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The Potential for an Environmentally Sustainable Green Revolution

-The Case of Ghana-

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ABSTRACT

This thesis aims to understand the state of the Green Revolution movement in Ghana, with a focus on environmental policy and its potential for future development. The main research question applied is "What is the potential for an environmentally sustainable Green Revolution-type advancement in agriculture in Ghana?".

A quantitative, comparative case study methodology is applied, in which three factors are examined for each case. These factors are cereal yields, nitrogen fertilizer applications, and pesticide use, chosen due to their established linkages to environmental impacts in Asia.

It was found that during the Green Revolution Southeast Asia an increase in cereal yields occurred, paired with a 45% increase in nitrogen fertilizer use since 2002. Pesticide use varied between countries. Ghana displayed similar patterns. Cereal crop yields show a growth of 38% after the implementation of the first Green Revolution project, with nitrogen fertilizer and pesticide usage following said increase.

In examining the environmental policy of Ghana; it was found that the country has a extensive roster of environmental organizations. Notable policies were the NCCAS, and the NCP. Further documents showed goals of awareness, land management, and preserving indigenous knowledge, suggesting that Ghana is in a position where there is potential for a sustainable agricultural development to be accomplished.

Key Words: Green Revolution, Ghana, Sustainability, Environment, Southeast Asia.

INTRODUCTION

In the 1960s an integrated package of practices was introduced across Asia, later coined the 'Green Revolution', which contributed to rapid developments within the realm of agricultural intensification. This led to greatly increasing crop yields in the region, allowing countries to avoid the famine that had previously been thought to be inevitable. Instead the region saw a growing agricultural sector, improved economies, and the possibility of attaining self-sufficiency in staple crops. Overall, the Green Revolution is credited to have played an important role in the present-day success of the region.

With the current state of Sub-Saharan Africa, a common discussion amongst academics relates to the potential for applying the ideologies and practices of this movement to the case of Africa. This discussion primarily focuses on the potential socioeconomic impacts of an African Green Revolution; frequently excluding the issue of the developing environmental degradation currently seen throughout Asia due to unsustainable practices, and the lessons that could be drawn from this for the African case. Therefore, this thesis will focus on the negative environmental effects experienced in Asia, and the potential for avoiding these when applying the concepts to Africa.

In doing so, the focus of this study will be on Ghana. This country was chosen due to its favorable environment for agriculture, as well as its relatively stable political climate compared to many other African countries. The overarching research question to be applied is; "What is the potential for an environmentally sustainable Green Revolution-type advancement in agriculture in Ghana?" To fully examine this, three sub questions have been identified.

The first concerns the practices seen in Southeast Asia between 1960 and present day, in order to establish a clear comparison point for the case of Ghana. The second question follows the same methodology as employed in the first, only this time examining Ghana following the introduction of the first Green Revolution project in 2006/7. The third question aims to establish an overview of the policy situation in Ghana related to agriculture and environmental sustainability. In tying these three questions together it is believed a well-informed conclusion can be developed that will prove relevant to a generalization to Sub-Saharan Africa as a whole, as well as establishing necessary research for the future.

The method applied for this study is a primarily quantitative, comparative case study – based examination of the state of the Green Revolution in Ghana. Southeast Asia is examined

first simply to maintain chronology in the study, and to provide a sound point of comparison to what is currently occurring in Ghana. Three factors are chosen for examination for the first two sub-questions; cereal yield growth, nitrogen fertilizer use, and pesticide application. The third question follows a different format, in which relevant policy documents are examined, as well as work and analyses done by other researchers, in order to create an overarching view of the current state of environmental policy in Ghana, as well as the relationship of this to the potential of the country's development. These are followed by a discussion section tying together the three parts, as well as bringing up further relevant points for discussion.

BACKGROUND

The Green Revolution approach as seen in Asia are commonly referred to as being a "package of practices" (Farmer, 1986 p. 176). Farming practices are shifted to an approach similar to a monoculture, in which High-Yielding Varieties (HYVs) of staple crops are favored over regular strains. In order to reach their full potential these strains require regular application of chemical fertilizers, most significantly nitrogen-based ones, as well as pesticides, herbicides, fungicides, and similar substances (Pingali, 2012). These seed varieties are also dependent on the steady application of water, so it is often a necessity to develop and expand the available irrigation infrastructures to fulfill this (Wilson, 2000, p. 819).

As stated, the Green Revolution was significantly successful in increasing crop production in Asia (Farmer, 2002, p. 305). In a few short years several countries were able to reach near self-sufficiency in notable staple crops, where they would previously have had to import to keep up with the demand (Wilson, 2000, p. 818). In India alone, grain production increased from 95 million tons in 1967 to almost 130 million tons in 1980 (Farmer, 1986, p. 176). Growth such as this had not been previously recorded in history, nor had the growth following this initial growth spike. Farmer (1986, p. 181) adds the statement that "so far as the Green Revolution is revolutionary at all, it still continues to increase productivity and production in South Asia."

However, research in recent decades has established a troubling growth of environmental degradation throughout Asia following the practices implemented during the Green Revolution (Liu, Pan, and Li, 2015, p. 83). Whilst the success of the movement in terms of crop yields and agricultural development cannot be disputed, it also contributed to the development of widespread issues such as land degradation, desertification, pollution, losses in biodiversity, as well as issues regarding water availability and quality due to excessive irrigation (Khan and Shah, 2011, p. 629).

Throughout the Green Revolution in Asia, the use of these practices has been intensively propagated by relevant policy-makers. For instance, while it is known that the application of chemical fertilizers and pesticides do contribute to improved production, it also carries serious risks with regards to the contamination of local water tables, as well as stockpiles being built up in soils and within nutritional chains. Yet farmers still received subsidies, tax-cut incentives, and were encouraged to participate in agricultural extension programs with the goal of promoting the use of these substances in farming (Khan and Shah, 2011, p. 636).

Similarly, the promotion of monoculture-style farming practices brings significant implications to the state of biodiversity within a region. The Green Revolution worked to promote a small number of improved strains, which replaced regions where vast numbers of different ones had previously been cultivated (Liu, Pan and Li, 2015, p. 84). For example, Khan (and Shah, 2011, p. 636) brings up the example of Bangladesh, in which one single strain of these improved seed varieties replaced roughly 67% of an area in which wheat was grown in 1983. Similarly, by the 1980s an area of India in which more than 30 000 different strains of rice had previously been cultivated was replaced by a group of ten improved varieties. This rapid decline in biodiversity has serious implications for the potential of long-term management of the state of the local ecosystem, as well as decreasing the potential for the local population to attain a diverse nutrition (Pingali, 2012).

Sub-Saharan Africa is today facing a situation similar to that of Asia in the mid-1900s. With the rapidly growing populations, urbanization, political conflicts, together with the risks created by natural phenomena such as drought, a persistent threat of food insecurity is present, as is the potential of famine occurring (Country Watch, 2018). Following this several proponents for implementing a Green Revolution in Africa have stepped forward, the most notable being that of Kofi Annan and the Alliance for a Green Revolution in Africa

(AGRA). This has led to the introduction of several Green Revolution-type projects in various countries in Sub-Saharan Africa; one of these being Ghana (AGRA, 2017)

Like Southeast Asia, Ghana relies on the agricultural sector for a significant portion of its employment and economic contributions. It is estimated that up to 50% of the working population is employed within agriculture, making up roughly 21% of Ghana's GDP (Sova et al., 2014, p. 1, and AGRA, 2017). There currently exist several key constraints to agricultural development within the country; including a limited access to fertilizers and other modern inputs exacerbating the issue of poor soil fertility, low rates of irrigation and a high dependence on rain-fed agriculture, minimal inclusion of mechanization technologies, as well as issues of climate change and variability putting yields at risk (Sova et al., 2014, p. 3. These, paired with the potential shown through its stable political system and recent surge in productive cash-crop farming showing the potential of the agricultural sector in the country, has led to Ghana being one of the countries in which Green Revolution projects have been introduced (Country Watch, 2018). This is also why Ghana was chosen as a focus case for this study.

This thesis will aim to examine whether lessons from the Asian experience are being drawn and appropriately applied to the Ghanaian case. Factors such as socioeconomic impacts will not be included for this topic, as there is already significant amounts of research and literature available on the overall potential of a Green Revolution in Africa. Rather, the focus will be upon examining the potential for this movement to be applied in a manner promoting long-term growth in which environmental integrity is maintained, and the negative environmental impacts seen in the Asian case are appropriately managed.

Liu (Pan and Li, 2015, p. 91) summarizes the overarching view applied for this thesis in the quote below;

"If there are no feasible solutions to alleviate the negative effects of production practices aimed to simultaneously increase crop yields and decrease environmental impacts of agricultural intensification, there will be a tradeoff between increased crop yield and environmental protection"

AIMS AND RESEARCH QUESTIONS

As stated, Ghana was chosen as the focus of this study due to its favorable geographical conditions making it an appropriate location to apply the ideas of the Green Revolution, as supported by the fact that it one of the primary locations AGRA has chosen to conduct their work in. This makes Ghana one of the few African countries in which information is at this point available on the topic studied.

Aims

The overall aim of this study is to come to an informed, predictive conclusion on the current state of the Green Revolution movement in Ghana through a thorough examination of available data and literature on both the case of Ghana, and that of Southeast Asia. A particular focus will be placed on the extent to which an effort is being made to avoid repeating the mistakes seen from the Asian Green Revolution.

Research Questions

The research question to be examined in this work is the following;

What is the potential for an environmentally sustainable Green Revolution-type advancement in agriculture in Ghana?

In expanding upon this, three sub-questions have been developed in order to provide structure and focus to the study;

What environmental impacts have been seen in the case of Southeast Asia due to the processes introduced by the Green Revolution?

What Green Revolution-type approaches have been implemented in Ghana at this point in time, and how are these likely to impact local environments?

How do policy implementations seen in Ghana regarding agricultural intensification and environmental sustainability show efforts being made to avoid the negative consequences experienced in Southeast Asia?

The aim of the proposed sub-questions is to create a logical flow to the development of ideas related to the main research question, allowing for sufficient information and analysis to be established in order to come to an informed conclusion on the topic. The first sub-question strives to examine the case of the Green Revolution in Asia, more particularly that of Southeast Asia, focusing on the negative environmental impacts that have developed post-Green Revolution. The second sub-question focuses on the current situation in Ghana; and aims to make predictions about a likely progression of impacts based on comparisons to the analysis done on the case of Southeast Asia. The third sub-question examines the Ghanaian case through relevant policy documentation in order to assess whether efforts are being made in order to avoid the problems discovered during the movement in Southeast Asia.

CONCEPTUAL FRAMEWORK

This study applies a theoretical framework based in environmental sustainability. The various sections of the thesis cover different topics, regions, and focuses, but all relate back to the concept of environmental stability, and the state of the environment of Ghana in relation to the current effort to increase agricultural output. In having a clearly established theoretical framework it is believed the sections can be better tied together, allowing for conclusions to be drawn based upon a clear line of thought that is developed throughout the study as a whole.

The Theoretical Framework

As stated, the theoretical framework for this study is one of environmental sustainability. The Environmental Protection Agency (EPA) defines the term as the "long-term maintenance of ecosystem components and functions for future generations" (United States Environmental Protection Agency, 2018). Essentially, the phrase refers to an on-going effort to maintain the health of the environments in which we operate. The idea central to this approach focuses on the importance of moving away from the "development first" mindset, in which rapid growth and economic development is achieved at the expense of the surrounding environment (Nyang'oro, 2013, p. 246). Environmental sustainability could entail any number of things related to the environment, but for this thesis the primary focus will be on the areas of biodiversity, soil health, pollution management, and overall resource management.

The research question presented in the previous section, as well as the associated sub-questions, aim to include a wide number of factors that are associated to the state of environmental management within a country. The first sub-question aims to create an overview of a case in which it has been established that environmental management has not been a priority. For this study this case is that of Southeast Asia, being one of the primary regions in which the Green Revolution occurred, as well as an area in which the resulting environmental degradation is well recorded.

