremity and very few permanent water resources thus receiving very little direct water although not totally rid of water in the wet seasons (Barrios et al, 2008). It is also worthy to point out that even though many large water basins and rivers exist on the continent with some parts noted to experience massive rainfall, there is particularly low run-off from these areas to the arid and semi-arid areas.

The year round high temperatures in the sub-Saharan Africa exacerbate the issue of water scarcity especially in the arid and semi-arid areas. Barrios et al. (2008) states that the average run-off is 15% lower on the African continent than any other continent of the world and it is lesser in the arid and semi-arid regions as the dry soils absorbs very much moisture. This makes the arid region the region with the lowest capacity to support human needs as long as agriculture is in the context of discussion (Mohammed-Saleem, 1995). Despite the relatively low supply of naturally produced water compared to other regions of the world, the sub-Saharan region has very much smaller proportion of its arable lands under irrigation. As a matter of fact, it is less than 10% of irrigation compared to 20% irrigated arable lands existing in other developing regions of the world (Barrios et al., 2008).

Agricultural production in the sub-Sahara is highly affected by the above described geographical variation of water availability in an ironic sense. More precisely, the abundance of water in the humid parts of the tropics has been ironically identified not to make it suitable for agricultural productivity (Barrios et al., 2008). Most soils in Africa are derived from high chemical weathering of granite and parent gneiss material fostered by high temperatures, making them coarse and abundant rainfall causes leaching, resulting in organic matter content and inherent fertility being very low (Barrios et al 2008; Mohammed-Saleem, 1995). These soils are notably deficient in nutrients such as nitrogen and phosphorus (Mohammed-Saleem, 1995). For the reasons as explained above, much crop production in sub-Saharan Africa is located in the semi-arid zones making it more susceptible water shortages (Barrios et al., 2008). The agricultural practices undertaken have also often contributed to the water shortage problem in Africa more than any other region due to differences in property rights. To be more precise, the preservation of natural resources including water resources have generally been viewed as a secondary objective by farmers since they usually do not own the farms on which they work. In the work of Barrios et al. (2008), the water problem associated with the sub-Saharan agricultural system is compounded by farmers predicting large fluctuations in rainfall by rudimentary non-scientific means.

Sub-Saharan Africa is a region dominated essentially by small holders and has very sensitive environment (Mohammed-Saleem, 1995). The farming systems were previously guided by principles of shifting cultivation which gave enough fallow periods for soils to regain fertility. As population grows and cropped areas expand, land use intensifies and fallow periods are progressively shortened interfering with soils ability to regain fertility, producing little fuel wood and providing a poor grazing resource. For the pursuit of alternative fuel sources, crop residues and dung which are desperately needed to help maintain soil structure and fertility are increasingly burnt (Mohammed-Saleem, 1995). This coupled with communal or uncertain land tenure over the most parts of the region makes the task of agricultural development harder.

Mixed cropping is undertaken mostly in the sub-Saharan region as Mohammed-Saleem (1995) states, farmers intercrop anything with everything. This method of growing a mixture of crops and varying land management helps in adjusting to different soil and water regimes. Intercropping is also said to possess other advantages such as providing a protective cover of vegetation which lowers soil temperature, increases water infiltration thereby reducing soil erosion and lowers labour needs for controlling weed. Mohammed-Saleem (1995) also states that the combination of crops and plants with different heights, root depths and periods of maturity complement each other in the in the use of light, water and nutrients. Although yields associated with intercropping are usually greater than monocropping, yields in general have declined in the absence of fertility replenishment stemming from short fallows.

Adoption of the use of fertilizers compensates for the shortened fallow periods but many farmers in the sub-Saharan Africa have no incentive for their use because of their scarcity or prices of farm produce not being sufficiently attractive (Kelly, 2005; Mohammed-Saleem, 1995). Manure is used where fertilizers are not easily accessible while mulching dominates in areas unsuitable for animals. The demand for power is however encouraging integration of animals into farming systems.

In a nutshell, the changing circumstances of the sub-Saharan farmer have not been catered for by technological innovation, infrastructure and extension services. Farmers moving activities into marginal lands have a deleterious impact on the environment while still not being able to increase productivity as they continue to use traditional techniques which have failed to sustain productivity in abandoned lands which were suitable for agriculture (Mohammed-Saleem, 1995). Most countries in the sub-Saharan region have their populations growing to the level where intensification of agriculture is more than a necessity.

3.4. EMISSIONS FROM UNDEVELOPED AGRICULTURAL SYSTEMS

The rain-fed agricultural systems in the undeveloped parts of the world especially sub-Saharan Africa are undertaken through slash and burn due to lack of machinery for large scale production and the general subsistence outlook. The slash and burn approach to agriculture was traditionally practiced on local or very small scale by farming communities and due to lower population levels which was then existent, it was characterized by long fallow periods and thus, undisturbed forest area was relatively large (Tinker et al., 1995). This made the system a fully sustainable one with no net input of CO_2 and other significant GHGs into the atmosphere as the carbon and nitrogen fluxes resultant from the traditional or earlier slash and burn effectively balanced. In the system, carbon fixation through the process of photosynthesis equals the sum of carbon loss through the process of respiration while the above and below ground biomass remained constant with soil organic carbon level (Tinker et al., 1995).

Increase in population in the recent decades has however caused a dramatic increase in tropical deforestation as a result slash and burn clearing to establish more permanent agriculture, plantations and pastures which has often resulted in degraded grasslands or degraded fallows (Tinker et al., 1995). For this reason, emissions from such systems of agriculture have been mainly related to resultant land use change (Verge et al., 2006). As Tinker et al. (1995) stated, any land clearing possess very important consequences as the felling and burning of forest lead to high GHG and aerosol emissions. Apart from GHGs arising from forest clearance, soil cultivation and growing of annual crops results in accelerated conversion of soil-C to CO_2 by soil microbes (Verge et al., 2006). One-third of global net CO_2 emissions are as result of agricultural related deforestation and burning (Johnson et al., 2007). Nitrogen is also mineralized and denitrified by processes such as tillage in the cultivation process which increases GHGs from these agricultural systems (Tinker et al., 1995). As was further described by Tinker et al. (1995), there is a nitrogen balance obtained between nitrogen of either biological fixation or rainfall and losses due to leaching and denitrification. However, this balance is seriously disturbed when good secondary forests are not able to re-establish and loss of carbon from soil and vegetation becomes permanent due to very short fallows.

Tropical rainforest areas are impacted most by agricultural land use change where native rainforests are continuously being cleared for cultivation. This contributes significantly to total global deforestation which exceeds 13 M hectares per year (Desjardins, 2010). Generally, it is accepted that the expansion of agriculture into natural ecosystems has already had a significant impact on climate as agricultural activities emitted the most CO_2 into the atmosphere before the 1970’s when burning of fossil fuels surpassed this emission. Lack of intensification in agricultural systems especially in areas like the sub-Sahara keeps expansion of agricultural lands being on the rise as was shown in table 1 (Smith et al., 2007) thus, a continually rising CO_2 emissions.

Although CO_2 is known to be the main GHG emitted from agricultural systems such as that practiced in the sub-Saharan region, some fire conditions during biomass burning in African savannas and forests may also release significant amounts CH_4 and N_2O (Tinker et al., 1995). Tinker et al. (1995) referred to estimated 29 particles per million by volume (ppmv) of CH_4 in smoke plumes in annual savanna fires and 0.37 megatons (Mt) N_2O lost from fires in the whole of Africa.

As outlined above, undeveloped agricultural systems could have significant impacts on the climate by releasing GHGs through several pathways. Most lands of such agricultural systems are dedicated to annual cropping which possess the capacity to radically change the hydrology, micrometeorology and conditions of the soil (Tinker et al., 1995).

3.5. EMISSIONS FROM ADVANCED AGRICULTURAL SYSTEMS

Unlike earlier agricultural systems and those practiced in the much undeveloped parts of the globe which are characterized mainly by CO_2 emissions, high level N_2O and CH_4 emissions characterizes agricultural production in the very advanced systems. The main anthropogenic emitter of N_2O which contributes highly to global warming and destruction of the ozone layer is thought to be agricultural production (Hoffman et al., 2001; Smith et al., 2007).

