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African food insecurity in a changing climate: The roles of science and policy

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Abstract

African population is projected to double to 2.48 billion people by 2050. The population increase poses a serious challenge of increasing food supply to meet the future demand. This challenge is compounded by climate change impacts on agriculture. In this paper, how poverty contributes to household food insecurity is explored and measures suggested to help address this challenge. To plan adaptation measures, linkages among food insecurity, poverty, and illiteracy should be considered. For the sub-Saharan Africa (SSA), adaptation (focused on poverty alleviation) should be prioritized and preferred to mitigation. Enhancement of adaptive capacity should not only be tailored toward empowerment of women but also made highly localized to household levels. Generally, efforts could be geared toward yield gap closure, addressing challenges regarding food distribution, promoting non-farm income-generating activities, and unification of government priorities in agriculture and food security. Government in each country of the SSA should ensure that governance strongly embraces transparency, accountability, and integrity otherwise as it is said a fish rots from the head down. Estimates of uncertainty in predicting future climate and their implications on expenditure related to adaptation should to always be made in an integrated way and reported to support actionable policies. To increase credibility in climate prediction especially at local scales, advances toward improving climate models (for instance by refining spatiotemporal scales, enhancing models' capacity to reproduce observed natural variability in key climatological variables like rainfall) should be made, and this requires support from the investment in climate science. Science–policy interfacing is required in planning and implementation of measures for adapting to climate change impacts. In summary, food insecurity and persistent poverty especially in the SSA should be of direct relevance and concern at a global scale. Thus, global collaboration in science is key to achieve food security in the SSA.

KEYWORDS

climate change, food insecurity, poverty, science–policy interface, sub-Saharan Africa (SSA)

1 | CURRENT AND FUTURE FOOD PRODUCTION

Population of Africa is projected to double to 2.48 billion people by 2050 (World Population Prospects WPP, 2015). This implies food supply should be increased to meet the huge future demand. Food production in Africa is projected to increase in the future. For instance, coarse grain cereal production in the sub-Saharan Africa (SSA) will be 2.3 tonnes/ha by 2050 compared to the 0.65 tonnes/ha of 1961 (Alexandratos & Bruinsma, 2012). However, will other crops exhibit such an increase in the future production? For the SSA, Alexandratos and Bruinsma (2012) asserted that the available technical and resource potential would, indeed, lead to an increased future production in Maize, Cassava, and other crops. This may prompt optimism with respect to future food security. Furthermore, it was projected that, for instance, by 2030, a boost in crop production of the SSA will mainly be as a result of yield increase (see Figure 1). Yield increase is herein thought of in terms of the productivity per unit area. It is noticeable from Figure 1 that the share in crop production boost due to yield increase over the period 1961–1999 was the lowest in the SSA compared to other regions of the world. This implies that the SSA exhibited wider yield gap than for other regions of the world. On further analyses of the Ratio of Cereal Production to Population (RCPP) in 50 of the African countries considering the period 1961–2014, Onyutha (2018a) showed that: (a) the RCPP was characterized by both an oscillatory behavior over multidecadal timescales and a general negative trend, and (b) in more than 85% of the African countries, the increase in crop production could still be adequately explained (at the significance level of 5%) in terms of expansion of the area harvested. Thus, prudence is required for the possible optimism in future food security. Instead, general efforts from various stakeholders in agriculture and sustainable developments from the SSA should receive attention, for instance, (a) rural poverty alleviation and (b) increasing the robustness of farming systems to allow them to cope with climatic uncertainty.

When it comes to food insecurity, its linkage to poverty remains very strong especially in the SSA (World Food Summit WFS, 1996). Even in the future, food insecurity is anticipated to be dominantly driven by poverty (Onyutha, 2018a). For instance, by 2050, there will still be significant poverty as well as persistence of significant levels of undernourishment in many countries (Alexandratos & Bruinsma, 2012). Forecast by the World Bank indicates that SSA will exceed Asia as the most food-insecure region with 40%–50% of people globally being undernourished in 2080 compared with the current 24% (Food and Agriculture Organization FAO, 2009a). Under future climatic conditions, the level of viable arable land for production by 2080 is projected to decline with 9%–20% of the arable land becoming much less suitable for agriculture (FAO, 2009a). Considering cereal crops by 2080, whereas the high greenhouse gas scenario (A2) for the selected model HadCM3 shows an increase in production at some locations, in certain areas there will be a decrease by more than 50% (Figure 2). Some regions such as the Western part of the Southern Africa as well as the Sahara desert will not be suitable for cereal crops even under the future climatic conditions. The smallest changes in potential cereal output will be in the Central Africa. This is consistent with results from several past studies (Dale, Fant, Strzepek, Lickley, & Solomon, 2017; Lobell et al., 2008; Rippke et al., 2016), which all showed that Central Africa will experience the smallest maize yield losses compared to other areas in the SSA. South Africa and the Sahel region will experience widespread cereal yield losses while there will be subregional increases in East Africa and at the Southern tip of the African continent (Dale et al., 2017). Even when based on the recent generation general circulation models (GCMs), the overall impact of climate change on yields of