While Southeast Asia has been massively successful in recent decades in terms of economic and industrial development, they are also countries in which environmental damage is becoming more and more noticeable. As the effects of the degradation has continued to impact the wellbeing of those in the area, the ability of local land to produce sufficient produce, and developed to a level in which it affects countries and region outside of the initially degraded area, the importance of environmental management is only now starting to become more established within the realm of policy-making and governance (Office of the Director of National Intelligence, 2018). The idea in examining this case is to create a basis for the analysis on developments in Ghana, in which the goal is to recognize potentially hazardous practices early; and examine the state of implementation of environmental management practices related to agriculture.

The second sub-question strives to create a similar overview for the case of Ghana, in which the Green Revolution package of practices has only been present for roughly 11 years (Moseley, 2012, p. 220). This will examine the current state on agricultural yields in the country, as well as the extent to which various Green Revolution practices are being implemented, and developing environmental concerns related to these. In elaborating upon the case of Ghana the third sub-question focuses upon the current state of environmental policy in the country, allowing for predictions to be made related to the sustainable environmental development potential for Ghana in the future.

It was chosen to conduct the same method for both cases. While the examination of Southeast Asia could have been done as a literature overview, it was determined that examining the same factors would allow for a more accurate comparison to be made on the state of each case, as well as make any relevant predictions for Ghana have a sounder foundation. The three factors examined are that of cereal yield growth, nitrogen fertilizer use, and pesticide applications, chosen due to their close linkages to both the Green Revolution package and the nature of environmental management, or lack thereof.

In creating this framework for environmental sustainability this study will depend on several key concepts; that of sustainable development, the Green Revolution, as well as environmental degradation. These particular focuses were chosen as they all present a different perspective of environmentally sustainable development, thus contributing to establishing a holistic overview of the state of environmental management for each case. This allows for the idea of environmental sustainability to be included throughout the entirety of the study.

Sustainable Development

One of the key concepts in this study, closely related to the theoretical framework, is that of sustainable development. The definition applied is one presented by the World Commission on Environment and Development (WCED); "sustainable development is the kind of development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations, 1987, p. 16) This relates directly into the theoretical framework of the study, as the specific focus is one of an environmentally sustainable development.

The potential definitions that could be applied to the term environmental sustainability are, in essence, very similar to that of sustainable development. The WCED suggest the definition of development "meeting the resource and services needs of current and future generations without compromising the health of the ecosystems that provide them" (United Nations, 1987, p. 16). For the sake of accuracy, this study will also rely upon one further specified definition. John Morelli (2011, p. 5) defines environmental sustainability as "a condition of balance, resilience, and interconnectedness that allows human society to satisfy its needs while neither exceeding the capacity of its supporting ecosystems to continue to regenerate the services necessary to meet those needs nor by our actions diminishing biological diversity" (Morelli, 2011, p. 6). While it could be argued that the WCED's statement of environmental "health" would include all factors specified in Morelli's definition, it is believed that explicitly stating each of the relevant factors to environmental health is to the benefit of the research.

Likewise, the emphasis on biological diversity in Morelli's definition is believed to be especially relevant to this study, as the depletion of biodiversity within environmental spaces is one of the key long-term effects experienced in Asia since the Green Revolution, as well as a key factor in potentially maintaining said health for the case of Ghana (Farmer,

1987, p. 181, and Liu, Pan and Li, 2015, p. 91). Therefore, it is determined that Morelli's definition is most relevant to the focus of this study.

The Green Revolution

Another key concept for this study is that of the Green Revolution, being the process through which the idea of environmental sustainable development will be examined. Being an extensive concept, the summary of the term as provided by Khan (and Shah, 2011, p. 631) becomes relevant; in which it is stated that the Green Revolution refers to the promotion of agricultural intensification as a means of achieving improved productivity in farming. The movement places a heavy emphasis on a combined effort of local governments and researchers alike, as well as the application of a "package of practices", including; agrochemicals, irrigation technologies, and high-yielding seed varieties of staple crops (Farmer, 1986, p. 176).

HYV's refer to genetically modified versions of staple crops, commonly rice or cereal, that have an improved efficiency in terms of "yields per unit of nutrient intake" (Wilson, 2000, p. 817). For this study the data examined will be on cereal crop yields, as these are common staples of both cases examined. In order for HYVs to achieve their full efficiency they require an increased application of nitrogen-based chemical fertilizers, as well as a stable supply of irrigated freshwater. These seed varieties also require a near-constant application of pesticides, herbicides, and insecticides, as they are more susceptible to pests and disease than the natural strains of these seeds would be (Wilson, 2000, p. 820).

While these efforts do contribute to a significant increase in crop yields, it is through these specific activities negative environmental impacts occur. Nitrogen fertilizers and pesticides are particularly troublesome in terms of long-term impacts, as has been seen in the incidences of pollution and soil degradation in large areas of Southeast Asia (Liu, Pan, and Li, 2015, p. 91). These topics are examined briefly for the case of Southeast Asia, and more extensively for the case of Ghana.

Environmental Degradation

As stated in previous sections, there has already been extensive research done on the potential and applicability of the Green Revolution movement for Sub-Saharan Africa. The overarching view of academics, as summed up by Clemens Breisinger (et al., 2009), is

that the Green Revolution approach to agricultural development is "strongly pro-poor and provides substantial transfers to the rest of the economy, thus providing a powerful argument to raise public expenditure on agriculture to make a Green Revolution happen in Africa." Therefore, this study does not strive to make an assessment of whether the Green Revolution is the 'right' approach to development for Sub-Saharan Africa, or the likely impacts the movement could have on the socioeconomic development of the region.

Instead, the focus is placed on the environmental degradation that occurred in Asia following the Green Revolution, and the related potential for avoiding these in Ghana. The definition applied to the term is that as provided by Duru (2014, p. 18); stating "environmental degradation constitutes a systemic destruction and depletion of the earth's ecological systems such as water resources, mangroves, plants, and natural soil and air, which are the sources of air." Essentially, this concept refers to an ongoing depletion of each of the factors that contribute to a sustainable state of environment.

Some of the factors examined in this study are those of land, water, and air pollution, eutrophication, and the loss in biodiversity. These are examined in relation to the Green Revolution process, in particular for the case of Ghana. Any potential efforts made to avoid the negative experiences of the Asian case are examined through national policies and plans of Ghana, as well as suggested policy in the country provided by AGRA.

METHOD

As stated above, the goal of this study is to gain an understanding of whether proponents for a Green Revolution in Sub-Saharan Africa are taking lessons from the Asian experience, or whether countries in which the process is currently being applied are at a similar risk of issues related to environmental degradation in the long-term. This section will present the chosen design and method for the study, a brief discussion on the sources applied, as well as an overview on the steps to be applied throughout the study.

Design and selection of method

The overarching approach chosen to examine the proposed research questions is that of a primarily quantitative, secondary analysis of existing data. There are several reasons behind this choice in method. Firstly; the time constraints present on a bachelor-level thesis makes it so that a secondary analysis is the most efficient means of examining this topic

(Bryman, 2016, p. 310). Secondly; in this choice of method there is the potential for examining the longitudinal changes present in the two cases in order to get an understanding of how the issues examined have developed over time, something that would not have been possible should a primary investigation been done on data collected first-hand (de Vaus, 2001, p.114). Lastly, and possibly most importantly; the data collected on this topic by researchers and prominent organizations is likely much more extensive and of higher quality than any data I would have been able to collect myself at this point in time, making this approach the most appropriate in ensuring the analysis and conclusions drawn are of as high quality as possible (Scheyvens, 2014, p. 88).

Given the nature of the research questions presented, the research design for the study is in the form of a comparative case study; in which the long-term development of environmental issues stemming from the processes introduced during the Green Revolution in Asia in the late 20th century is compared to the case of contemporary Ghana (de Vaus, 2001, p. 221). It is worth noting that this study could have been conducted using many other research designs, such as a qualitative case study, potentially examining relevant factors such as soil degradation, changes in wildlife patterns, freshwater withdrawals and the quality of available water tables (Bryman, 2016, p. 398). A quantitative approach focusing primarily on nitrogen fertilizer application and the increasing dependency on pesticides were chosen for this study due to their importance in the Asian case, the presence of personal interests, as well as the simple fact that these two indicators have readily available data for both cases, making it possible for a more extensive examination to be done than would have been possible should, for example, freshwater withdrawals have been chosen as the focus.

Sources of data

One of the primary sources of data for this investigation is one of the databases provided by the Food and Agriculture Organization of the United Nations (FAO), FAOSTAT (FAO, 2017). This database contains large amounts of data related to agriculture and various indicators involved in agricultural processes. The data gathered from this database are that of crop yields, fertilizer application rates, and changes in the use of pesticides.

For each of these indicators a specific item was chosen as the focus, as the database includes incredibly vast amounts of data, and including every potential factor in each of these indicators would have resulted in more data than is possible to manage within the timeframe allowed. For crop yields the chosen item to focus on was that of total cereal

production, as cereals and grains make up a significant part of the diet in both cases selected. For fertilizer application that of nitrogen-based fertilizers were chosen, as this is the one of most significance in the context of the Green Revolution process, as well as the environmental impact. Lastly, rather that dividing the data on the last indicator into insecticides, fungicides, herbicides, and the many other versions, all based on different substances, it was chosen to examine the total pesticide application for both cases.

Another important source for this study is that of AGRA's Ghana Operational Plan (2017). This extensive document is applied in examining the work done by AGRA in Ghana relating to Green Revolution promotion, as well as when examining the environmental and agricultural policies introduced by the Ghanaian government, and the potential plans for future work on the topic. This document also provides some relevant contextual information.

Various other documents are applied as well, for example that of the 'Climate Change Adaptation Policy in Ghana: Priorities for the Agriculture Sector', as well as similar sources as provided by the Ministry of Food and Agriculture in Ghana (Sova et al., 2014). Likewise, a wide range of academic articles will be applied both to gain necessary contextual information for both cases, but also to complement the findings of the quantitative examination of collected data. Several pieces of geographical literature are also applied as a means of gaining relevant background information on the areas and topic, mostly for the case of Ghana and Sub-Saharan Africa.

Steps involved in study

The steps in this study follow the order of the listed sub-questions. For the first question, in which the focus is on Southeast Asia, two factors are examined; that of rates of nitrogen fertilizer application, and pesticide usage. Changes to crop yields is also examined as a means of connecting these two aspects; but is as a factor on its own not as significant. This data is examined through the creation of line graphs, as well as an examination of data tables and calculations of percentage changes between different years. The analysis for the second sub-question follows the same steps as seen for the first question, only with an extended analysis section in order to properly examine the implications of the comparisons drawn between the two cases. Given the inherent overlap of the first two sub-questions they will be analyzed in parallel, in order to present the cases and analysis as clearly as possible.

For the third sub-question, a more qualitative approach is applied in examining the relevant policy implemented in Ghana. The foundation for this section lies in the work

currently being done by AGRA, as they are one of the primary proponents for applying the Green Revolution approach as a means to agricultural development in the region. At this point they have done significant amounts of work in partnership with the Ghanaian government, and the documents provided by the organization provide an extensive overview of the state of the movement in the country.

It is worth noting that while the three sub-questions are clearly separated both in topic and regional focus, the information gathered throughout is to be viewed as a whole, in relation to the overarching research question. This point is especially relevant in the examination of the third sub-question, as the policy currently in place will have strong implications on the predictive aspect of the main research question in determining the likely outcomes of this movement in Ghana.

ANALYSIS

This section will make up the bulk of the examination of the three sub-questions. Due to the inherent overlap in the first two questions these will be examined together, in order to allow for an improved flow of thoughts throughout the text, as well as the integration of the theoretical framework. The third sub-question will be examined separately; and be followed by a brief discussion connecting all three questions.

