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Improving Maize Production in Tanzania Using Cell Phone & Computer Vision Technology

Introduction

Our current world population of 7 billion is expected to increase to 9.7 billion by the year 2050 (1). More than half of this population growth is expected to occur in Africa (1). Tanzania is a major developing country in East Africa, located on the Indian Ocean between Kenya and Uganda to the north, Rwanda, Burundi, and the Democratic Republic of Congo to the west, and Zambia, Malawi, and Mozambique to the south (2). With a land area slightly more than twice that of California, Tanzania has a current population of about 52 million (2). Tanzania's population is estimated to increase to 90 million by 2038, and it is one of 10 African countries where population is expected to increase five-fold by 2100 (1). With this rapid population growth, it will be critical to increase agricultural yields to maximize food production and lessen the risk of food insecurity.

Maize is the most important cereal crop in sub-Saharan Africa (SSA) including Tanzania and an important staple food, providing 25% of total calories in the average diet (3). While in industrialized countries maize is often used in animal feed and for raw materials in industrial production, in SSA maize is often consumed directly in the human diet. Major factors contributing to malnutrition and food insecurity in SSA are low maize yields, about 16 bushels/acre, compared with yields of approximately 160 bushels/acre in industrialized countries such as the U.S (4)

A big factor limiting sub-Saharan agricultural productivity is reduction of soil fertility through depletion of nitrogen, phosphorus, and other nutrients during decades of farming without replenishment through fertilizer application (4). Nutrient replacement is important in optimizing agricultural productivity. At the same time, it is important to limit fertilizer use to the amount needed to avoid negative economic and/or environmental impacts. Nitrogen fertilizer is expensive in Tanzania, especially for smallholder farmers with limited incomes. Excess nitrogen runoff into groundwater aquifers can compromise drinking water supplies (2, and nitrogen runoff into surface water streams and rivers can lead to ecologically disruptive algae blooms (3).

Fortunately, several new technologies may help us maximize agricultural production while limiting input use to the amounts required. This paper will discuss the use of cell phone technology combined with computer vision image analysis to optimize nitrogen fertilizer application and improve maize production in Tanzania

Family Size & Composition, Diet, Education, & Access to Health Care

As of the most recent (2012) census, the average family size in Tanzania is 4.8 people (5). About two-thirds of the population are below age 25, with 44% below age14. The median age is 17.5 years, compared with 37.8 in the U.S. and 46.5 in Japan (2). The birth rate in Tanzania is 2.79%, the 14th highest in the world (2). There are 5.4 children/woman, compared with just over 2 children/woman in the U.S. and under 2 children/women (below replacement rate) in Japan and many countries in Europe (5). Infant mortality (considered one indicator of overall population health) in Tanzania is 42.43/1000 live births, ranking 58th highest world-wide and similar to that in India (2). Overall health spending in Tanzania is 7.3% of GDP, ranking 81st highest worldwide. Life expectancy at birth, another indicator of population health, is 61.71 years, ranking 181st highest worldwide, compared with 79 years in the U.S. (6).

Primary school enrollment rates are high for both girls and boys in Tanzania. Many children (particularly girls) drop out before completing primary school, however. Only 30.8% of children enroll in secondary school, and only 1.9% start upper secondary school. For children who complete primary school, seven out of 10 and nine out of 10 are unable to read basic Swahili or English (two of the main languages in Tanzania). The U.S. Agency for International Development is currently working with the Tanzanian Ministry of Education and corporate partners including Intel, Microsoft and Tanzanian companies UhuruOne and Zantel to improve educational outcomes (7).

Total calorie consumption in Tanzania averages 2,137 calories/day. Dietary patterns in Tanzania vary with geography. The Southern Highlands is a maize-producing region, and families in this part of the country obtain 50% of their calories from maize. Families in the Lake Zone in the northwest portion of the country near Lake Victoria obtain 32% of their calories from maize, and the remainder from tubers such as cassava (19% of calories) and other crops such as bananas (5%). The population in more affluent urban areas such as the capital Dar es Salaam enjoys a more diverse diet, but still obtains 23% of calories from maize. Access to adequate amounts of food varies with geographic location as well. Although total food costs are somewhat higher in Dar es Salaam, incomes are significantly higher as well, and food access is generally good. Food costs in maize producing areas such as the Southern Highlands are also low relative to income, resulting in generally good food availability in these areas. In the Lake Zone, however, food costs are higher and incomes lower, resulting in food access problems. Overall, up to 40% of the population may experience at least intermittent food insecurity (8).

Farming in Tanzania: Current Status

Agriculture is one of the leading sectors in Tanzania accounting for 24% of GDP and over 75% of national employment (9). However, only 24% out of about 44 million hectares (at 2.4 acres/hectare, 105.6 million acres) of total arable land have been farmed so far, according to UNESCO. These areas are being mainly cultivated by smallholder farmers, with average farm sizes between 0.9 and 3.0 hectares (1 to 7.4 acres), using non-mechanized, labor-intensive methods. Only 10% of the arable land is cultivated using mechanized equipment (10). As noted above, maize is the dominant food crop in Tanzania, and occupies 56% of the cultivated land area (10).