Fertilizer application in the advanced agricultural systems is the main cause of N_2O emissions while enteric fermentation and manure application causes the major part of CH_4 released. As much as 78% of total N_2O in the United States is said to result from application of nitrogenous fertilizers and cropping practices (Johnson et al., 2007). Ten percent (10%) of GHG emissions in the European Union is said to be due to N_2O and CH_4 of which 63% and 49% respectively have been associated with agriculture.

Agricultural development has for a long period of time followed a general rule which has been expanding lands and land use intensification as population density increases (Mohammed-Saleem, 1995). However, advancement and mechanization of agricultural systems have aided the output associated with intensive farming. In East and West Asia, the transition to intensive farming was aided by irrigation while more sophisticated crop rotations involving legumes and integration of livestock with arable farming ensured a transition in the Middle Ages of Europe; two processes which have to a very high extent eluded the undeveloped agricultural systems like those practiced in the sub-Saharan Africa to aid transition (Mohammed-Saleem, 1995; Smith et al., 2007).

As was noticed before in the previous sections, mechanization of agriculture including massive use of fertilizers which have increased N_2O and CH_4 has on the other hand been successful in increasing production over very small areas causing decrease in agricultural land in the developed world contrary to the case scenario in the developing world (table 1). An assessment of the Environmental Protection Agency of the United States (US-EPA) as referenced by Smith et al., (2007) showed manure management was the only source of agricultural GHG emissions in which agricultural systems in the developed world surpassed that of the developing parts. According to their assessment, GHG emissions in the Europe, one of the regions with widespread advanced forms of agricultural systems amongst its countries is the only region with its agricultural GHG emissions projected to decrease until 2020 ***(table 2)***.

Table 2: Trends in GHG emissions from different agricultural sources in different regions of the world from the period 1990-2020 ***(Redrawn from Smith et al., 2007)***

REGION	N_2O soils	CH_4 enteric	CH_4 rice	CH_4, N_2O manure	CH_4, N_2O burning	Total
Developing countries of South Asia						
Mt CO2-eq. year^{-1} in 1990	396	228	113	34	23	795
% change in 2005	35	21	14	18	4	26
% change in 2020	62	48	41	34	4	52
Developing countries of East Asia						
Mt CO2-eq. year^{-1} in 1990	459	158	409	88	59	1173
% change in 2005	31	87	6	44	-10	28
% change in 2020	54	153	18	86	-10	54
Latin America and The Carribbean						
Mt CO2-eq. year^{-1} in 1990	258	384	19	20	160	840
% change in 2005	39	16	34	25	-12	18
% change in 2020	114	43	57	55	-12	55
Sub-Saharan Africa						
Mt CO2-eq. year^{-1} in 1990	252	183	12	12	145	603
% change in 2005	39	34	81	33	-1	28
% change in 2020	102	77	172	83	-1	70
Middle East and North Africa						
Mt CO2-eq. year^{-1} in 1990	76	34	7	3	2	121
% change in 2005	33	20	53	0	0	30
% change in 2020	98	49	97	33	0	81
Subtotal (developing regions)						
Mt CO2-eq. year^{-1} in 1990	1441	987	560	157	389	3533
% change in 2005	35	32	11	54	-10	26
% change in 2020	78	68	30	72	-7	58
Former Soviet Union						
Mt CO2-eq. year^{-1} in 1990	121	160	4	50	10	346
% change in 2005	-36	-40	-18	-20	-60	-36
% change in 2020	-17	-28	-19	-8	60	-22
Central and Eastern Europe						
Mt CO2-eq. year^{-1} in 1990	103	76	1	28	3	210
% change in 2005	-19	-32	-25	0	0	-21
% change in 2020	11	-26	-15	7	0	-3
Western Europe						
Mt CO2-eq. year^{-1} in 1990	218	153	2	93	1	469
% change in 2005	-7	-12	1	-12	0	-10
% change in 2020	-11	-17	1	-14	0	-14
OECD Pacific						
Mt CO2-eq. year^{-1} in 1990	25	92	8	4	10	140
% change in 2005	28	0	-8	75	70	11
% change in 2020	54	4	-4	75	70	19
OECD North America						
Mt CO2-eq. year^{-1} in 1990	282	181	8	57	7	534
% change in 2005	7	-2	7	19	0	6
% change in 2020	19	5	-2	37	0	16
Subtotal (developed regions)						
Mt CO2-eq. year^{-1} in 1990	749	662	23	229	31	1699
% change in 2005	-7	-16	-13	-2	3	-10
% change in 2020	5	-12	-16	5	3	-2
Total						
Mt CO2-eq. year^{-1} in 1990	2190	1649	583	389	430	5230
% change in 2005	21	12	10	12	-8	14
% change in 2020	53	36	27	31	-8	38

3.6. SITUATION OF GLOBAL FOOD SECURITY

The 1974 World Food Conference set a very ambitious goal to eradicate hunger from the human society in a decade under the proclamation; “every man, woman and child has the inalienable right to be free from hunger and malnutrition” (Gebremedhin, 2000). There has been an enormous improvement in global food supply since the early 1960s with world food supplies being 18% higher than 30 years ago.

The global grain yields per hectare in the decade of 1990s were nearly 2.5 times the 1.15 tons per hectare in the 1930s. In 1994 alone, world grain harvests rose by 2.9% to 1,747 million tons (M-tons) from a value of 1,697 M-tons in 1993. With the exception of slight fluctuations in some years basically attributed to drought and other natural disasters, world grain production especially wheat, corn and rice is seen to have shown a general upward trend (Gebremedhin, 2000). Meat production of the world also shows an increasing trend with a recorded 184 M-tons output in 1994 up from 177 M in 1993. The past two decades have seen the world make remarkable progress towards increasing food production and reducing food insecurity (von Braun et al., 2003) due to very favourable agricultural conditions that were experienced in the 1980s and 1990s (Gebremedhin, 2000). As referenced in von Braun et al. (2003), the number of food insecure people in developing countries fell from 920 M people in 1980 to 799 M in 1999 with the proportion taking a drop from 28% to 17% as according to FAO statistics. Furthermore, the present level of global food production has the capacity to satisfy the minimum calories of every individual within the total world population should there be an even distribution of available food supplies (von Braun et al., 2003).

There is no doubt that the general picture of world food production has improved over the years. Gebremedhin (2000) and von Braun et al. (2003) have stated that the trend of increasing productivity will continue in the decades ahead due to improved agricultural technology. Despite these improvements and optimistic future projections, the world still faces a serious crisis which is as perilous and life threatening to millions of people as was in the past since they do not share in this abundance (Gebremedhin, 2000). During the World Food Conference in 1996, two decades and two years after the 1974 proclamation, a renewed world food crisis was noticed as it was realized that many children still went to bed hungry, many families ended the day without a guarantee for the next day’s meal and many people faced the risk of stunted growth as a result of hunger and malnutrition which made it clear that the goal of the 1974 conference had not been achieved (von Braun, 2003). The general outlook of food sufficiency for the earth's population has not reflected in all countries as it is evident that the poor have all too often not had access to the food. This can be attributed to the fact that many poor countries have not had the capacity to be self-sufficient as long as food and agricultural production is concerned due to various economic, social and political reasons (Gebremedhin, 2000).

Due to unreliable data from many countries especially developing ones, it is difficult to estimate the total number of undernourished people today as different authors have published different figures (Gebremedhin, 2000). Despite this inconsistency, there is a general agreement that an extremely large number of people are affected by hunger and malnutrition. An estimated 1 billion people were estimated not to have enough food to lead to healthy and productive lives and out of seven people on the earth is affected by hunger by World Bank in 1996 (Gebremedhin, 2000). As referenced in Gebremedhin (2000), the Food and Agriculture Organization also estimated in 1997 that 840 million of the world's 1.1 billion poor people live in rural areas with 15 million of them dying annually from starvation and its related diseases.