The Questions;

Sub-Question 1; What environmental impacts have been seen in the case of Southeast Asia due to the processes introduced by the Green Revolution?

Sub-Question 2: What Green Revolution-type approaches have been implemented in Ghana, and how are these likely to impact local environments?

In examining the Asian Green Revolution, all the data applied in this study will be focused upon Southeast Asia. The countries included for Southeast Asia are; Brunei Darussalam, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, Thailand, Timor-Leste, and Vietnam. These were chosen based on the FAO's classification of regions within Asia. This region was chosen as Southeast Asia, together with India, were the some of the first countries to see significant impact from the implementation of HYV strains of rice and maize, whilst the rest of Asia saw growth in these seeds first in the decades following (Pingali, 2012).

It was decided to examine a region rather than an individual country in establishing a case for Asia as countries applied the Green Revolution to different extents; and saw varying results on a country-to-country basis, for a wide range of reasons. It is believed that by examining the data for the Southeast region an estimate of the overall impact of the process can be examined, which can then be efficiently compared to the case of Ghana.

As was introduced in the 'background' section, the primary goal of the Green Revolution was to increase the yields of staple crops through land intensification, as the extensification approach to food production was reaching its limits (Khan and Shah, 2011, p. 630). This included the previously discussed implementation of new technologies, seeds, and agricultural practices was heavily promoted across Asia, having significant impacts on the overall yields seen across the area (Wilson, 2000, p. 816).

For Ghana, the possibility of a Green Revolution-type approach began in 2007 with the introduction of Kofi A. Annan as the chairman of the Alliance for a Green Revolution in Africa (Moseley, 2012, pp. 219). The goals of the movement in Africa are very similar to those expressed in the Southeast Asian case; combat hunger by increasing the production of food through an intensification of agricultural practices, with an emphasis on introducing improved seed varieties and modern technologies aimed to benefit these new seeds. The one main difference in the two movements is the possibility at including genetically modified seed varieties in the push in Africa, rather than relying purely on HYVs (Moseley, 2012, pp. 227). In introducing the two cases this study will first examine the overall changes in cereal crop yields between 1961 and 2015.

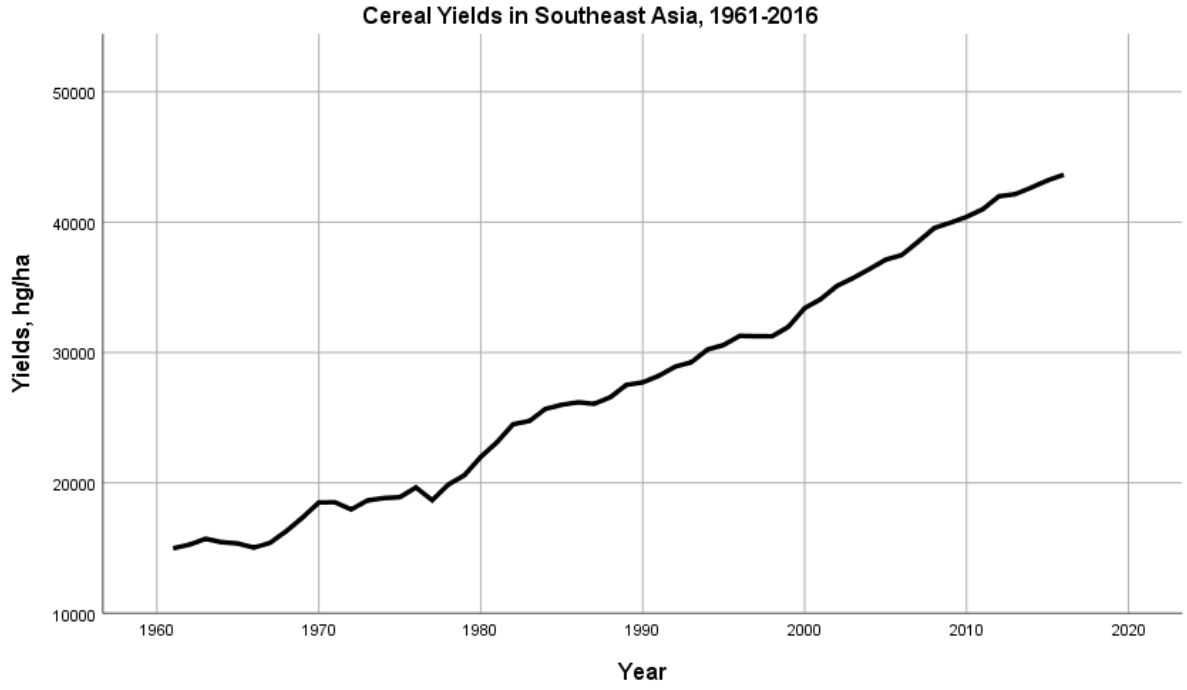
Yield Growth

The first data set examined is focused upon cereal yield changes for both cases. This is chosen as the starting point as the application of modern inputs that affect the environment are done in order to attain the positive impacts on yields, and it is therefore important to first established how these have changed in recent decades. Graph 1.1 shows the yields for cereals in Southeast Asia between 1961 and 2016, expressed in hg/ha, with graph 1.2 showing the same for Ghana. The year 1961 was chosen as a starting point as this is roughly when the Green Revolution is said to have begun, and 2016 is the most recent data available for the region (FAO, 2017). It was decided to focus on the yields of cereals, as the Green Revolution strives to improve strains of staple crops, which commonly focuses on

various cereals and grains popular in the region. In Southeast Asia this primarily focused on rice crops, while Ghana also includes grains such as maize and sorghum.

While it would have been possible to examine fruits, vegetables, and a wide range of other crops, this would have been ineffective for the purpose of making a comparison to the case of Ghana, as the two regions produce entirely different goods outside of the basic staple crops. An overlap can be seen in the reliance upon rice crops both for consumption and income. In Ghana, rice makes up for a significant portion of the income for many farming households, as up to 70% of the rice produced is sold, making it a key crop both for the development of food security for the country, but also in developing its economic conditions (Ragasa and Chapoto, 2016, p. 1).

Graph 1.1: Growth in Cereal Yields in Southeast Asia, 1961-2016



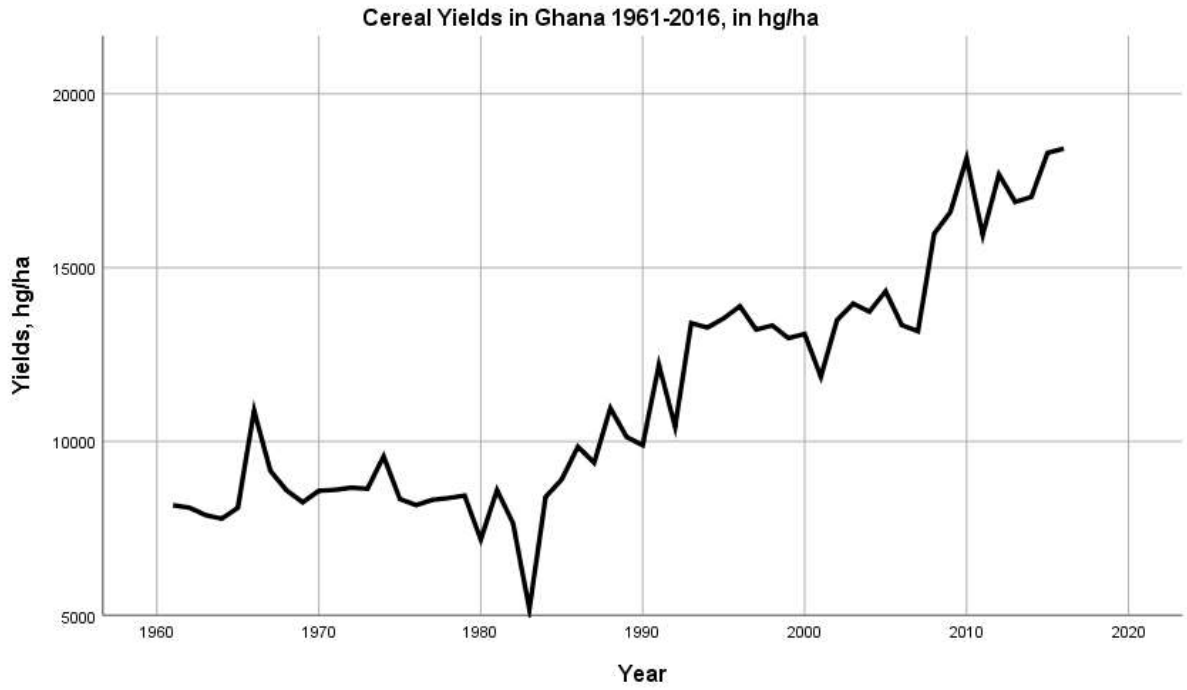
Source: Data points for this graph were collected from FAOSTAT, the agricultural database of the Food and Agriculture Organization of the United Nations. (FAOSTAT, 2017). For full data set, see Appendix I.

From the graph above it is seen that there is a relatively steady linear growth in the overall yields of cereals in the years examined. Between 1961 and 1977 the yield increase is less stable than throughout the rest of the sample, which can be attributed to the fact that the processes of the Green Revolution were still spreading and would have had various levels of

impact in different countries in the early years of its spread (Pingali, 2012). After 1977 the growth is, overall, steadily increasing. While there are some dips in growth, as seen in for example 1987 where there is a slight decrease from 26 182 hg/ha to 26 062 hg/ha, or between 1997-1999 where there was barely any increase in yields, the overall experience is one of impressive growth. In the fifty years being examined cereal yields increased from 14 975 hg/ha per year to 43 649 hg/ha; an increase of more than 190%.

As stated by Lipton and Longhurst (1989); "history records no increase in food production that was remotely comparable in scale, speed, and duration". This rapid increase in crop yields allowed the area not only to avoid the predicted food crisis, but several Asian countries were able to reach self-sufficiency in multiple staple crops where they would previously had had to import goods in order to sustain the population (Wilson, 2000, p. 818). Not only did the measures implemented in the early 1960s allow for the region to avoid widespread famine, but the growth in yields has continued to increase until as late as 2016.

Graph 1.2: Growth in Cereal Crop Yields in Ghana, 1961-2016.



Source: Data points for this graph were collected from FAOSTAT, the agricultural database of the Food and Agriculture Organization of the United Nations. (FAOSTAT, 2017). For full data set, see Appendix I.

From the graph above it is seen that while there is an overall growth to cereal production in Ghana between 1961 and 2016, it is anything but stable. In the production in Southeast Asia, as seen in graph 1.1, the growth in yields was almost linear, but for the case of Ghana several dips and stagnations can be examined to the growth of cereal crop yields. Firstly, it is seen that between 1961 and 1987 production was essentially at a stable level, with very limited increases being visible. Between 1984 and 1993 there is an increase in production by 59.5%, before production yet again stagnates until 2006. After the introduction of the Green Revolution movement in 2006/7 production can be seen to increase yet again, rising from 13 345 hg/ha in 2006 to 18 424 hg/ha in 2016, showing an overall growth of 38%.

The limited growth in the early years can likely be attributed to the overall instability of the country post-independence. Gaining independence in 1957, Ghana went through a number of different regimes before the election of a president through public elections in 2001. Between independence in 1957 and elections in January of 2001 the country also went through four military interventions/revolts, meaning the priorities and policy implementations within the country were anything but stable prior to the 21st century (Country Watch, 2018, and Schraeder, 2004, p. 230)

The growth seen after 2006 can theorized to stem from the relative political stability within the country, as while the president changed twice the ruling party remained the same, as well as the introduction of donor and aid work focused on the Green Revolution approach to agricultural intensification (Ragasa and Chapoto, 2016, p. 2, and Nyang'oro, 2013, p. 258). While the growth seen as of 2016 is nowhere near the growth experienced in Southeast Asia yet, the growth can still be seen as a solid start in introducing the movement in the region. Other than a brief dip in production in 2011, the growth to crop yields has been reasonably stable post- 2006.