Total food production in Tanzania has been restricted not only by the limited proportion of arable land being farmed but also by the relatively low productivity per acre of land under cultivation. As noted above, maize yields in Tanzania may be as low as 10% of those in developed countries (4). The average food crop productivity in Tanzania is 1.7 tons per hectare, whereas in pilot projects with improved management practices including fertilizer use yields have improved to 3.5-4.0 tons per hectare. The use of hand tools and the dependence on rain for crop irrigation may also reduce yields, particularly during times of drought, as have occurred recently (11).

Two of the main obstacles that hinder agricultural production include poor access to and low usage of improved seeds and, particularly, low application rates of nitrogen-containing fertilizer. Fertilizer has historically been relatively expensive in Tanzania. Inorganic fertilizer costs in Tanzania are often twice those in other developing countries, and up to four to six times higher than costs in industrialized countries (12). This has been related in part to government regulation and taxes which have limited imported fertilizer supplies (13). In 2008, the Tanzanian government instituted the National Agricultural Input Voucher Scheme (NAIVS), to raise maize and rice production, and thus preserve Tanzania's household and national food security. The program has helped 2.5 million smallholder farmers to buy one acre packages of maize or rice seed and chemical fertilizer at a discount of 50% from the market price and has helped to raise the demand for improved seeds with currently 20% of smallholder farmers using them, and 12%-15% using chemical fertilizer, compared with approximately 3% before the subsidy program (9, 14). Adding nitrogen, even in micro-doses, has resulted in increased yields. The cost-effectiveness of providing fertilizer is 6–10 times greater than providing imported maize as supplements to the food supply (12). Although the results of this program are promising, the usage rate of nitrogen fertilizer is still much lower in Tanzania than in developed countries such as the U.S., where 86-99% of planted corn acreage is fertilized (15). Given the projected increase in population in Tanzania and related increase in maize demand, it would be helpful if a system could be developed to help allow economically and environmentally sustainable delivery of nitrogen fertilizer to increase maize yields.

Possible Future Farming in Tanzania: Using Technology to Optimize Sustainable Fertilizer Application

As noted above, applying nitrogen fertilizer can greatly improve maize yields. Application of excess fertilizer, however, can strain the limited incomes of smallholder farmers. Runoff of excess fertilizer can compromise ground and surface water supplies. In developed countries, soil and/or plant testing can be performed to determine if levels of important nutrients such as nitrogen and phosphate are adequate. Soil and plant analysis may not be available or may be too expensive for routine use in developing countries, however (4). Fortunately, a low-cost solution incorporating cell phone and computer vision image analysis technology holds promise in helping smallholder farmers in Tanzania to determine the optimum amount of nitrogen fertilizer to apply.

This solution is related to a technology used to support agriculture in the developed world, remote sensing. Remote sensing is the process of acquiring information about objects or areas from a distance (19). In agriculture, remote sensing entails the collection of images which provide information about crop health, pest infestation, and crop yield. These images can help support precision agriculture practices, allowing the application of optimal amounts of fertilizer, pesticides, and irrigation to maximize yield, while minimizing expense, waste of precious water, and harmful environmental effects due to excess agrochemical runoff (20). In the past, remote sensing images were often provided by satellite systems at significant expense, limiting their potential use in many developing countries.

The process in Tanzania would begin with the farmer taking pictures of sample maize plant leaves early during plant growth using a cell phone. Over the last few years, cell phone use in sub-Saharan Africa, including Tanzania, has greatly expanded, transforming communications there. As of 2014, 73% of Tanzanians owned cell phones, up from only 10% in 2002. Smart phone use (with direct access to applications and the internet) is also increasing. Cell phones are commonly used for sending text messages and taking pictures or video (16).

Once the maize leaf photos are taken, they would be sent via SMS systems (in the case of "non-smart" phones) or via smart phone data systems to cloud servers for analysis using computer vision techniques. Computer vision is defined as the field devoted to the acquisition, analysis, interpretation, and understanding of images or sequences of images, with the goal of using information derived from computer vision as a basis for decision making in a variety of applications. Recently there has been increasing interest in use of computer vision technologies in agriculture for tasks including vegetable inspection and beef quality control (21). RGB analysis, a powerful computer vision technique where images are broken down into red, green, and blue components, has been employed recently in a variety of biological applications (22) and may be well-suited for use in agriculture.