In 1994, 1.4 billion people were estimated to be living in absolute poverty by Childers and Urquhart as was referenced by Gebremedhin (2000). This number was said to be 40% more than the number estimated half of a century earlier. It is also estimated that nearly one out of every four people living on the planet lives on the edge of poverty, too poor to obtain food needed to work. The livelihood and well-being of many people are being adversely affected by the consequences of hunger and malnutrition thereby causing the development of many undeveloped countries to be inhibited (Gebremedhin, 2000). Associated with the hunger situation in very poor countries is the lack of purchasing power (combination of income and the price of goods and services purchased) among the poorest segments of the society since the income distribution in such countries is skewed towards the high end of the scale making it difficult for the poor to purchase adequate food supplies.

Dependency on natural resources for food supply or using income derived from natural resources for purchasing food is a critical commonality between developing countries. According to the United Nations, about 70% of the 5.2 billion hectares of dry lands dedicated to agriculture are already degraded and this affects the livelihood of an estimated 250 million people around the world (Mwakalobo and Shively, 2002). The last quarter of the twentieth century is said to have seen a reduction of world's arable land by about 25% and this has had dire implications for food security and people dependent on degraded lands. The situation is especially worse in sub-Saharan Africa where the dependence on natural resources is potentially very high as it is said to presently produce less food per person than it did 30 years ago (Gebremedhin, 2000; Mwakalobo and Shively, 2002).

Economic Research Service (ERS) predicts growing gaps for low-income countries mostly in sub-Sahara and Asia over the next decade despite the increase in food supply in developing countries over the past two decades (Mwakalobo and Shively, 2002). There is a deterioration of food security in sub-Sahara African countries and is recognized as the most vulnerable region. The sub-Saharan region accounts for 65% of total gaps for all countries within the ERS assessment. The population of the sub-Saharan Africa grows at around 3% per year which is much greater than the rate at which food production increases, 1% per year (Davidson et al., 2003; Mwakalobo and Shively, 2002). The International Food Policy Research Institute (IFPRI) measured food insecurity with a new methodology which goes beyond the assessments done on the basis of food availability data. This new approach took into consideration information gathered by nationally representative surveys at household levels which is the level at which access to food actually takes place. Preliminary results from 10 sub-Saharan countries showed a very high food insecure population which is worse than estimated by assessments based on food availability data (von Braun et al., 2003).

With China out of the picture, the number of food insecure people in the developing world increased from the 1980s through the 1990s by nearly 50 million people as shown in figure 3 (von Braun et al., 2003). In sub-Sahara alone, the number of people living in hunger is said to have jumped nearly 20% and with almost a doubled number of food insecure people by the end of the decade *(*Mwakalobo and Shively, 2002; von Braun et al., 2003). According to the FAO, the situation could have been more precarious in the absence of large in-flows of food aid. There is still a forecast of acute food shortage and persistence of severe malnutrition in the sub-Saharan Africa and the Sahel by FAO (Mwakalobo and Shively, 2002).

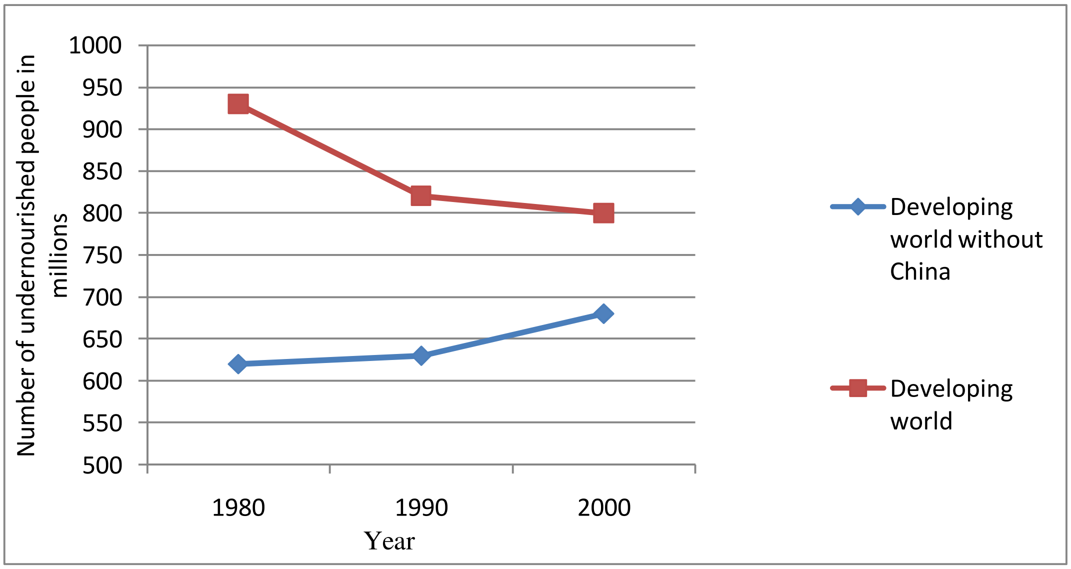

Figure 3: Hunger in the developing world, with and without China as by FAO *(Redrawn from von Braun et al., 2003)*

The rather precarious nature of food insecurity in most developing countries especially sub-Saharan Africa amidst a general growth in the world is one of the most visible manifestations of rural poverty deserving of considerable attention in both theory and policy (Mwakalobo and Shively, 2002). Highlighting the real causes of malnutrition and hunger in the region to raise awareness is very necessary to serve as a challenge to policy makers and planners to make changes in policies and development programs to alleviate poverty and ensure food security (Gebremedhin, 2000).

3.7. CURRENT AND PROJECTED EMISSIONS FROM AGRICULTURE- Global and regional levels

As a result of the Green Revolution, fertilizers have been highly utilized to improve and sustain food production and their use is expanding on the global scale to meet the food, fiber and fuel demands of a constantly rising population (Snyder et al., 2009; Verge et al., 2006). Population increase and increased emissions from agricultural activities are positively correlated in so many countries (van Beek et al., 2010) due to increased fertilizer usage which in turn is positively correlated with N_2O flux (Johnson et al., 2007). N_2O from soils and N inputs to crop and soil systems is the most important GHG considered in agriculture although CO_2 is generally the major GHG issue for the global economy (Snyder et al., 2009). As noted earlier however, the amounts of all the 3 major GHGs; CO_2, N_2O and CH_4 released through agricultural activities are significant.

Globally, the agricultural sector contributes about 45-50% of global anthropogenic CH_4 emissions (i.e. enteric fermentation, cultivation of rice in wetlands, animal waste decomposition) and 20-70% of global anthropogenic N_2O emissions (i.e. biomass burning, use of synthetic and manure fertilizers, manure deposition, agricultural soils). In various ways, factors such as land use changes, crops and cropping systems also have effects on weather elements (Pitesky and Stackhouse, 2009; Verge et al., 2006). Livestock production contributes highly to CH_4 emissions with an estimation of 20-34% of all CH_4 produced around the globe from enteric fermentation and animal waste storage while contributing about 94 Tg of N in manure yearly, a magnitude similar to N from fertilizers (Johnson et al., 2007). Between 1990 and 2005, GHG emissions resultant from agricultural emissions increased by 14% (table 2), with annual emission on the average of 49 Mt CO_2-eq. per year. The greatest increase in emissions from agricultural sources were from N2O from soils, N2O from manure management, and CH4 from enteric fermentation which showed increases of 21%, 18% and 12% respectively (Smith et al., 2005). Within this same period however, N_2O and CH_4 emissions released from burning of biomass decreased by respective values of 8% and 6%.

In 2005 alone, agriculture is said to have accounted for about 14% of the total estimated global emission of non-CO_2 GHGs of 5969 Mt CO_2 -eq. per year while contributing to 47% and 84% of total anthropogenic CH_4 and N_2O respectively in the year as by US-EPA (2006) referenced in

Smith et al. (2007). N_2O emissions from soil and CH_4 from enteric fermentation were the highest contributors to the total non-CO_2 emissions in 2005 contributing 44% and 31% respectively. Both the magnitude of emissions and the relative importance of the different sources show a wide variation among the different world regions (table 3). According to Smith et al. (2007), 74% of the total agricultural emissions in 2005 were contributed by a group of five regions consisting predominantly of non-Annex I countries with developing countries in East Asia emitting about 25% of the world total.