In comparing the two graphs it can be seen that the overall pattern of growth in Ghana has been significantly lower than seen in Southeast Asia post-1960s. Up until the 1990s cereal crop yields were fairly stagnant, with a spike occurring first in the 1990s and then again in 2007. However, with the rate of growth seen in the last decade in Ghana it could be expected that yields would continue to grow if the country were to follow similar Green Revolution practices as Southeast Asia did in the long term, as the yield growth for the case of Southeast Asia has been incredibly stable overall, showing few decreases in yields in the time frame examined.

Fertilizer

The second dataset to be examined is that of fertilizer applications. A significant proportion of the growth in yields in both cases can be attributed to the increased usage of chemical fertilizers, as the HYVs could not be fully taken advantage of without the steady, increasing application of fertilizers (Farmer, 1986, p. 176 and Wilson, 2000, p. 819). This means that the implementation of HYVs cause a practical explosion in overall chemical fertilizer consumption (Khan and Shah, 2011, p. 633). In Southeast Asia, the use of fertilizers increased sevenfold between 1966 and 1986, and across the entirety of Asia the average application of fertilizer increased from roughly 42 kg/ha in 1975 to 93 kg/ha in 1985 (Wilson, 2000, p. 820).

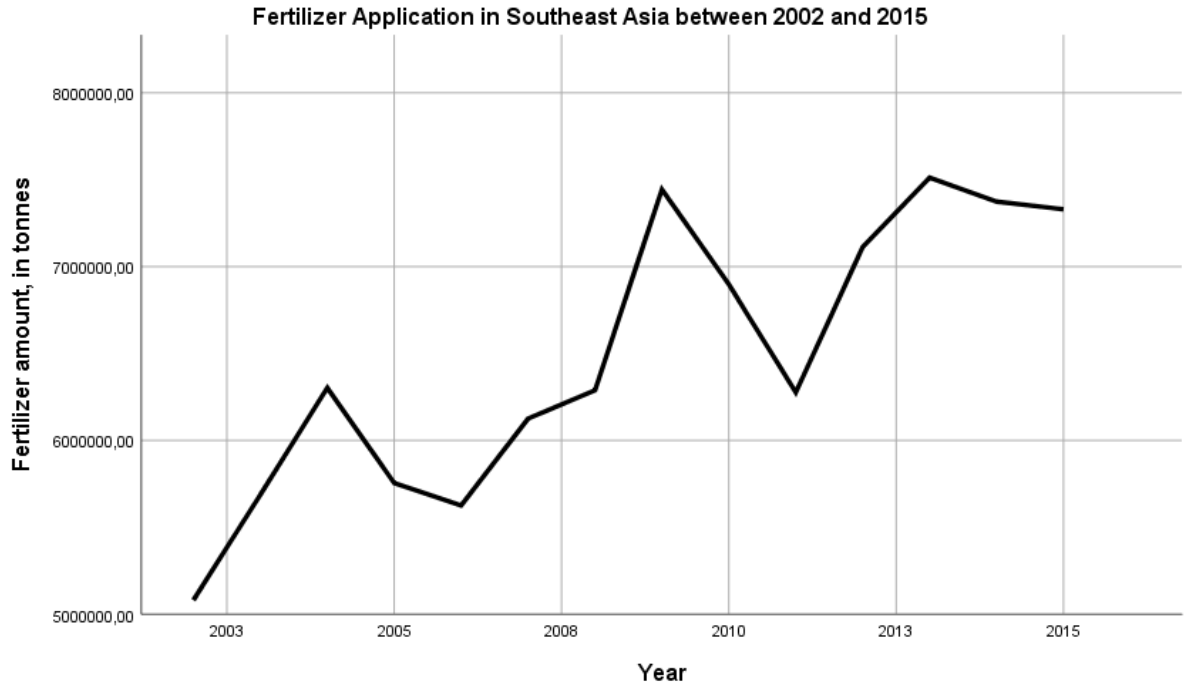
Graph 2.1 shows the changes in fertilizer usage in Southeast Asia between 2002 and 2015. This dataset focuses only on the application of Nitrogen fertilizer, as this is the kind that is used most extensively in relation to HYVs, and is the form of fertilizer which has the most extensive environmental impacts (Farmer, 1986, p. 181). For this variable data was only available post-2000; and while it would have been ideal to have data going as far back as 1960 in order to make a comparison between yields and fertilizer application, the patterns displayed in the available data are sufficient in demonstrating the overall development of fertilizer usage in the region. However, the limited data available does impact the strength of any conclusions or arguments that can be drawn, as the time-frame for which one can examine any changes and pattern is very limited compared to what is available for, for example, changes in crop yields.

Graph 2.2 shows the changes in nitrogen fertilizer use in Ghana between 2002 and 2015. As with the case of Southeast Asia, the introduction of HYVs in Ghana has come accompanied by a growing use of nitrogen fertilizer (Ragasa and Chapoto, 2016, p. 19). With much of Africa's land being very dry, in combination with the growing desertification from decades of human mismanagement of the available land, the use of fertilizers and irrigation technologies quite possibly become even more important in achieving the potential of the HYVs, and in alleviating many of the issues related to human population growth and a lack in food and land availability (Nyang'oro, 2013, p. 257).

In discussing this topic it is important to recognize that an increase in chemical fertilizer applications is not the sole cause of the rapid growth in yields experienced in either case, but rather a supplement to the wide overall range of actions employed. As stated

previously, the Green Revolution package included changes in land use patterns in order to promote the ideal of agricultural intensification, the implementation of mechanization of agricultural practices, spread of HYV of seeds, as well as a widespread development of irrigation infrastructure (Pingali, 2012). Rather than being a driving factor of yield growth, fertilizers were employed in order to maximize the efficiency of the newly-developed HYVs, making its success only relevant in the parallel examination of other related practices. Whilst the quantitative contribution of each individual factor is difficult to establish, nitrogen fertilizers are here chosen as a focus due to its direct relationship to the success of HYVs yield increase, as well as its recognizable impact on environmental degradation (Pinstrup-Andersen and Hazell, 1985, p. 4).

Graph 2.1: Nitrogen Fertilizer Application in Southeast Asia, 2002-2015



Source: Data points for this graph were collected from FAOSTAT, the agricultural database of the Food and Agriculture Organization of the United Nations (FAOSTAT, 2017). For full data set, see Appendix II.

From this graph, it is clear that fertilizer usage in the region is much less stable than what was seen when examining the yield growth. It can be seen that while there are several spikes and drops in the rates at which nitrogen fertilizer is consumed, the overall pattern seen is an increasing one. Between 2002 and 2015 the consumption increases from 5 081 043 tonnes to 7 373 804 tonnes, showing an overall increase of roughly 45%. The instability in consumption can be attributed to several things, including factors such as fertilizer prices, availability of fertilizer to buy, development of new strains of HYVs, or relevant policy changes and donor conditions. Likewise, the political and economic conditions of each country in the region will likely impact the rates of consumption on a year-to-year basis, making the fluctuations in the data likely to be seen in earlier decades of the revolution as well.

As this data displays the usage of nitrogen fertilizer relatively late in the Green Revolution process, it is likely that the growth would have been much more rapid in the earlier years of its development. However, the fact that this is still increasing holds several important implications for the development of further environmental issues as consumption continues to increase.

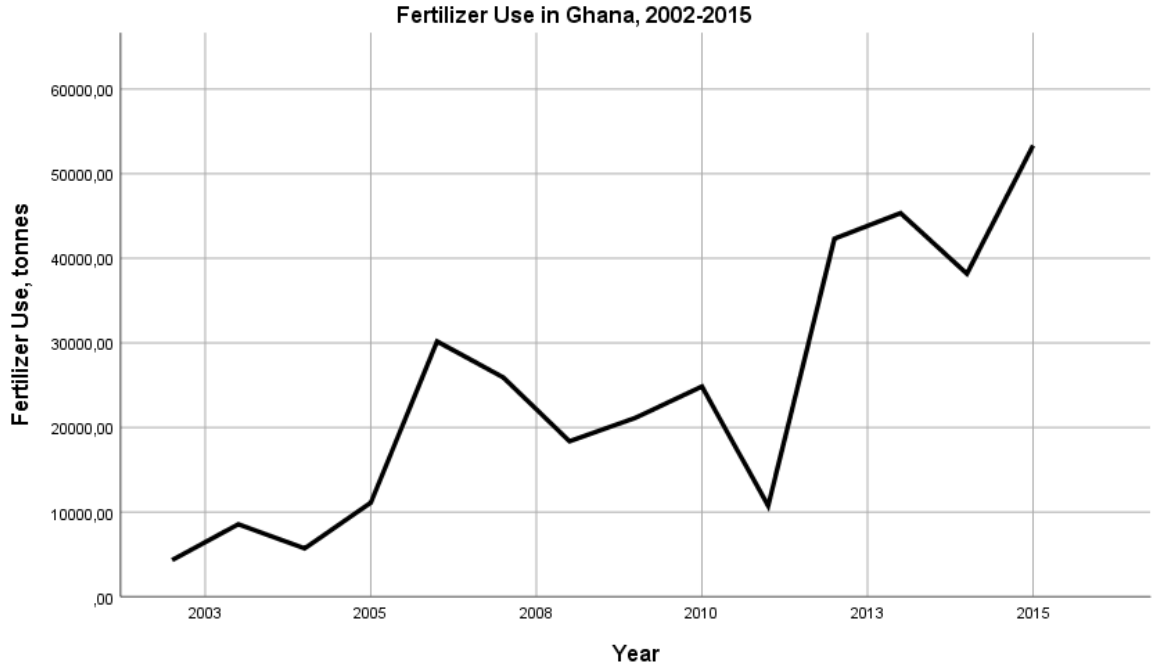
Changes to fertilizer consumption is significant as the continuous use of nitrogen fertilizers is one of the primary contributors to environmental issues in Southeast Asia related to the Green Revolution processes. This is seen especially in examining the declining soil quality from agricultural pollution. As the reliance of seed strains on inorganic fertilizer continues to increase, so does the potential for soil acidification (Khan and Shah, 2011, p. 636). This not only decreases the agricultural potential of the available soil, but as the risk of depleting the naturally available organic matters in the soil grows, the need to continuously increase the amounts of chemical fertilizer continues to increase as well (Wilson, 2002, p. 823). This creates a harmful cycle in which the application of nitrogen fertilizer degrades the soil quality, and in order to continue increasing yields despite this it is necessary for farmers to increase the fertilizer application, furthering the damage done to the land, and so the cycle continues.

In recent decades this has been experienced in Asia in the form of widespread land degradation. Out of the currently used farmland it is estimated that roughly 40% of that land is either moderately or severely degraded (Khan and Shah, 2011, p. 635). The degradation takes several forms, but is most notably seen through a decline in available organic matter in the soil, a loss in soil fertility, a buildup in soil toxicity, and an increased soil salinity from pollution (Liu, Pan, and Li, 2015, p. 84).

Another prominent impact of this excessive inorganic nutrient supply is the water pollution caused through the process of eutrophication. As water moves through the fertilized soils, a process worsened by intense irrigation practices, nitrates seep from the soil into local streams, rivers, lakes, and other water supplies (Bouman, Castañeda, and Bhuiyan, 2002, p. 197). The sudden boost in nutrients results in a spontaneous growth in aquatic flora such as algae, a process which clogs up the waters resulting in widespread depletion of beneficial organisms such as fish and ground-dwelling flora as they get denied access to sunlight and the necessary nutrients for survival (Liu, Pan, and Li, 2015, p. 86 and Wilson, 2002, p. 823). This has resulted in the degradation of water qualities throughout Asia, as well as a loss in overall biodiversity and balance between species. The pollution has also contributed to a growth in the production of ozone, as well as the development of tropospheric smog (Liu, Pan, and Li, 2015, p. 86).