I have personally been researching the use of RGB analysis to study the relationship between nitrogen fertilizer administration and corn plant health, and have developed an algorithm which can perform an automated RGB analysis of corn leaf images. In my early field research using images from both close-up digital photos (as would be taken with a cell phone) and drone-acquired photos, the findings from this analysis correlate with nitrogen levels in experimental plants. This algorithm may therefore hold promise in allowing efficient, inexpensive, and non-invasive assessment of maize nitrogen levels. The results of this cloud-based analysis could be communicated by text message or, in the case of smart phones, through an app which would advise the smallholder farmer whether adequate nitrogen has been administered or whether more would be required.

To confirm that the RGB image analysis is measuring nitrogen content and not another nutrient, further field testing including soil and plant analysis by an agronomist in Tanzania is suggested. Although it appears that nutrients have unique RGB "signatures" or appearance, this correlation can be confirmed by further research and testing by an agronomist.

It may also be helpful to integrate the use of RGB analysis, which provides plant specific data with a resource, such as Optimizing Fertilizer Recommendations in Africa (OFRA). Through a partnership between the Center for Agriculture and Biosciences International (CABI), a non-profit organization, the University of Nebraska, and the African Soil Health Consortium, a database has been established of on-going research and trials to determine optimal fertilizer utilization, based on crops in 13 countries in Sub-Saharan Africa, including Tanzania. OFRA data combined with information from RGB analysis can help farmers to more precisely determine optimal fertilizer application to improve efficiency, increase quality, yield and profitability of crops. (23)

Other Factors Affecting Agricultural Productivity and Food Security in Tanzania

Although improved fertilizer administration would hopefully benefit maize production in Tanzania, there are a number of other factors which can also affect food security for the Tanzanian population. As noted above, the projected rapid population growth rate may put a strain on both food production as well as food storage and distribution systems, which are still developing. Maize and rice, another important crop in parts of Tanzania, are both water-intensive. As noted above, droughts have been a problem in recent years, and both agriculturally damaging droughts and floods may become increasingly frequent in the setting of climate change (17). Tanzania also relies on hydroelectric generation for much of its electricity supply. Recent droughts have interfered with electricity availability (18), which may negatively impact food security in several ways including interruption of factory fertilizer production as well as failure of cold food storage and distribution systems.

Possible Roles of Communities, Academia, Industry, Government, and Non-Governmental Organizations in Implementing a Cell Phone-Based System of Fertilizer Optimization

There are a number of ways in which communities, academia, industry, government, and NGO's can help implement a cell phone-based maize image analysis system. Communities of smallholder farmers can cooperate via smartphone sharing or loan programs to ensure that all farmers have access to this technology. Academic institutions and commercial testing laboratories can work together with farmers to correlate the findings of the RGB image analysis algorithm with actual plant nitrogen levels in test plantings in Tanzania to ensure that the cell phone-based nitrogen assessment technique provides reliable information. Government and academia can work together to develop extension programs to educate smallholder farmers on the use of this technology, and government agencies, NGO's, and industry can jointly develop microfinance and/or subsidy programs to allow farmers to afford cell phones and required service plans as well as initial supplies of fertilizer to implement this technology. Non-profit organizations, such as CABI, have piloted programs utilizing mobile technology to provide information and advice on crop agronomy, animal health, and market prices for crop, with plans to expand programs to include finance and micro-finance programs for small-holder farmers in India and Kenya. (24) With the continued proliferation of mobile technology, similar partnerships can expand to countries in Sub-Saharan Africa. The Government can also work on improving transportation systems to ensure that smallholder farmers can get their crops to market successfully. In addition, Government agencies and industry can hopefully partner to promote less expensive importation and distribution of fertilizer and possibly construction of local fertilizer production plants.

Conclusions

As a major country on the continent with the highest anticipated rate of population growth for the rest of this century, Tanzania faces challenges in improving food security for the 40% of its population who are currently at least partly food insecure and in ensuring food security for its rapidly growing population in the future. Fortunately, there is the potential for greater agricultural productivity in Tanzania through increased use of modern agricultural technology including mechanization, improved seed, and fertilizer on acreage currently under cultivation, as well as future cultivation of the significant area of arable land which is not being farmed now. Pilot studies have suggested that even low-level nitrogen supplementation can significantly increase yields of maize, the major grain crop and food staple in Tanzania (4). The rapid and widespread increase in cellphone availability may serve as a platform for introduction of a relatively simple, cloud-based computer vision image analysis technique allowing smallholder farmers to inexpensively and non-invasively assess the nitrogen status of maize plants and determine whether supplemental nitrogen would be helpful. Cooperative efforts involving smallholder farmers, academia, industry, and government and non-governmental agencies could hopefully promote adoption of nitrogen assessment technology such as the proposed cell phone based system as well as other tools, such as the OFRA database recommendations and agricultural practices including carefully increased fertilizer application and mechanization. Increases in maize production through these measures would hopefully allow increased maize sales throughout Tanzania and possibly maize exports to other countries in Africa, resulting in improved food security in Tanzania and its neighbors and improved economic prosperity for the smallholder farmer in Tanzania.

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