Table 3: Contribution of GHGs from different sectors of agriculture in 2005 as by different regions of the world (*Redrawn from Smith et al., 2007*)

REGION	N_2O soils	CH_4 enteric	CH_4 rice	CH_4, N_2O manure	CH_4, N_2O burning	Total
Developing countries of South Asia						
Mt CO_2-eq. year^{-1}	536	275	129	40	24	1005
% of region's total	53	27	13	4	4	100
% of sources world total	20	15	20	9	3	17
Developing countries of East Asia						
Mt CO_2-eq. year^{-1}	600	294	432	127	53	1505
% of region's total	40	20	29	8	4	100
% of sources world total	23	16	68	29	14	25
Latin America and The Carribbean						
Mt CO_2-eq. year^{-1}	359	446	25	25	141	996
% of region's total	36	45	3	3	14	100
% of sources world total	14	24	4	6	37	17
Sub-Saharan Africa						
Mt CO_2-eq. year^{-1}	350	244	21	16	143	775
% of region's total	45	32	3	2	18	100
% of sources world total	13	13	3	4	37	13
Middle East and North Africa						
Mt CO_2-eq. year^{-1}	101	41	10	3	2	157
% of region's total	64	26	6	3	2	100
% of sources world total	4	2	2	1	0	3
Subtotal (developing regions)						
Mt CO_2-eq. year^{-1}	1946	1300	617	211	363	4438
% of region's total	44	29	14	5	8	100
% of sources world total	74	70	97	48	92	74
Former Soviet Union						
Mt CO_2-eq. year^{-1}	78	96	3	40	4	222
% of region's total	35	44	1	18	1	100
% of sources world total	3	5	0	9	1	4
Central and Eastern Europe						
Mt CO_2-eq. year^{-1}	88	52	0	28	3	166
% of region's total	50	31	0	17	2	100
% of sources world total	3	3	0	6	1	3
Western Europe						
Mt CO_2-eq. year^{-1}	203	135	2	82	1	424
% of region's total	48	32	1	19	0	100
% of sources world total	8	7	0	19	0	7
OECD Pacific						
Mt CO_2-eq. year^{-1}	33	93	7	7	17	156
% of region's total	21	60	5	4	10	100
% of sources world total	1	5	1	2	4	3
OECD North America						
Mt CO_2-eq. year^{-1}	303	178	8	68	7	564
% of region's total	54	32	1	12	1	100
% of sources world total	11	10	1	16	2	9

Subtotal (developed regions)	**700**	**554**	**20**	**225**	**32**	**1531**
Mt CO_2-eq. $year^{-1}$	**46**	**36**	**1**	**15**	**2**	**100**
% of region's total	**26**	**30**	**3**	**52**	**8**	**26**
% of sources world total						
TOTAL						
Mt CO_2-eq. $year^{-1}$	**2646**	**1854**	**637**	**436**	**395**	**5969**
% of region's total	**44**	**31**	**11**	**7**	**7**	**100**
% of sources world total	**100**	**100**	**100**	**100**	**100**	**100**

This falls in line with an assertion made by Pitesky and Stackhouse (2009) who stated that two-thirds of all anthropogenic agricultural GHG emissions is from the developing world. In their study, it was indicated that six out of the 10 world regions grouped, N_2O from soils (primarily due to fertilizer and manure application) was the primary source of GHGs which is almost as the seven out of 10 by Smith et al. (2007).

Many programs have been initiated to reduce the amount of GHGs from agricultural systems and considerable progress has been made so far in reducing emissions per unit product (Desjardins, 2010; Popp et al., 2010). Despite this progress, the total amount of GHGs from agriculture is still on the rise due to a continually growing food and energy demand from a constantly growing global population, hence failure in reducing the impact of agriculture on the environment.

Increase in population in the forthcoming decades will prompt an increase in demand of food demands (Verge et al., 2006). The US-EPA forecasted an accelerated global agricultural GHG emission for the period 2005-2020 compared to 1990-2005 (table 2) (Smith et al., 2007). N_2O emissions from agricultural sources forecasted to rise by 35-60% by 2030 due to increased adoption of N fertilizer use and production of animal manure. Global livestock-related CH_4 production is also projected to increase by 60% in the year 2030. Agricultural CO_2 emissions from land use change may however be on the decline to the year 2030 (Smith et al., 2007).

Based on expected food consumption and demand levels, total GHG emissions from agriculture between the years 2000 and 2030 is expected to increase by about 50% (Verge et al., 2006). In the coming decades, the group of regions with the largest share of global agriculture GHG emissions, those with developing countries are also expected to have the largest increase in emissions (table 2) (Smith et al., 2007). Asia is and will be expected to remain the largest food consumer and the largest source of agricultural GHGs through the coming decades based on the year 2000 consumption levels (table 4 and 5) (Verge et al., 2006).

Table 4: Regional food consumption in total (10^9 KJ day^{-1}) and per capita (KJ capita^{-1}day^{-1}) (*Redrawn from Verge et al., 2006)*

Year	Africa	Asia	South America	North and Central America	SW Pacific	Europe
2000						
Total	8.7	44.0	4.0	6.7	3.3	9.2
Per capita	11.0	11.7	11.4	13.7	12.4	12.9
2015						
Total	11.7 (34%)	52.8 (20%)	5.0 (25%)	7.5 (12%)	3.8 (15%)	8.8 (-4%)
Per capita	10.9	12.0	12.0	13.1	12.0	12.6
2030						
Total	16.7 (92%)	62.4 (42%)	6.3 (58%)	8.4 (25%)	4.2 (27%)	8.4 (-9%)
Per capita	12.0	12.7	13.3	13.0	11.9	12.5

Table 5: Current and projected regional GHG emissions (*Redrawn from Verge et al., 2006)*

Year	Africa	Asia	South America	North and Central America	SW Pacific	Europe
2000						
Total GHG (Tg CO_2-eq.)	626	2670	757	713	264	626
Total GHG per capita (kg CO_2-eq.)	787	723	2180	1459	994	878
2015						
Total GHG (Tg CO_2-eq.)	796	3203	966	789	296	594
Total GHG per capita (kg CO_2-eq.)	734	731	2313	1373	936	849
2030						
Total GHG (Tg CO_2-eq.)	1422	3788	1207	877	329	566
Total GHG per capita (kg CO_2-eq.)	1017	773	2558	1356	929	841

Based on the 2000 consumption levels, the highest increase in food demand will however occur in the African and South American region (table 4) leading to very high GHGs release into the atmosphere (table 5) (Verge et al., 2006). This is consistent with an observation by Smith et al. (2007) who stated that the Middle East and Africa were expected to experience the highest growth during 1990-2020 with a 72% combined increase in their emissions.

3.8. REDUCING EMISSIONS IN PRODUCTIVE AGRICULTURE

Agriculture has been proven to be a primary source of all the three major GHGs; CO_2, N_2O and CH_4 and increase in food demand and diet shift as projected would escalate annual emissions even further. This is especially true for the sub-Saharan region whose increase in food demand in the coming decades will be exponentially high and therefore will likely result in the adoption of more fertilizer use in the intensification of agriculture and expansion into unexploited areas (Smith et al., 2007; van Beek et al., 2010; Verge et al., 2006).

There is a need for new and improved production techniques and mitigation strategies to be made to farmers especially in the sub-Saharan region to reduce the impact of the agri-food sector on climate as several possibilities exist to increase yields, reduce emissions and land use change resulting from agricultural expansion in the tropics, which easily result in land degradation (Verge et al., 2006). Recent studies and observations as in the European region have demonstrated the potential of mitigation in agricultural systems (Smith et al., 2007). Mitigation measures have the potential to reduce emissions from agriculture by 30-85% depending on the effectiveness of measures for a specific farming system (van Beek et al., 2010), the local and regional meteorological and soil conditions (Pitesky and Stackhouse, 2009). Similarly, Verge et al. (2006) estimated mitigation techniques have the potential to reduce radiative forcing by agriculture between 1.2-3.3 Pg CO_2-eq per year. Despite this positive outlook however, previous studies have shown that less than 30% of the total biophysical potential for agriculture GHG mitigation might be achieved around the world by the year 2030 due to price and non-price related barriers to implementation of mitigation strategies and therefore the need remove these barriers through creative policies (Smith et al., 2007).