In relating this to the case of Ghana, AGRA does present a goal in which they strive to accomplish adequate water management through the development of inexpensive, small-scale water management approaches to be applied by farmers, as well as the improved management of irrigation techniques (Moseley, 2013, p. 220). This suggests that it could be possible to avoid some issues related to the eutrophication process. This would, however, be dependent upon the way in which the water management projects are implemented. If the goal prioritizes management of water in terms of using smaller amounts it may not have much impact on eutrophication, but if it were to be included in the project process improvements might be developed to better control this issue.

Graph 2.2: Nitrogen Fertilizer Application in Ghana, 2002-2015



Source: Data points for this graph were collected from FAOSTAT, the agricultural database of the Food and Agriculture Organization of the United Nations (FAOSTAT, 2017). For full data set, see Appendix II.

Graph 2.2 above displays changes to nitrogen fertilizer use between 2001 and 2015, and shows a similar pattern to that of cereal crop yields. Up until 2006 there was little or no growth in its usage, but leading up to 2006 there was a rapid spike in the overall use. After a brief decline between 2008 and 2011, nitrogen fertilizer use is seen to be on a steady increase. The most rapid change in use is seen between 2011 and 2013, where the use grew from 10 738 tonnes to 45 343 tonnes, an increase of 322%. Overall, the time frame for which data was available shows a growth of more than 1130%.

There are several judgments that can be made from this data. Firstly, it is likely that the use of modern technologies such as the combination of HYVs, nitrogen fertilizers, and irrigation, would lead to an increase in crop production and allow dry areas of the country to avoid some of the issues related to desertification. However, it is highly unlikely that this could be done without high risks of further environmental degradation in the long run, as well as the issues of cost and threats to human health (Thorburn, 2015). This is especially likely in the case of irrigation application, as heavily irrigated areas are more prone to salinization or alkalization of the available land than may be seen in a case such as Southeast Asia

(Nyang'oro, 2013, p. 258). This would then require additional water to be used in order to flush away the layers of salt, which would present a significant problem in a country such as Ghana where many areas may already face difficulties acquiring sufficient levels of water.

In comparing this pattern to that as seen in the case of Southeast Asia it is clear that both cases show steadily increasing rates of nitrogen fertilizer usage. The actual amounts consumed in Southeast Asia are significantly higher than what is seen in Ghana, with a high of 7 373 804 tonnes compared to Ghana's 53 348, making it crucial to recognize the different stages of the Green Revolution movement the regions were present in the time frame exhibited through the data. In 2002 Southeast Asia, as well as being a collection of a number of countries, had already been involved in the Green Revolution approach since the early 1960s. The movement first started gaining ground in Sub-Saharan Africa after 2006, and is therefore still in the early stages of its development (*Information Communication…,* 2018). With the increases seen post-2011 especially, it is notable that if the current patterns are to continue as they have been in the future, Ghana will likely accomplish significantly higher levels of nitrogen fertilizer consumption than are present currently within the country.

In examining the relatively low levels of fertilizer consumption of Ghana, as well as many other African countries in comparison to that of Southeast Asia, Carol B. Thompson (in Moseley, 2012, p. 225) presents a compelling thought. Thompson questions the application of similar strategies as seen in Asia's Green Revolution for Africa, given the extent of environmental destruction documented, wondering "what if we decided that Africa's lack of use of fertilizer is a sign of sustainable development, not of backwardness?" Questions such as this bring into play vital concerns regarding if the environmental and health-related risks of the technological package required in order to fulfill the potential of HYVs is truly worth it. This relates primarily to the use of chemical fertilizers, pesticides, and widespread irrigation (Pingali, 2012).

Related to this, several studies have been done examining the impact of nitrogen fertilizer application in various crops within Ghana. One example of these is the study done by Ragasa and Chapoto (2016, p. 5), in which they investigate the limitations to a Ghanaian rice Green Revolution in examining the impact of factors such as fertilizer application and its effect on yields, as well as factors such as pesticide application and irrigation. From this study it is stated that each kilogram of nitrogen fertilizer applied to a rice plot result in a yield of 27 kilograms more than would be experienced without this fertilizer application. It is found that the impact on yield growth decreases per each additional kilogram of nitrogen fertilizer

applied, with the peak being at roughly 270 kg/ha in irrigated areas (Ragasa and Chapoto, 2016, p. 20).

A study showing the opposite results is one conducted by Daramy (Sarkodie-Addo and Dumbuya, 2017), in which the relative effects of nitrogen and phosphorous fertilizer on both the overall growth and yield of Cowpea crops in Ghana is examined. Cowpea were chosen as it is one of the primary grain legumes used for crops in the developing world, as well as the fact that it is a popular crop choice for its reputation of improving the fertility of soil due to its ability to fix atmospheric nitrogen (Daramy, Sarkodie-Addo, and Dumbuya, p. 39). Through this study it was found that the amount of nitrogen fertilizer applied had no significant impact on the growth or yield of the crop, suggesting that the natural nitrogen fixation may be sufficient for growth in cowpea. This could suggest that scheduled nitrogen fertilizer application may in some cases be entirely unnecessary, depending on the soil and crop, and may be creating risks to the local environment where there does not need to be one (Daramy, Sarkodie-Addo, and Dumbuya, 2017, p. 41).

However, the results of this study directly contradict the results of studies such as the one by Abayomi (et al., 2008), in which it was found that nitrogen fertilizer application greatly increased the growth and yield of cowpea crops, albeit in a different country, so it is likely further research will be necessary in order to come to a sound conclusion on the necessity of chemical fertilizers in a Green Revolution-type agricultural development. Likewise, as these studies focus on different food crops it is likely that research would need to be done on the nitrogen efficiency on increasing crop yields of each individual staple food crop that is chosen as a focus for the agricultural intensification movement, as both research groups agree that the efficiency of nitrogen fertilizer application varies depending on a variety of factors such as soil fertility, availability of irrigation or rain, type of planting employed, as well as the type of improved variety used in each case (Ragasa and Chapoto, 2016, p. 34, and Daramy, Sarkodie-Addo, and Dumbuya, 2017, p. 40)

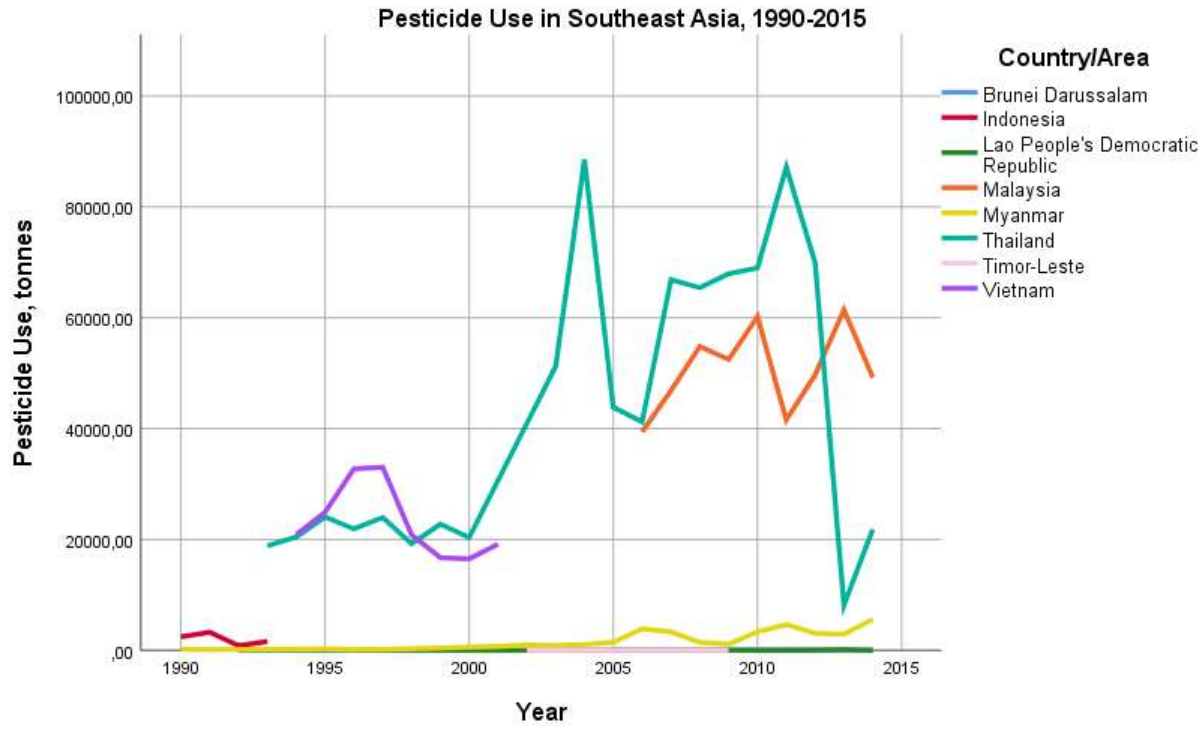
Pesticides

The role of pesticides in Southeast Asia's Green Revolution is very similar to that of nitrogen fertilizers. The many benefits of HYVs are paired with the fact that these strains have a significantly lower resistance to pests and disease than natural strains, meaning that in order to fulfill their full potential they require not only continuous fertilizer applications, but also that of pesticides, herbicides, fungicides, and similar substances (Estudillo and Otsuka, 2006, p. 124).

Graph 3.1 shows the changes to pesticide application in various countries in Southeast Asia. For this data set it was decided to exclude rates of herbicides, fungicides, and other substances, as the available data for these were much less extensive than that of pesticides and would be unlikely to have shown any relevant patterns. Unlike the previous graphs, in which the region was examined as a whole, this chart shows values for individual countries. This is due to the fact that pesticide usage varies significantly between countries; and showing the average of these would not provide an accurate representation of what the distribution is throughout the area (Bouman, Castañeda, and Bhuiyan, 2002, p. 194).

Likewise, as pesticide usage is a fairly controversial topic there is not extensive data available for many countries, and the range of the years in which data is available varies greatly between cases. However, it is believed that for the purpose of this study an examination of this available data still provides sufficient and valuable insight into the overall development of pesticide usage within the region.

Graph 3.1: Pesticide Consumption in Southeast Asia, 1990-2015



Source: Data points for this graph were collected from FAOSTAT, the agricultural database of the Food and Agriculture Organization of the United Nations (FAOSTAT, 2017). For full data set, see Appendix III.

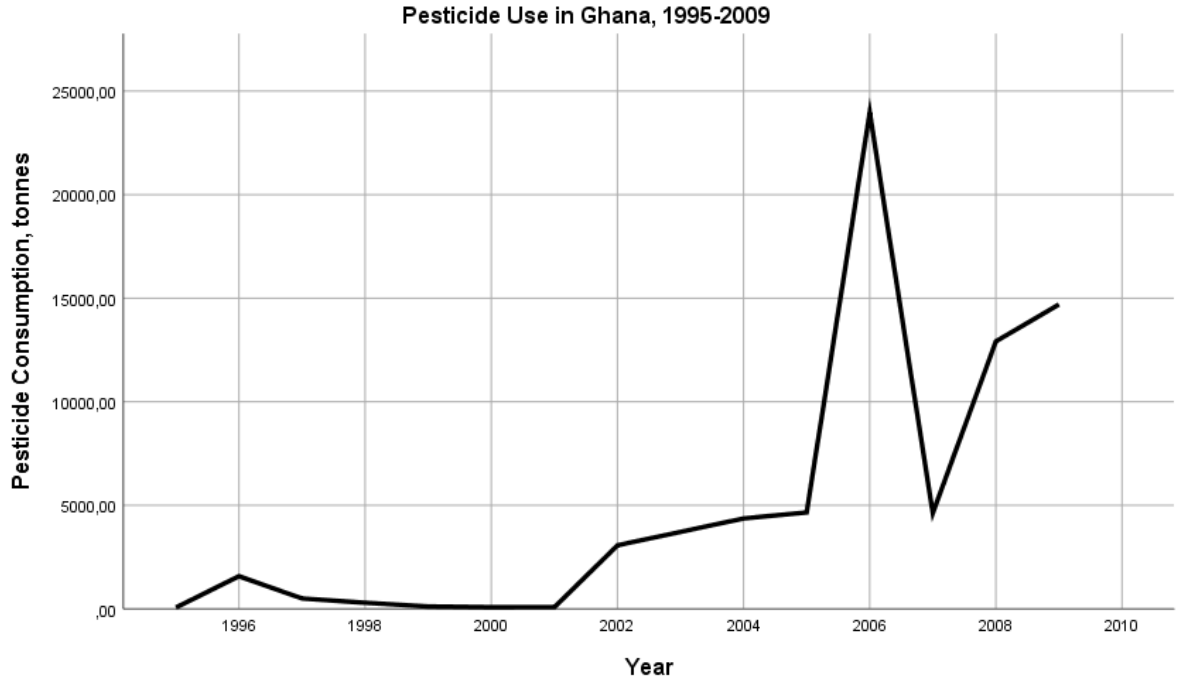
From this graph it can be seen that available data on pesticide consumption is, at best, limited, and varies greatly between countries. Thailand is the one case in which a reasonable amount of data is available, and shows a rapid increase between 2000 and 2004, as well as 2007 and 2011. Post- 2011 a rapid decrease is shown, with hints at a slight increase afterwards. Myanmar, Laos, Indonesia, and Timor-Leste show such slight usage of pesticides in comparison to the other cases that they are barely relevant at this point. As Southeast Asia barely used pesticides prior to the Green Revolution it is likely that the most significant changes would be observed prior to 2000, which is the decades in which not enough data is available in order to make any concrete observations. Regardless, as it is known that pesticide consumption increased drastically in Southeast Asia during the Green Revolution it can be concluded from the data viewed in this study that while there is a large variation in amounts applied between countries based on the data that is available, each country has seen some increase throughout the years.

In combination with the introduction of HYVs, pesticides were heavily incentivized throughout Southeast Asia through means such as subsidies, tax cuts, and various agricultural programs that were established (Khan and Shah, 2011, p. 636). Throughout recent decades the use of pesticides in Southeast Asia has increased by as much as 35-40% for some countries, and it is expected to continue to rise (Liu, Pan, and Li, 2015, p. 83). This is due to several reasons. Firstly, with the shift to mono-cropping pesticides were commonly applied based on a schedule rather than incidences of increased pests or diseases, which caused issues in native fauna populations as the pesticides entered local food chains (Smith, 1972, and Khan and Shah, 2011, p. 636). In several cases the pollution caused a rapid decrease in native predator species, creating an imbalance through which pests were allowed to thrive, requiring even larger applications of pesticide in order to protect the crops (Wilson, 2011, p. 826). This created a cycle similar to what was seen in fertilizers.

This effect could also be seen when examining the relative size of different pest populations. When focusing on suppressing a primary pest species within an area, it is possible that the reliance on pesticide to control this population may instead allow another species to thrive, as was seen in the rice brown plant hopper explosion in the 1970s (Lichtenberg and Nguyen, 2001, p. 2 and Thorburn, 2015). Prior to the 1960s these had been a secondary pest in rice crops, but once an overuse of pesticides and insecticides had been established these were allowed to increase their population sizes considerably, leading to issues of whether further pesticides should be applied in order to manage this new outbreak, or if other means are to be encouraged (Lichtenberg and Nguyen, 2001, p. 20). Resurgences of pests are of significant concern as if they are not managed properly they threaten to undermine the increases in yields that have been accomplished through the Green Revolution package of practices, particularly when occurring in staple crops such as rice and maize (Lichtenberg and Nguyen, 2001, p. 3).

Graph 3.2 shows the changes in pesticide use in Ghana between 1995 and 2009. As is the case for Southeast Asia, the available data for this variable is limited. Ideally, data would have been available at least to the year of 2016 in order to adequately discuss the changes occurring after the introduction of the Green Revolution package in 2007. In order to make up for this, several studies will be applied in analyzing the changes seen in the data, so that any relevant patterns are managed as extensively as possible.

Graph 3.2: Pesticide Consumption in Ghana, 1995-2009



Source: Data points for this graph were collected from FAOSTAT, the agricultural database of the Food and Agriculture Organization of the United Nations (FAOSTAT, 2017). For full data set, see Appendix III.

The graph above shows a fairly stable level of pesticide consumption up until 2005. Between 2005 and 2006 the consumption rate increases by 414%, from 4 654.88 tonnes to 23 972 tonnes, before again decreasing back to the level of 4 626.23 tonnes. After that spike and dip consumption is seen to yet again increase up until the latest data from 2009. Overall, pesticide consumption in Ghana shows significant growth.

As is the case for fertilizer use in Ghana, it is seen that the data available for pesticide consumption is likewise limited. Although extending moderately farther back, starting in 1995 rather than 2002, there is a clear limitation in not having available data examining the changes to pesticide consumption prior to the introduction of the Green Revolution movement, preferably as far back as the introduction of the Green Revolution movement in Southeast Asia in the 1960s. However, it is theorized that this lack in collected data stems from the instability of Ghana, as well as the African continent overall, post-independence, and it is only after the significance of consumption of these substances was established that extensive data collection ensued, which has then likely been supported in

recent decades by the current relative stability of Ghanaian politics (BBC, 2018). As the data does go farther back than the introduction of the Green Revolution movement in Ghana, it is determined the data is sufficient for the purpose of this study, although the clear limitations are identified and included in the development of the analysis.

The growing use of pesticides are possibly the greatest threat to the environment out of the major contributors to the Green Revolution technological package, as it does not only pose a threat in terms of degradation, but also in the area of toxic waste and all the risks this carries with it. One of the contributors to this, as presented by Weir and Schapiro (1981), relates to the lack of established policies regulating the quality of chemicals used within developing countries. The duo states that while the Western world has developed regulation preventing the use of dangerous pesticides outside of certain restricted uses, many developing countries do not have that. This results in these pesticides being shipped off to be used in countries such as Ghana, where the lack of knowledge regarding these chemicals create high risks to human health and the environment. Likewise, the stated lack of regulation, illiteracy, and questionable working conditions in many areas contribute to a situation in which even some of the supposedly 'safe' pesticides can have heavy implications for the wellbeing of the area it is being used in (Donkor et al., 2016, and Pingali, 2012, and Nyang'oro, 2013, p. 258).

Africa is already facing issues related to increased pesticide usage, with the continent having built up stockpiles of up to 50 000 tons of toxic pesticides, which are polluting the soils as well as causing risks for inhabitants on the area (Nyang'oro, 2013, p. 259). A significant amount of these are Persistent Organic Pollutants (POPs), an estimated amount of up to a third of the amount of pesticides present, which remain toxic for extensive periods of time, and are known to move efficiently through the local environment through processes related to water, soil, and air movement (Donkor et al., 2016). While this would cause an issue in any country it is present in, it becomes especially significant for the case of Africa as many countries do not have either the facilities, resources, or knowledge to adequately manage and dispose of these stockpiles (World Bank…, 2003, in; Nyang'oro, 2013, p. 258).

It is worth noting that there have been successful projects implemented with the goal of managing the rising pesticide use. For example, between 1989 and 1999 Indonesia presented an alternative approach through their National Integrated Pest Management Program (IPM) in which the idea of a top-down spread of knowledge was abandoned in favor of a farmer-driven experiential sharing of knowledge, with the goal of achieving "ecosystem

health" and "grow[ing] a healthy crop" (Thorburn, 2015). This project was initiated with the ban of "28 broad-spectrum pesticides in 57 formulations", followed by the forced spread of pest-resistant rice varieties, the introduction of a secondary food crop within rice-producing areas, as well as extensive plans on how to deal with pest outbreaks. Under this program, the application of one of the 10 allowed pesticides was considered a last resort; and was to be done by applying it in target areas, rather than regularly, spread, and over a longer period of time (Thorburn, 2015).

However, since its conclusion the pesticide situation in Indonesia has been anything but favorable to the goals of the project. After the resignation of the President Suharto in 1998, the support for IPM principles has declined significantly in favor of a return to an excessive use of pesticides. Indonesia has since seen a resurgence of brown plant hoppers incidences in the majority of its primary rice-producing regions (Thorburn, 2015). The success of this project while it was active presents several opportunities for the development of ecologically sustainable pest-management programs with the opportunity of working alongside the mechanisms of the Green Revolution movement. However, due to the rapid decline of IPM principles following the resignation of the president responsible for its implementation raises questions similar to that of the possibility of sustaining a Green Revolution-type movement in a manner that preserves ecological viability. This suggests that unless sustainability and environmental management programs are adequately integrated into the plans and policy of Ghana, they are unlikely to survive in the long-term, and are prone to following a similar decline as seen in this example of Indonesia.

Another issue related to the application of pesticides relates to the process of eutrophication, as discussed previously. Although indirect, the application and consequent seepage of nitrogen fertilizer indirectly contributes to increase the use of use in pesticides and herbicides within affected areas. In an attempt to manage the rapid weed growth and increase of aquatic fauna in local water sources, as well as the pests these attract, a common approach is to increase the amount of pesticides and herbicides used within the area (Wilson, 2011, p. 825). Several environmental impacts can be identified from this, including; the furthered pollution of available water sources, destruction of biodiversity of both flora and fauna species within the area, as well as the further buildup in pesticide stockpiles as these water sources travel to other areas, or get used for irrigation and is spread into agricultural soils. There is also the concern of pests eventually developing a resistance to particular types of pesticides, further increasing the risk of losses in yields due to further pest incidences which

are then more difficult to contain, as well as the risks related to the resulting increase in other pesticides, herbicides, and similar chemical substances in order to manage the situation (Smith, 1972, p. 10).

In summary; while the introduction of HYVs has allowed for large increases to be achieved in crop yields, these require constantly increasing amounts of nitrogen fertilizer and pesticide application, along with several other chemical substances, creating an unsustainable situation in which agricultural development is being accomplished at the cost of environmental stability. Through the Green Revolution processes Southeast Asia has encountered issues such as land degradation, desertification, biodiversity losses, as well as the pollution of soils, water, and air (Khan and Shah, 2011, p. 635). Without proper management and balance between development ambitions and ecological sustainability, Ghana is at risk for facing an equally dire environmental situation in the future.

Sub-question 3: How do policy implementations seen in Ghana regarding agricultural intensification and environmental sustainability show efforts being made to avoid the negative consequences experienced in Southeast Asia?

This section will aim to examine the relevant policy formulations related to agriculture, agricultural intensification, and environmental preservation. The thought behind this is to follow up upon the analysis of the previous section, in which what has already occurred is examined, by doing an analysis on the potential outcomes for the future. To do this the section will be divided into three parts; one examining the work done by AGRA in Ghana up to this point, including their planned work for the future and suggested policy implementations, one examining the priorities of the Ghanaian government and the state of agricultural policy, and lastly a section on other relevant institutions present within the country. These will then be followed up by a discussion section tying together the information found from all three sub-questions.

Alliance for a Green Revolution Africa

In examining the work done by AGRA the primary reliance will be upon the most recent document released from the organization; the AGRA GHANA Operational Plan from November of 2017. This document serves to provide information about several key aspects; the strengths and weaknesses of the Ghanaian agricultural and political arena, the goals and interventions of the AGRA projects within the country, and the organization's views for the future (AGRA, 2017).

As previously stated, agriculture makes up a significant portion of employment and GDP income in Ghana. From this AGRA strives to work towards economic growth and development within the country through and intensification and increase in agricultural productivity, with a specific focus on allowing smallholder farmers to develop their practices (AGRA, 2017, p. 12). Their current projects within Ghana are focused within two separate Agro-Ecological Zones; Brong Ahafo, having a high density of farmers as well as being the country's primary producer of cassava, and the Northern Regions, being the primary producers of both rice and maize.