Reduction of GHG emissions in agriculture will primarily be achieved from improved land management practices, efficient management of fertilizer and practices that will take advantage of existing organic matter supplies for example returning manure to the field to help increase crop yields while improving pasture (Verge et al., 2006). Many management practices such as; agro-forestry, crop management, tillage/residue management, nutrient management, rice management, water management, manure/ biosolid management, grazing land management/pasture improvement, management of organic soils, land restoration, bio-energy crops, enhanced energy efficiency, livestock management (improved feeding practices, specific agents and dietary additives, longer term structural and management changes, and breeding), increased C storage in products, and reduced biomass burning have the potential to affect GHG emissions directly by affecting NO_3^- availability or indirectly by modifying the soil microclimate and the cycling process of C and N (Smith et al., 2007; Smith et al., 2011, van Bleek et al., 2007).

Some of the above practices have wide applicability and others would have to be considered for regional application. Below summarizes some practices with the potential to reduce GHG emissions from agriculture while increasing productivity.

3.8.1. Carbon Sequestration

Historically, agriculture has been a major contributor to CO_2 in the atmosphere and still remains a substantive contributor following up after fossil fuel combustion. Strides have been made to reverse the process and make agriculture a net sink via C sequestration instead of a net contributor (Verge et al., 2006) since studies have shown that agriculture has the potential to reduce CO_2 emissions and the lands can sequester CO_2 as organic matter (Snyder et al., 2009). Sequestration of C is the net transfer of atmospheric CO_2 into long-lived C-pools (Johnson et al., 2007) and it is considered as the main option for mitigating climate change as long as agriculture is concerned (Desjardins, 2010). Due to the very high depletion of soil C-stocks by farming, agricultural soils from around the globe are estimated to have room for sinking 30 to 90 Pg C over the next century (Desjardins, 2010). This sequestration of soil organic carbon (SOC) has the potential to offset about 15% of global CO_2 emissions as estimated by Lal (2007) referenced in Johnson et al. (2007). According to Snyder et al. (2009), there is a potential for high-yield agriculture to increase annual input of crop residue C to soils as a carbon isotope studies with corn in Ontario by Gregorich and Drury (1996) showed that a 35-year fertilization period led to a higher level of corn-derived C in soil while the native soil C level was the same as in unfertilized soil.

Beyond the obvious target of offsetting CO_2 emissions, Johnson et al. (2007) states that there are other benefits associated with C-sequestration in forest and agricultural soils. Improved soil quality (water infiltration, water-holding capacity, aeration, bulk density, penetration resistance and soil tilth), increased soil productivity, reduced soil erosion and sedimentation, decreased eutrophication and water contamination are some of the benefits that arise from collateral soil C sequestration. Carbon pools for sequestration can be extant biomass (for e.g. trees), long-term biomass products (for e.g. lumber), soil living biomass (for e.g. microorganisms and perennial roots) or recalcitrant organic and inorganic C in soils and deeper subsurface environments as outlined by West and Post (2002) referenced in Johnson et al. (2007). In agriculture, sequestering plant biomass C into SOM is recognized as a key sequestration pathway. Below shortly describes some means of sequestering C in agricultural systems.

3.8.1.1. Carbon sequestration in form of Biochar/ Charcoal/ Black C

The application of biomass-derived black C (biochar) to soil has been proposed as a novel approach for establishing a significant long-term sink in terrestrial ecosystems (Desjardins, 2010) since soil C can be sequestered in charcoal which may persist up to 1500 years (Johnson et al., 2007). Charcoal or black "C" is a unique recalcitrant form of C found in many soils especially those with history of burning activities as it results from incomplete combustion of biomass C and can contribute to sequestration of C (Johnson et al., 2007). Due to its recalcitrant nature to microbial and chemical decomposition, charcoal can represent 10-35% of total soil organic carbon. As stated by Johnson et al. (2007*)*, protection from microbial degradation within stable microaggregates is necessary for effective sequestration of C in the soil.

It has been suggested that the soil quality of Oxisols could be improved by converting from "slash and burn" to "slash and char" which is more C and nutrient conservative (Johnson et al., 2007). Study by Karhu et al. (2011) confirms the assertion of improvement in soil quality as water holding capacity was increased in a biochar treated soil. Biochar amendment of agricultural soils could also increase uptake of N_2O and CH_4 to a very high level (Johnson et al., 2007; Karhu et al., 2011).

Biochar infused with other nutrients (i.e. N as ammonium bicarbonate) can act as a slow release fertilizer and has the potential to decrease leaching and run-off. In Christoph et al. (2007) as cited by Johnson et al. (2007), addition of charcoal to NPK fertilizer improved plant growth and doubled the yield of grain compared to the application of inorganic fertilizer alone in Brazilian Oxisol soil. When applied under the proper conditions, biochar has a remarkable nutrient affinity and enhances the cation exchange capacity as well as biological processes (Johnson et al., 2007). Application of biochar also has the potential to adsorb pesticides and other pollutants as stated by Lehman et al. (2006) referenced in Johnson et al. (2007).

3.8.1.2. Sequestration by no-tillage and conservation tillage

No-till is one of the well accepted techniques to promote the increase in soil carbon levels and is widely used amongst countries (Seguin et al., 2007). West and Post (2002) referenced in Johnson et al. (2007) found that changing from conventional tillage to no-tillage (NT) sequestered 0.57 +/- 0.14 megagram of carbon per hectare per year (Mg C $ha^{-1}yr^{-1}$). In another study Huggins et al. (2007) referenced by Johnson et al. (2007), SOC was lost in all tillage and cropping treatments in comparison to initial SOC levels; however, the least loss was experienced with conservation tillage and no-tillage.

In the United States alone, Sperow et al. (2003) also cited by Johnson et al. (2007) suggested that adopting no-tillage on all annually cropped land area could sequester about 47 tetragram of carbon per year (Tg C yr^{-1}). Similarly, Hutchinson et al. (2006) suggested that SOC gains under no-till management in semi-arid conditions on Canadian Prairies were about 0.25 Mg C $ha^{-1}yr^{-1}$ greater for all other tillage systems regardless of cropping intensity. No-tillage as a management practice also serves as an effective erosion control mechanism. In addition all stated above, it reduces CO_2 emissions from fossil fuels by means of reducing the need for fossil fuels (Johnson et al., 2007; Hutchinson et al., 2006).

3.8.1.3. Sequestration by Organic Agriculture

According to IFOAM (2009), organic agriculture can be described as a production system that sustains the health of soils, ecosystems and people. This agricultural system makes use of ecological processes, biodiversity and cycles which are adapted to local conditions rather than using inputs that result in adverse effects. It uses the combination tradition, innovation and science to benefit the shared environment and promote fair relationships and a good life quality for all involved (IFOAM, 2009).

Organic agriculture reduces GHGs by converting atmospheric CO_2 into soil organic matter (SOM) (Leu, 2009). Organic production utilizes practices recommended for enhancement of microbial functions and promotion of SOC sequestration such as surface mulching, continuous cropping, cover cropping, legumes in rotation, and manure application. As again stated by Johnson et al. (2007), animal manures and cover cropping practiced in organic agricultural systems contribute to SOC sequestration. Several studies have been conducted to support the assertion that organic agricultural systems emit less GHG gases compared to conventional agriculture and are also efficient in removing CO_2 from the atmosphere. Organic agriculture was proven to emit about 30% less GHGs compared to conventional agriculture in two long-term (21 and 22 years) comparison studies by Mader et al. (2002) and Pimentel (2005) as referenced in Len (2009). Rodale (2008) also cited in Len (2009) stated that organic farming practices can sequester about 7000 kilograms of CO_2 in a hectare of farmland. Based on this, it was estimated that converting100 million hectares of cropland to organic practices would be equivalent to the removal of more than a third of all cars in the world. Likewise, it has been suggested by IFOAM (2009) that adoption of organic agriculture around the globe could sequester up to 32% of all current GHG emissions from anthropogenic activities.