Their projects focus specifically on six different crops, four primary crops and two secondary ones. These include maize, rice, cassava, and soybean, as well as yams and sorghum, respectively (AGRA, 2017, p. 4). AGRA presents four primary goas for their work in Ghana;

“ 1) Increased staple crop productivity for smallholder farmers.

2) Strengthened and expanded access to output markets.

3) Increased capacity of smallholder farming households and agricultural systems to better prepare for and adapt to shocks and stresses.

4) Strengthened continental, regional, and government multi-sectoral coordination and mutual accountability in the agriculture sector. (AGRA, 2017, p. 31)”

These goals show a combination of applying the Green Revolution goals as seen in the case of Asia with addressing the weaknesses of the agricultural sector and its linkages to markets and leading institutions within Ghana. With the significance placed on governmental involvement and the prevalence of ongoing research within the Green Revolution model of development this particular goal seems especially valuable to the development of the movement, allowing possibilities of efficiently consolidating the ties between various organizations and governmental branches in their work to improve agricultural output within Ghana.

A range of interventions are presented as possibilities to accomplishing these goals, most notably; increasing the commercialization of agricultural production, increasing the adoption of relevant technologies to increase productivity, developing a subsidy model in coordination with regional governments in order to allow for relevant technologies to be spread, as well as improving credit access for smallholder farmers, and improving access to relevant market opportunities (AGRA, 2017, p. 4).

From an examination of this document it is first of all important to note that the stated goals, commitments, and interventions include very little mention of any kind of environmental aspect to the work done, nor to sustainability. There is mention of the government’s commitment to the Sustainable Development Goals, as well as a mention of the volatility of food prices due to climate change and variability throughout different regions, but no proposed measures to be taken in ensuring the implementation of yield enhancing technologies is balanced with an environmentally sustainable approach to development

(AGRA, 2017, p. 10). This raises concern of there being a prioritization of growth over environment, the same ideology which led vast areas of Asia to a point of widespread environmental degradation. The reference to the SDGs seems to occur more in arguing for why Ghana is a choice for country with high potential for accomplishing a Green Revolution-type movement, as it was one of the few countries that accomplished the Millennium Development Goal of reducing overall poverty, as well as hunger (Ragasa and Chapoto, 2016, p. 2).

In terms of potential for growth, the work presented by AGRA shows a positive situation with much potential within Ghana. In the ten years they have been developing their projects within the country a technology base has been built, as well as a range of partnerships and development models that could have the potential to significantly improve agricultural growth and development within Ghana. However, it is also stated that the US$31M investment of AGRA makes up less than 1% of what would be necessary in order to obtain a wide-scale agricultural revolution in the country, making its projects lean more towards testing of potential for development rather than a primary driver for development (AGRA, 2017, p. 14). This limits the ability of AGRA itself to work as a driver for agricultural growth within Ghana outside the realm of smaller development and research projects, but the work done thus far does present a favorable view of the potential of the region, given the consolidation of its ideals and goals within the Ghanaian government and leading organizations.

The Government of Ghana

This section will work to examine the presence of environmental concerns within agricultural and national development policies in Ghana. The primary document examined for this is the "Climate Change Adaptation Policy in Ghana: Priorities for the Agriculture Sector" as presented by the CGIAR (the Consultative Group for International Agricultural Research) Research Program on Climate Change, Agriculture and Food Security. While the document is from 2014, it provides a valuable overview of the state of environmental policy post- 2010, after several years have passed since the introduction of Green Revolution-type work within Ghana.

Agricultural policy in Ghana is developed primarily in two different documents; the Food and Agriculture Sector Development Policy (FASDEP II), which serves as a statement of intent for the long-term goals of agricultural development, and the Medium Term

Agriculture Sector Investment Plan (METASIP), which presents an investment framework for the implementation of said goals (Sova et al., 2014, p. 20). FASDEP II was developed in the summer of 2007, with the first period of METASIP having run between 2011 and 2015. Both programmes were developed under the Ministry of Food and Agriculture branch of Ghana's government (Sova et al., 2014, p. 19, and the Ministry of Environment, Science and Technology, 2017).

The goals for investment included a wide range of development themes, such as; improving available nutrition, supporting livelihood diversification, as well as the development of "warning systems and emergency preparedness" (Sova et al., 2014, p. 21). Several goals that relate to the Green Revolution approach are mentioned as well; such as improving agricultural productivity, a mechanization of available services, increased application of modern technologies and the use of biotechnologies in agriculture. Most notably, however, is the inclusion of several environmentally-focused investment focuses, in which the importance of adequate management of irrigation and water usage is mentioned, as well as the goal of increasing overall awareness and the use of "sustainable land management technologies" within agriculture (Sova et al., 2014, p. 21).

While these are listed in the lower ranks of priorities for development goals, the fact that they are present at all presents hope in the priorities of the Ghanaian government in including some manner of environmental management in their development plans. This is especially true in theorizing the growth of these types of policies in the future as environmental concern ideally will continue to rise. The majority of the currently existing, or planned, policy within the country have occurred post- Rio Convention in 1992, showing a significant growth of environmental policy within Ghana despite its current status as a developing country (Hens and Boon, 1999, p. 1).

An example of the type of policy recently run in Ghana is the Northern Rural Growth Programme (NRGP), a joint initiative that was developed by the African Development Bank, the Ghanaian Government, as well as the International Fund for Agricultural Development. Running between 2007 and 2015, the main goal of the program was to contribute to sustainable development in rural areas of Northern Ghana, with a focus on poverty reduction and food security (International Fund for Agricultural Development, 2015, and Sova et al., 2014, p. 24). While the program was not specifically labeled as an environmental or climate change-related program, it did reference both throughout; promoting the importance of adapting practices related to irrigation, as well as the conservation of soil

and water resources in order to preserve local environments (African Development Fund, 2007, p. 3). Similarly, and unusually for development projects in developing nations, the NRGP also included the need for a "Strategic Environmental Assessment" both for the NRGP and the FASDEP project (Sova et al., 2014, p. 25). Initiatives such as this show respectable focus of the local government in promoting the importance of environmental sustainability as well as that of economic and agricultural development, and although these are at this point running in cooperation with various international organizations it is a clear starting point for the Ghanaian government in potentially accomplishing a sustainable development for the country.

Other Relevant Institutions and Initiatives

The institutional scene in Ghana has a number of established environmental organizations, all fulfilling different roles in policy creation and maintenance. The EPA manages both the regional and the international initiatives and climate change conventions of the United Nations Framework Convention on Climate Change (Country Watch, 2017, p. 256). The Ministry of Environment, Science, Technology and Innovation (MESTI) house the National Climate Change Council of Ghana, who are in charge of developing and promoting the National Climate Change Policy, as well as being in charge of implementing the EPA (Ministry of Environment, Science, and Technology, 2012). Lastly, there is the Ghana Environmental Conventions Coordinating Authority (GECCA), which was established in order to coordinate and manage the Rio Conventions, as well as ensuring synergy in the management of the 35 international environmental conventions that Ghana has signed (Sova et al., 2014, p. 25).

Similarly to the development of FASDEP II and METASIP, these institutions have contributed to the development of two significant initiatives; the National Climate Change Adaptation Strategy (NCCAS), and the National Climate Change Policy. NCCAS was developed in cooperation with the United Nations Environment Programme and the United Nations Development Programme; and includes ten primary programmes covering multiple sectors (Ministry of Environment, Science and Technology, 2012, p. 13). Related to agriculture, the strategy presents several goals similar to those shown by the Ghanaian government, such as improving overall living standards and increasing crop yields (Sova et al., 2014, p. 29).

The development of a national climate change policy in Ghana is reliant primarily on the results of NCCAS, and is developed into three stages. The results of the first stage presented the implementations discussed in the previous paragraphs. Stage two will develop these results into a range of initiatives and actions to be implemented to improve the policy, and stage three will elaborate upon how the initiatives identified in the second stage can be further spread and included across the country (Sova et al., 2014, p. 30). At this point this policy is still being developed, with a six-year expected draft period being established in 2014, and stages two and three are currently developing.

Differing from the policy of the official government, the NCCAS also includes a wide range of environmentally-specific strategy implementations, including; to "build and strengthen capacity of local farmers to increase agricultural productivity and awareness of climate issues", "protect the environment through the promotion of agricultural biodiversity", and to "document existing indigenous knowledge and best practices" (Sova et al., 2014, p. 29). Goals such as these share similarities with policies only now coming into place within the so-called developed world, putting Ghana in a positive position to managing development in that there is some manner of policy being developed that includes goals important to the notion of sustainability, rather than solely focusing on achieving economic growth as rapidly as possible.

Likewise, these three examples of goals presented in NCCAS share a striking similarity to the recommendations provided by academics studying the environmental impacts of the Green revolution in Southeast Asia. For example, Khan and Shah (2011, p. 641) suggest targeting farmers knowledge through education on sustainable farm management approaches and striving to increase overall awareness of the relationship between agricultural practices and the state of the environment. Liu (Pan, and Li, 2015, p. 91) suggests the implementation of a biological pest control, such as those present in some forms of rice production where certain kinds of fish are used both to manage local pest populations as well as to provide an additional source of protein for farmers. This could be interpreted as a point showing that the policy development scene in Ghana is taking advantage of lessons learned from other regions in the past, but the question of whether these will be applied to the process of agricultural growth remains.

The establishment of these types of initiatives and policies could prove significant for the development of ecologically sustainable agricultural growth, as the management of land resources, biodiversity, pollution, and similar factors could pave the way

for the development of an approach to growth that differs from the Green Revolution strategy in the potential for sustainability of the project in the long-term. If this range of environmental institutions and environmentally-minded policies within Ghana were present within project planning to the extent the policy documents suggest, it would be possible to state that the implementation of Green Revolution technologies would likely be monitored, modified, and assessed regularly in order to conform to the standards set by the policies presented. However, this raises the question of the relative efficiency and mainstreaming of the projects in practice. While a set of goals and intended actions can look full off potential on paper, it is difficult to judge how well these will in fact be implemented, and to what extent.

Similarly, as the National Climate Change Policy has only been existent since 2012, it is difficult to make any well-informed, clear assessments of the extent to which the policy is succeeding in managing its goals. This holds true for much of the relevant environmental policy in Ghana, as if it has not been fully established yet no conclusive judgements can be made on the level of impact such a policy can have nationally, but in terms of goals, proposed actions, and overall focus of the policy on paper, there does seem to be a potential for the Ghanaian government to have the capacity to manage development in a sustainable manner.

DISCUSSION

From this analysis, it is seen that the environmental policy environment within Ghana is quite extensive, showing a wide range of goals related to a number of different areas linking into environmental sustainability, climate change, and agricultural practices in general. While the policies do not share any single priority or goal that's seen across all of them, it is possible to identify several key points that are present in the majority. These include the focus on spreading awareness of environmental impacts of agricultural activities, improving the capacity of farmers, improving the overall management of land resources, as well as continuing to develop relevant HYVs and other improved seed varieties. These findings are consistent with what is established in the analysis done by Sova (et al, 2014, p. 44).

The presence of these types of goals suggests a movement away from the top-down semi-enforced spread of Green Revolution technologies and practices as seen in Southeast Asia, and instead favors a development focused more on the farmer-level. In developing the movement with a sound foundation in the knowledge and abilities present in

the farming population already, it could be possible that the benefits of the introduction of modern technologies could be experienced whilst simultaneously applying knowledge gained from increased environmental awareness to maintain the ecological integrity of the land farmed. Likewise, a movement built from the farming level and up would also have the potential to allow some level of adaptability to the movement to each area it is implemented, as the long-term farmers within the region will have greater knowledge of the area in question than would be found in a situation where an identical copy of the movement is implemented across a wide range of areas, each displaying different contexts and having different needs.

In particular, the goal to continue to develop improved seed varieties suggests that lessons are being drawn from the experiences in Southeast Asia, as well as Asia as a whole. During the movement in Asia, successful HYVs of common food crops were implemented across several countries and regions, with varying success between countries as they each have different ecological conditions, and abilities to supply the crops with the modern inputs necessary to experience the full benefits possible (Khan and Shah, 2011, p. 637).

In several studies on the case of Asia it is suggested that one of the most important lessons to learn from this is the necessity to continue developing strains suitable to independent regions, as well as furthering the development of strains that are more pest resistance, have a greater resistance to disease, or that simply show improved quality of grains to previous strains. (Estudillo and Otsuka, 2006, p. 145) If this were to be implied in practice, it would also be possible to avoid some of the environmental impacts related to the overuse of inputs such as chemical fertilizers and pesticides, as these crops would have the potential to require smaller amounts of these inputs in order to provide successful yields.

However, these developments are entirely dependent on the efficient spread of the goals discussed above; that of awareness, environmental knowledge and management, and the development and accessibility of improved seed varieties. If these are developed inefficiently Ghana stands in a similar position to Southeast Asia, where there is potential to acquire agricultural intensification, but at the cost of the degradation of the local environments. Estudillo (and Otsuka, 2006, p. 145) summarizes this view in stating “the spark of Green Revolution in Africa … might not be sustained in the long run without further improvement of varieties and production practices at the farm level”.

A clear limitation to the potential for Ghana successfully developing a framework for long-term, ecologically sustainable agricultural development lies in the heavy involvement of various development agents in the country, and their role in the development of the country's policy agenda. A significant amount of the national budget, estimated to number up to 40%, is at this point in timed supplied by a range of international agencies independent of the Ghanaian government, and the incentive of creating the country's first climate change policy was introduced almost entirely by these actors (Sova et al., 2014, p. 64). The involvement of the Ghanaian government has increased throughout the development of these policies, which brings into question the level of ownership and the potential for sustainability for policies related to climate change and environmental sustainability within the country. However, it could also be interpreted as outside actors introducing important incentives to the country and the local Government learning from this knowledge and continuing to develop upon the idea to suit the local environment. Making an accurate judgement of the status of this is, however, difficult to do as the relevant policies have at this point in time either not being active for very long; or has not yet been implemented in practice.

In developing a policy environment in which projects can attain long-term sustainability would also require the spread of awareness and environmental knowledge beyond farmers, governmental workers, and relevant policymakers, to also include the general public. Currently, the prevailing view of the importance of the environment is primarily in the form of "the environment as sanitation". While this has resulted in several successful project initiatives in urban areas of Ghana, through which environmental management has been promoted to achieve higher levels of sanitation throughout cities, it places limitations on the potential of environmental policies being successful in the long run (Sova et al., 2014, p. 65). It would be necessary to create an increased focus on the importance of factors such as biodiversity loss and the role of sustainable land management in contributing to agricultural development if support for important policy implementations is to remain significant enough to achieve long-term changes in practices throughout Ghana.

CONCLUSION

Through the development of this study, there are several significant findings that can be identified. Firstly, it is seen that in Southeast Asia several environmental issues have occurred post- the Green Revolution movement, most significantly those of land degradation, pollution, and losses in biodiversity. These have occurred primarily due to excessive uses of nitrogen fertilizers, pesticides, and unsustainable land management practices. Through the examination of these factors for Ghana it is seen that Ghana has similarly been experiencing large increases in nitrogen fertilizer and pesticide applications since the introduction of the Green Revolution movement in the country, as well as a significant growth in cereal crop yields. This, accompanied by the fact that AGRA priorities are focused primarily on yield growth and market linkages with little or no policy initiatives related to environmental sustainability, presents a situation in which there are limitations to the potential of Ghana achieving a sustainable long-term development that does not harm environmental stability.

However, an examination of relevant policy document reveals that there is an extensive plan in place for environmental organizations and policies in Ghana, and although many are not fully established there is being work done on the topic. Likewise, Ghana is signatory to a large number of international UN environmental conventions, and has shown great open-mindedness in allowing the involvement of international actors and the implementation of development projects. As is the case for any type of policy, there is the limitation of being unable to determine how widespread and efficiently the goals are applied in practice, but it is worth noting that Ghana is at this point in time significantly further along the path of environmental policy development than would have been seen in Southeast Asia in the 1960s.

These discoveries contribute to the field in several ways. Firstly, it serves to fill the knowledge gap existent in the prevailing focus on whether the Green Revolution is applicable at all to the African case, excluding the importance of the environmental factors related to the movement. Secondly, it is established that Ghana, albeit on paper, seems to be in a fairly positive position to develop a Green Revolution with fewer environmental risks than seen in Southeast Asia. If they were to succeed this information could provide a foundation for frameworks in other developing countries reliant on agriculture for growth.

So where do we go from here? It is the view of the author that the issue is no longer whether a Green Revolution is necessary or relevant to the African case, but rather

how to promote agricultural and economic growth that does not come with the cost of extensive environmental destruction. Rather, the importance now lays in furthering the amount of research related to topics such as the necessity of nitrogen fertilizer applications and pesticides, as well as the further development of modern seed varieties that are suitable for the areas in which they are being implemented.

With the potential shown in Ghana the question instead becomes how to adapt these approaches to fit the individual contexts of Sub-Saharan Africa, as this region shows much greater variability both in environment, socioeconomic contexts, and the political status, and with the focus of environmental management it becomes important to involve local governments in developing relevant policy initiatives. In summary, it can be stated that Ghana shows great potential for the development of a long-term, ecologically sustainable Green Revolution type movement, showing hope for the sustainable development of agriculture throughout the African continent. However, this will require great amounts of cooperation both internationally and locally, and a focus will need to be placed on allowing the African governments and farmers to claim ownership for the long-term development and adaptation of the movement to local contexts.

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APPENDICES

Data for this thesis originates from FAOSTAT, the agricultural statistics database run by the Food and Agriculture Organization of the United Nations.

APPENDIX I: Data on Cereal Yields in Southeast Asia and Ghana, 1961-2016

Country	Year	Cereal Crop Yield (hg/ha)
Southeast Asia	1961	14975
	1962	15258
	1963	15711
	1964	15447
	1965	15350
	1966	15036
	1967	15411
	1968	16317
	1969	17349
	1970	18501
	1971	18513
	1972	17959
	1973	18656
	1974	18835
	1975	18907
	1976	19647
	1977	18667
	1978	19876
	1979	20598
	1980	21990
	1981	23116
	1982	24500
	1983	24745
	1984	25681
	1985	25988
	1986	26182
	1987	26062
	1988	26574
	1989	27526
	1990	27712
	1991	28224
	1992	28917
	1993	29252
	1994	30233
	1995	30580
	1996	31276
	1997	31254

Southeast Asia	1998	31246
	1999	31975
	2000	33412
	2001	34098
	2002	35114
	2003	35721
	2004	36398
	2005	37125
	2006	37483
	2007	38500
	2008	39547
	2009	39962
	2010	40410
	2011	40996
	2012	41992
	2013	42147
	2014	42654
	2015	43203
	2016	43649
Ghana	1961	8164
	1962	8096
	1963	7882
	1964	7776
	1965	8092
	1966	10887
	1967	9161
	1968	8593
	1969	8248
	1970	8582
	1971	8607
	1972	8671
	1973	8637
	1974	9571
	1975	8343
	1976	8167
	1977	8320
	1978	8372
	1979	8442
	1980	7178
	1981	8600
	1982	7640
	1983	5174
	1984	8401
	1985	8907
	1986	9848

Ghana	1987	9386
	1988	10958
	1989	10129
	1990	9892
	1991	12208
	1992	10421
	1993	13402
	1994	13275
	1995	13541
	1996	13892
	1997	13217
	1998	13338
	1999	12970
	2000	13092
	2001	11861
	2002	13490
	2003	13964
	2004	13733
	2005	14323
	2006	13345
	2007	13170
	2008	15981
	2009	16598
	2010	18143
	2011	15942
	2012	17681
	2013	16888
	2014	17034
	2015	18303
	2016	18424

APPENDIX II: Data on Nitrogen Fertilizer Use in Southeast Asia and Ghana, 2002-2015

Country	Year	Amount used, in tonnes
Southeast Asia	2002	5081043,00
	2003	5687836,00
	2004	6302550,00
	2005	5754934,00
	2006	5626012,00
	2007	6125593,00
	2008	6288493,00
	2009	7443879,00
	2010	6897936,00
	2011	6276364,00
	2012	7113070,26
	2013	7511840,34
	2014	7373804,88
	2015	7329806,57
Ghana	2002	4330,00
	2003	8559,00
	2004	5702,00
	2005	11105,00
	2006	30171,00
	2007	25924,00
	2008	18374,00
	2009	21160,00
	2010	24835,00
	2011	10738,00
	2012	42320,00
	2013	45343,00
	2014	38177,00
	2015	53348,04

APPENDIX III: Data on Pesticide Use in Southeast Asia and Ghana, 1990-2014

Country	Year	Amount used, in tonnes
Brunei Darussalam	2005	2,10
	2006	9,92
	2007	13,65
	2008	5,98
	2009	27,93
	2010	38,49
	2011	9,06
	2012	1,62
	2013	11,97
	2014	20,54
Indonesia	1990	2432,00
	1991	3259,00
	1992	825,00
	1993	1597,00
Lao People's Democratic Republic	1992	21,00
	1993	46,00
	1994-1996	**N/A**
	1997	4,38
	1998	0,66
	1999	N/A
	2000	1,28
	2001-2005	**N/A**
	2006	4,33
	2007	0,44
	2008	0,07
	2009	25,67
	2010	1,83
	2011	43,80
	2012	43,53
	2013	125,89
	2014	3,00
Malaysia	2006	39406,48
	2007	46868,35
	2008	54821,91
	2009	52464,19
	2010	60194,83
	2011	41562,16
	2012	49710,48
	2013	61445,60
	2014	49199,43

Myanmar	1990	209,08
	1991	114,00
	1992	151,18
	1993	160,33
	1994	190,00
	1995	264,76
	1996	137,24
	1997	145,54
	1998-2000	**N/A**
	2001	694,89
	2002	949,06
	2003	858,94
	2004	1042,39
	2005	1448,85
	2006	3872,16
	2007	3329,67
	2008	1419,16
	2009	1091,08
	2010	3340,09
	2011	4642,42
	2012	3044,78
	2013	2898,20
	2014	5583,40
Thailand	1993	18849,00
	1994	20448,00
	1995	24062,00
	1996	21901,00
	1997	23960,00
	1998	19212,00
	1999	22761,00
	2000	20334,00
	2001-2002	**N/A**
	2003	51221,00
	2004	88548,00
	2005	43831,00
	2006	41220,00
	2007	66858,00
	2008	65423,00
	2009	67933,00
	2010	68986,00
	2011	87191,00
	2012	69921,00
	2013	8136,00
	2014	21800,00

Timor-Leste	2002	,06
	2003	2,30
	2004	0,82
	2005	0,70
	2006	**N/A**
	2007	2,47
	2008	1,39
	2009	1,78
Vietnam	1994	20912,00
	1995	24896,00
	1996	32745,00
	1997	33019,00
	1998	20841,00
	1999	16695,00
	2000	16502,00
	2001	19154,00
Ghana	1995	65,8
	1996	1575,5
	1997	502
	1998	297,78
	1999	114,13
	2000	81,63
	2001	82
	2002	3068
	2003	**N/A**
	2004	4364,52
	2005	4654,88
	2006	23972
	2007	4626,23
	2008	12913
	2009	14701,55

Note; This particular data set has great variation in availability and extent of data for each country. In light of this, the study made use of the available data as efficiently as possible, and supported the thoughts drawn from these with additional research into previously done studies in the relevant areas.