Building up the fertility of soil is one of the significant tenets of organic agriculture as the SOC sequestrated increases organic matter levels, particularly humus which is a source of improvement in soil health and productivity (Leu, 2009). The higher levels of humus associated with soils in this form of agriculture give them a better water holding capacity making them more efficient in water use by virtue of improved structure. Since C sequestration is affected by saturation levels, soils which have low inherent carbon and those which have been degraded through poor practices generally have a greater sequestration potential (IFOAM, 2009). Some studies have proven organic systems are more resilient and to be higher yielding than conventional farming under extreme weather conditions such as droughts and floods (Leu, 2009). The Food and Agriculture Organization (FAO) therefore considers organic agriculture as an effective strategy in the quest to mitigate climate change and improve production (IFOAM, 2009).

3.8.2. Appropriate Use of Fertilizer and Manure

Nitrogen fertilizer and manure use are constantly on the rise to satisfy demand for fuel and food of a growing global population as already indicated. This accounts for substantial releases of

N_2O and CH_4 into the atmosphere (Snyder et al., 2009) with fertilizer application being the main cause of agricultural N_2O emissions (Johnson et al., 2007).

3.8.2.1. Fertilizer application

For a myriad of reasons; fertilizer formula, N release rate, time and place of application and climate conditions, efficiency of crop uptake of N from fertilizers is considered to be less than 50% with remaining unutilized fraction lost to the water table by leaching or to the atmosphere as gaseous emissions (Smith et al., 2011; Verge et al., 2006). It is also outlined in Snyder et al. (2009) that apart from increase in direct soil N_2O emissions, ammonia (NH_3) volatilization and NO_3 leaching can also be increased by agricultural practices. The volatilized N according to the study could be subjected to transformations which along with denitrification of discharged or leached NO_3 may result in more N_2O emissions.

Application of fertilizer in itself as an agricultural practice should not necessarily result in GHG emissions if applied in the right amount (Snyder et al., 2009). Several studies have been conducted to show that, it is when agronomic N threshold level is surpassed that N_2O emissions increase dramatically. For example, a study by Malhi et al. (2006) referenced in Snyder et al. (2009) observed N_2O emissions increased only when N rates exceeded 80 $kgha^{-1}$ in a specific cropping study. As also indicated by Hoffman et al. (2001) in their study, there was no significant correlation between the amount of N applied and N_2O emitted at low fertilizer dosage while higher application rates was accompanied by very high emissions. It is however difficult to match N release with plant uptake and work is being done on the rate of release and the place and time of fertilizer application (Verge et al., 2006).

Applying at the right source, at the right rate, at the right time and with the right placement form the foundation on which good fertilizer stewardship rests. Improvement in N use efficiency helps in carbon sequestration and increases in biomass production which restores and maintains SOC levels (Snyder et al., 2009). Fertilizer consumers are therefore urged to improve the efficiency of N use through better management in the field to minimize GHG emissions and protect water resources while contributing to the sustenance of soil resources and provision of a healthy economy (Snyder et al., 2009).

3.8.2.2. Manure application

As stated by Pitesky and Stackhouse (2009), the amount of N applied as manure applied in agricultural fields around the globe is almost as much as that applied as synthetic fertilizer (77.4 Tg yr^{-1} for each) as estimated by Moiser et al. (1996) by reference. According to Verge et al. (2006), fewer problems are encountered with the application of N in organic sources such as dry manure as they are progressively decomposed by soil bacteria for plant uptake. The capacity of organic sources such as manure to improve soil quality and fertility, and its ability to retain nutrients for later uptake are some of the additional benefits for their application.

Despite the above benefits of manure application, Velthoff et al. (2003) cited in Snyder et al. (2009) have showed in their study that N_2O emitted from manure could be very high. In this referenced study, N_2O emissions from manure application to soils with low organic matter were higher than when the same soils were treated with mineral fertilizers. Differences in amount of emissions were also recorded from the different types of manure and their quality as affected manure management and handling. Due to its high water content, liquid manure which is usually the most preferred as being economical, requiring less time and manpower is identified to be a very significant source of CH_4 emissions, more than stockpile (Snyder et al., 2009).

Manure stored uncovered in fields also release very high amounts of N_2O. Management techniques must be developed address handling, storage and disposal of manure in order to reduce N_2O and CH_4 emissions (Verge et al., 2006).

3.8.3. Other means of improving yield while reducing emissions

Carbon dioxide (CO_2) emissions from agricultural systems are relatively more difficult to control as they occur primarily from above and below ground carbon stocks that are difficult to manage and have no permanent character. However, there exist the possibilities of more permanent options to reduce N_2O and CH_4 emissions as they are strongly linked to inputs and management (van Beek et al., 2010).

Employing management practices that improve pest and disease control as well as water management can contribute to increase in food production while causing a reduction in GHG emissions by reducing energy consumption, as well as post harvest losses that occur during storage (Johnson et al., 2007; Verge et al., 2006). Crop rotation as a management system, particularly one that includes legumes enhances fertilizer use efficiency and improves pest management.

Water control in rice production has been identified as key to reducing CH_4 emissions (Johnson et al., 2007; Verge et al., 2006). In China, it has been proven that draining the field intermittently or during the second half of a growing season caused a substantial decrease in CH_4 emissions. According to Johnson et al. (2007), draining the water and allowing soil to become aerobic reduces CH_4 production as it is oxidized.

Addition of other nutrients along with N fertilizers has been shown in Snyder et al. (2009) to have the potential to enhance efficient use N and improve yields. Addition of right amount of P along with N fertilizer led yield increase, improved economic returns and reduced NO_3-N levels in soil profile thereby reducing N emissions into the environment (figures 4 and 5). This is because crop uptake efficiency of N and retention of NO_3-N in the upper soil profile are improved.

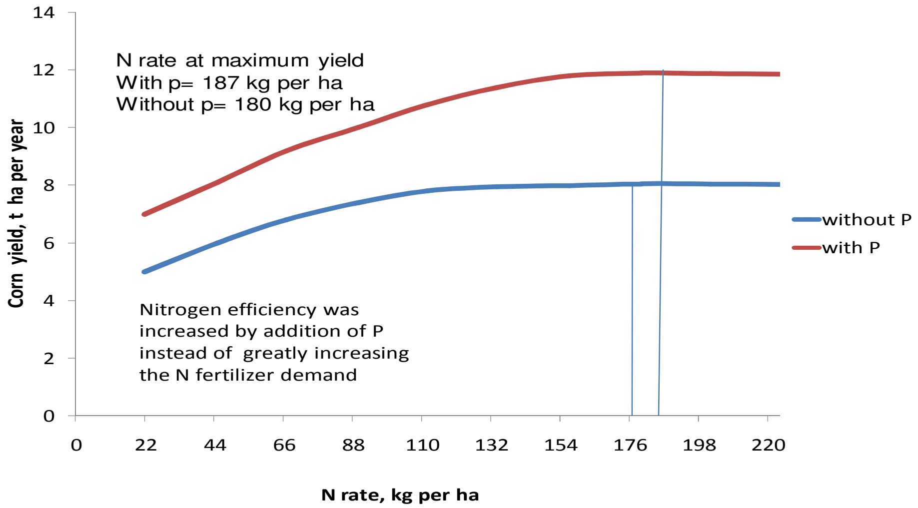

Figure 4: Right amount of P nutrition improves yield of corn and maximizes response to N rate (*Redrawn from Snyder et al., 2009*)

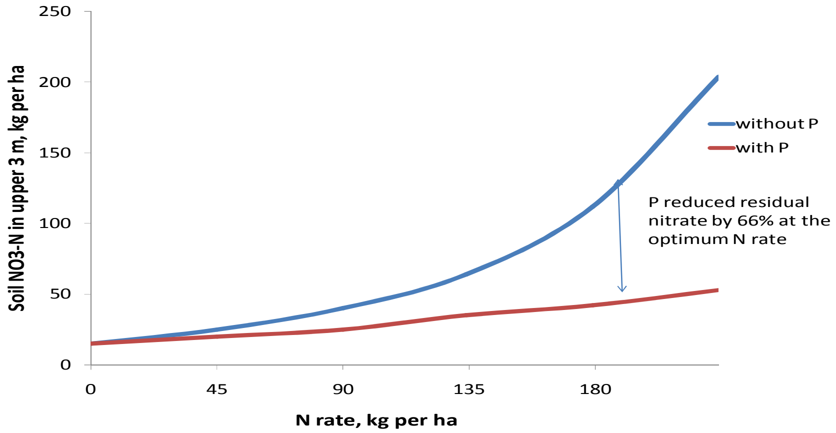

Figure 5: Adequate P nutrition causes a reduction in residual soil NO$_3$-N in corn (*Redrawn from Snyder et al., 2009)*

Another referenced study, Gordon (2005) showed that addition of essential nutrients like S in the right amount along with N, P and K can significantly increase crop apparent recovery of N (figure 6).

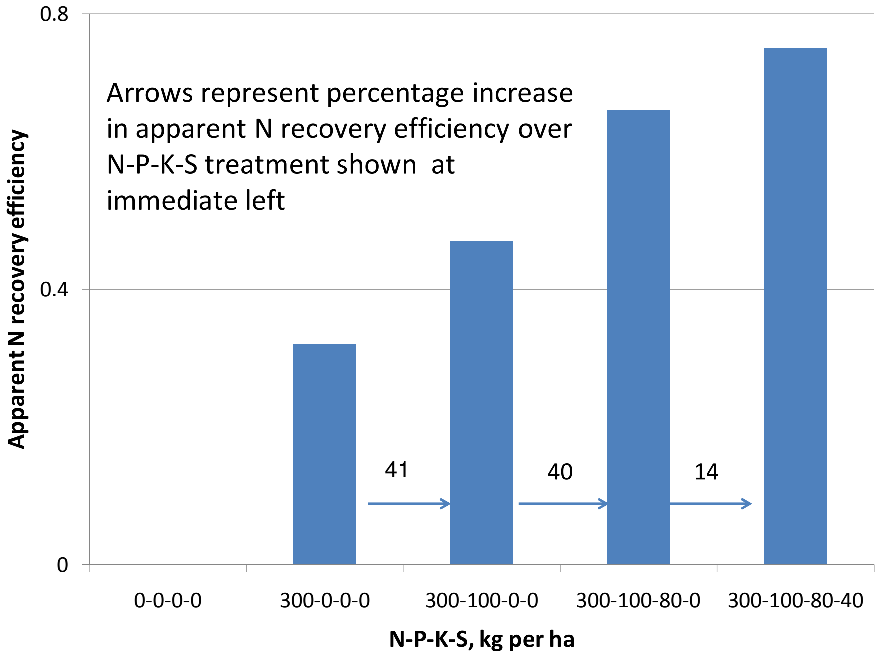

Figure 6: Apparent N recovery by corn using balanced fertilization (*Redrawn from Snyder et al., 2009)*

3.9. CLIMATE CHANGE EFFECTS ON AGRICULTURE

It is an accepted assertion that no matter what happens with future emissions of GHGs, the phase of global warming has already been entered and thus inevitable climatic pattern changes will be experienced (Cooper et al., 2008). Changes in rainfall distribution, increased storm intensity, accelerated species extinction rate, decreased capacity for carbon sequestration in agricultural soils and food shortages are some of the observed and anticipated impacts of climate change (Desjardins, 2010; Johnson et. al., 2007). Similarly as stated by Tirado et al. (2007), many are the pathways through which food safety may be impacted by climate related factors and some of these are changes in temperature and precipitation patterns, increased frequency and intensity of extreme weather conditions. Hazards of food safety that may be caused directly or indirectly by climate change and variability can arise at various stages of the food chain, from primary production to consumption.

Although the world has made progress in productivity of the agri-food sector with the help of improved technology, weather and climate still play very key roles in productivity (Johnson et al., 2007). In the study of Johnson et al. (2007), it was estimated that food prices could increase by about 45% by 2080 due to climate change effects. This would have more adverse effects on the most vulnerable people with limited coping capacity due to insufficient resources to purchase adequate amounts of food (Johnson et al., 2007; O'Brien and Leichenko, 2000).

Some regions like Europe and America are seen as with greater adaptive capacity for the climate change scenario. In contrast, arid and sub-humid tropics especially sub-Sahara Africa have a very low adaptive capacity which will exacerbate production decreases and risk of hunger (Johnson et al., 2007).

3.9.1. Effects of Climate change on sub-Saharan Agricultural productivity

In the light of global warming, tropical regions are expected to experience the strongest changes in precipitation. This makes Africa one of the most vulnerable regions to climate change as two-thirds of the continent is covered by dry lands and much of the continent has already experienced interannual climate variability resulting in a general decline in rainfall (Barrios et al., 2008; O'Brien and Leichenko, 2000). The effects of climate change will likely be worsened by the extreme poverty and often degrading resource base of the continent which limits the capacity for adaptation (Cooper et al., 2008; O'Brien and Leichenko, 2000). The rain-fed farming system generally practiced in the sub-Sahara makes it exceptionally sensitive to many of the projected changes (Beg et al., 2002; Cooper et al., 2008). This assertion is confirmed by the study of Barrios et al. (2008) who found that total agricultural output of developing countries in sub-Saharan Africa have been negatively affected by changes in climate in the latter half of the 20th century while no such effects have been experienced in the other developing countries. This was attributed to two reasons; differences in geography and agricultural practices.

Low production potential due to persistent droughts which have taken place in Africa over the past two decades have increased international relief efforts to prevent widespread famine. The case may be worsened in the coming years according to Johnson et al. (2007) whose modeling studies estimated projected additional 70 million people at the risk of hunger in Africa by the year 2080 due to climate change. The study projected a decrease in cereal productivity in some case scenarios to about 12% by 2080. In line with these projections is the study of Cooper et al. (2008) who also projected that cereal deficits of sub-Saharan Africa which currently stands at 9 million tonnes annually could triple to 35 million tonnes by 2025. By this estimation, the sub-Saharan region is rightly identified as "food trade hotspot" but the poverty level of the region leaves it in no capacity to finance such huge imports.

Many countries in Africa could face acute water shortages by 2025 due to the combined impacts of climate change and population growth. This has the potential to work contrary to the aspirations of the Millennium Development Goals as it will curtail the ability of irrigation in agriculture to respond to the expansion of food requirements of Africa in the coming years (Cooper et al., 2008).

According to Tirado et al. (2010), climate change will increase disease outbreak in the agricultural sector which could take an enormous toll in developing nations. It is projected that the use of pesticides for crops such as corn, cotton, potatoes, soybeans and wheat could increase due to warming and increased precipitation. The over use of pesticides would however result in environmental deterioration, breeding of resistant pests and also cause virtual elimination of protective predators (Tirado et al., 2010).

Although there is always differing views from different studies about the exact nature and extent of the impacts of climate change, it is generally accepted that it is the very poor and vulnerable peasant farmers in rain-fed agriculture areas like sub-Saharan Africa that will be the most affected (Cooper et al., 2008). Moving towards achieving the goals of the Millennium Development Goals has been incredibly slow in the sub-Saharan Africa and consequences of climate change seem to worsen the case.

3.9.2. Adapting sub-Saharan agriculture to climate change

The contribution of rain-fed agriculture is and will continue to be tremendous in the sub-Saharan Africa as it remains the dominant contributor to staple food production and forms the foundation of livelihoods of the rural poor (Cooper et al., 2008; O'Brien and Leichenko, 2000). Climate variability has however had adverse impacts on this form of agriculture and the likely continual increases in temperature along with decreases in precipitation expected as a result of climate change predicted by some computer models are likely to worsen the case (Cooper et al., 2008; O'Brien and Leichenko, 2000). To prevent the increase of current hunger scenario in the sub-Saharan Africa, emphasis must be placed on reversing the scenario of climate change impacts on rain-fed production systems and helping increase their productivity (Cooper et al., 2008).

Climate change as a phenomenon is taking place in an era of global history with several challenges arising from other stresses of development, notable poverty, fluctuating oil prices and food insecurity accompanied by changes in the environment such as land degradation and drought (Stringer et al., 2009). These increase the climate related shocks on the very poor countries in the sub-Saharan Africa and therefore makes it more important to develop adaptation strategies to enable agricultural communities and associated stakeholders to cope better with the current variability in climate and aid in adaptation to projected future climate change (Cooper et al., 2008; Stringer et al., 2009). Adaptation techniques optimizing water use will be required if the rain-fed agriculture systems in the region should meet the food security requirements of future Africa (Barrios et al., 2008). Adaptation to climate change is rather a more urgent imperative than a long-term response option which if does not gain priority will have its consequences prove daunting for most and impossible for many (Cooper et al., 2008).

There currently exists tools and approaches to better understand, characterize and map climate risk management strategies (Cooper et al., 2008) which if fully implemented have shown to drastically reduce the adverse impact of climate change and variability on agriculture and even at times, increase productivity despite seemingly adverse conditions (Cooper et al., 2008; FAO, 2007). As stated by FAO (2007), there are two approaches in the response to climate change; autonomous which is for example, the reaction of farmers to changes in precipitation patterns and planned which is a deliberate enhancement of the adaptive capacity of agricultural system through conscious multi-sectoral strategies. Planned adaptation will be necessary for farmers and all stakeholders with whom they interact to adjust to the foreseen long term changes since the extent to which people deal with new conditions such as what will be presented in the context of climate change depends on their adaptive capacity (Cooper et al., 2008).

According to Cooper et al. (2008), the idea of livelihood assets is central to the concept of adaptive capacity. Strengthening the asset base of a community and ensuring its resilience enhances their adaptive capacity and level of security. The study cited an illustration in rain-fed agriculture system in the semi-arid tropics of India (Kothapally village) as by Shiferaw et al. (2005) which evaluated the effects of integrated watershed management. The results indicated improved resilience of agriculture system in the project village compared to the non-project ones. Despite a high drought season, share of crop income as a percentage of total household income remained unchanged at 36% compared with an average season but reduced from 44% to 12% in the non-project areas ***(table 6)***.

Table 6: Effect of integrated watershed initiative on alternative sources of household income in the semi-arid tropics of India (Rs 1000) (60 sampled farmers in each group) (*Redrawn from Cooper et al., 2008)*

Year	Village group	Statistics	Crop income	Livestock income	Off-farm income	Household income
2001(average year)	Non-Project	Mean income	12.7	1.9	14.3	28.9
		Share of total income (%)	44.0	6.6	49.5	**100**
	Watershed project	Mean income	15.4	4.4	22.7	42.5
		Share of total income (%)	36.2	10.4	53.4	**100**
2002 (drought year)	Non-Project	Mean income	2.5	2.7	15.0	20.2
		Share of total income (%)	12.2	13.3	74.5	**100**
	Watershed project	Mean income	10.1	4.0	13.4	27.6
		Share of total income (%)	36.7	14.6	48.7	**100**

The results of this illustration can be useful for agriculture systems in the sub-Saharan Africa. It proves that investment in the farming practice to strengthen the livelihood asset base of rural communities is not only capable of aiding the adaptation process but can also result in positive output.

The study of Cooper et al. (2008) also shows the importance of development of climate analytical tools for seasonal weather forecasting. Pilot studies and surveys in employing these tools in Eastern and Southern Africa have shown that farmers recognize opportunities for adjustment in seasonal operations and benefit from the forecasts. It is further indicated in Cooper et al. (2008) that integrating the impact of variable weather with a range of soil, crop and water management choices in simulation models can be very useful in the approach to yield improvement. Agriculture Productions Systems Simulator (APSIM) is an example of such simulators and if properly calibrated, has achieved success in Kenya and semi-arid areas in Zimbabwe. In Zimbabwe, every farmer made significant gains as the amount of nitrogen fertilizer recommended by the model increased maize yields by 30-50% despite poorer than average rain season.

4. CONCLUSION

The amount of food production in the sub-Saharan region (growth rate of 1%) has been found to be very disproportional to its population growth (growth rate of 3%) worsening the picture of its food insecurity and thus a very slow advancement in the quest to achieve the Millennium Development Goals (Davidson et al., 2003; Mwakalobo and Shively, 2002). This makes the issues relating to climate change a far less important issue of concern with the possibility of intensifying agriculture to feed its growing population being the priority since improvement on food security is what is needed to make headway in meeting aspirations of its citizens. The high demand for food due to projected population increases and shifts in consumption patterns will likely increase GHG emissions (especially in the form of N_2O and CH_4) from the region into the atmosphere accelerating climate change (tables 4 and 5 adopted from Verge et al., 2006) unless agricultural systems are diversified and amount of GHG emissions are successfully decoupled from population growth. The focus of most literature on sub-Saharan food situation has been increasing productivity without much concern to possible negative effects of the noble pursuit. However, the literature reviewed have shown that some suggested practices in advanced agricultural systems in reducing the amount of GHGs could be employed in sub-Saharan Africa without compromising the primary objective of increasing food production.

Although the worst case scenarios of the climate change phenomenon are yet to be experienced according to predictions from studies, undeveloped agricultural systems like the dominant rain-fed agriculture in the sub-Saharan Africa have been noted to have rather exhibited very weak response to the on-going climate variability as productivity is already being affected (Barrios et al., 2008; Cooper et al., 2008; O'Brien and Leichenko, 2000). This shows the importance of adopting innovative technologies and practices from around the globe to reduce emissions while improving production to eliminate poverty and malnutrition in the region Smith et al. (2007) as the synergism of mitigation and adaptation has been acknowledged by the UNFCCC as important in managing future climate change (Stringer et al., 2009).

Limiting emissions from productive practices

Application of fertilizers is seen as a very important means to improve productivity while enhancement of carbon sequestration is recognized as with the potential to mitigate GHGs in the atmosphere by reducing the global warming potential (GWP) of the agricultural systems (Johnson et al., 2007; Snyder et al., 2009; Verge et al., 2006). The purposes of both fertilizer application and carbon sequestration have been shown as with the potential to reinforce each other under the stewardship of best management practices (BMPs).

The practice of applying fertilizers should not necessary increase GHG emissions as several studies have shown that application in the right amount and at the right time and place will not only achieve increased yields but also help in mitigating GHG emissions by aiding carbon sequestration from resultant increase in primary productivity while carbon sequestrated (by biochar amendment of soil, conservation/no-tillage practices and organic agriculture) also contributes to the build-up of SOM or rich humus to improve soil fertility (Johnson et al., 2007; Karhu et al., 2011; Snyder et al., 2009). Increasing gains in agriculture production by these could reduce the spread of croplands into forests and other natural lands. This will serve the best purpose as Synder et al (2009) has stated that land spared from production presents the best opportunities for net mitigation in agriculture and this can be supported by Smith et al (2007) in figures 1 and 2 which have shown a decrease in agricultural land area in Europe leading to significant reduction in its agri-food sector GHG emissions.

Adaptation of rain-fed agriculture to climate change effects

In the sub-Saharan Africa, recognizing the importance of rain-fed agriculture to the livelihood of communities and individuals is an important necessity as it has been identified as their main life-support system contributing about 90% of staple food production. Enhancing the adaptive capacity of farmers and other stakeholders in this agricultural system is an important necessity to reduce climatically induced shocks as it has been recognized as one of the most vulnerable systems as long as climate change impacts are concerned.

Available tools and approaches should be employed to develop crop, soil and rainfall management strategies in enhancing adaptive capacity (Cooper et al., 2008). In general, the degrading resource base has also contributed to the weakness of rain-fed agriculture system in response to climate change (Mwakalobo and Shively, 2002) and therefore strengthening and providing a more resilient and a more varied asset base will go a long way in enhancing their adaptive capacity as well as taking advantage of any possible climate related opportunities to increase production. In this project, the importance of a stronger and more resilient asset base has been illustrated with a case study from Kothapally village in India (table 6 adopted from Cooper et al., 2008) from which lessons could be drawn for the sub-Saharan case.

In adaptation to climate change and attempting to increase agricultural production while limiting emissions, the different countries in the sub-Saharan region are confronted with similar challenges but different opportunities will be presented by virtue of geographical location and national asset base. Continuous in-country assessment of adopted techniques, technologies and practices in this pursuit will be necessary in order to address specific local problems with available resources which will be economically viable to improve food security and reduce impacts on the environment.

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