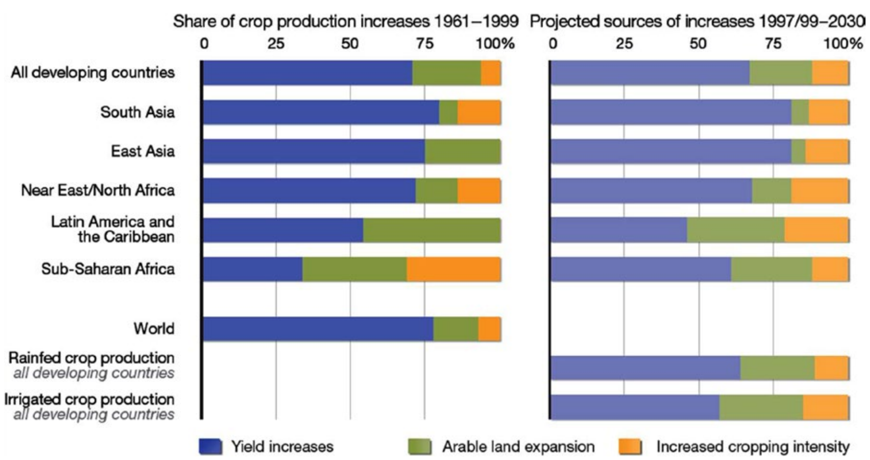

FIGURE 1 Projected food consumption (Source: GRID-Arendal, 2008a)

major cereal crops in Africa predicted by Intergovernmental Panel on Climate Change IPCC (2014) was stated (with high levels of confidence) as likely to be negative amid strong regional variation (see Niang et al., 2014). This assertion by the IPCC was also reechoed for maize production in the SSA (Challinor et al., 2014; Dale et al., 2017; Rosenzweig et al., 2014). Furthermore, the majority of countries in Africa will experience novel climates over at least half of their current crop area by 2050 (Burke, Lobell, & Guarino, 2009). The "novel" crop climates will potentially change crop productivity by altering growing season temperature, changing crop durations, etc. For instance, Challinor, Koehler, Ramirez-Villegas, Whitfield, and Das (2016) showed, using the high Representative Concentration Pathways RCP 8.5, that in the majority of maize growing areas of the SSA, crop duration (in terms of the period between germination and maturity) will become significantly shorter than the current ranges by 2031 (see Figure 3D). The emergence of new thermal environments under other RCPs 2.6, 4.5, and 6.0 can be seen in Figure 3A–C. Each year in Figure 3 represents the midpoint of the 20-year window for which the crop duration median falls below the 25th quantile of baseline period (1995–2014). This decrease in crop duration is expected to be in a systematic way starting as early as 2018 at some locations in the SSA (Challinor et al., 2016). It is noticeable (in terms of the gray grid cells) that the areas where the crop duration remains within the 25th–75th quantile until at least 2038 are more scarce for the RCP 8.5 (Figure 3D) than other RCPs (Figure 3A–C). This means that, under the RCP 8.5 (i.e., high global energy imbalances or radiative forcings in watts per square meter by the year 2100), 2038 is supposed to be the latest possible date for delivery of an improved crop variety. For this to be achieved, it means, considering a 30-year time frame required for the development, delivery, and adoption of the new crop variety (Challinor et al., 2016) needed to have started by 2004, a highly unlikely development for the SSA.

To ensure future food security given the climate change impacts, several measures need to be taken. In areas where future climatic conditions will not be favorable for a particular crop type, opportunities need to be explored for other suitable crops. There should be an enhancement of agronomic practices in the various agroecological zones. New crop varieties well suited to the future climatic conditions are required (Burke et al., 2009; Ceccarelli, Grando, Maatougui, & Michael, 2010; Mba, Guimaraes, & Ghosh, 2012) for future food security in the SSA. For climate

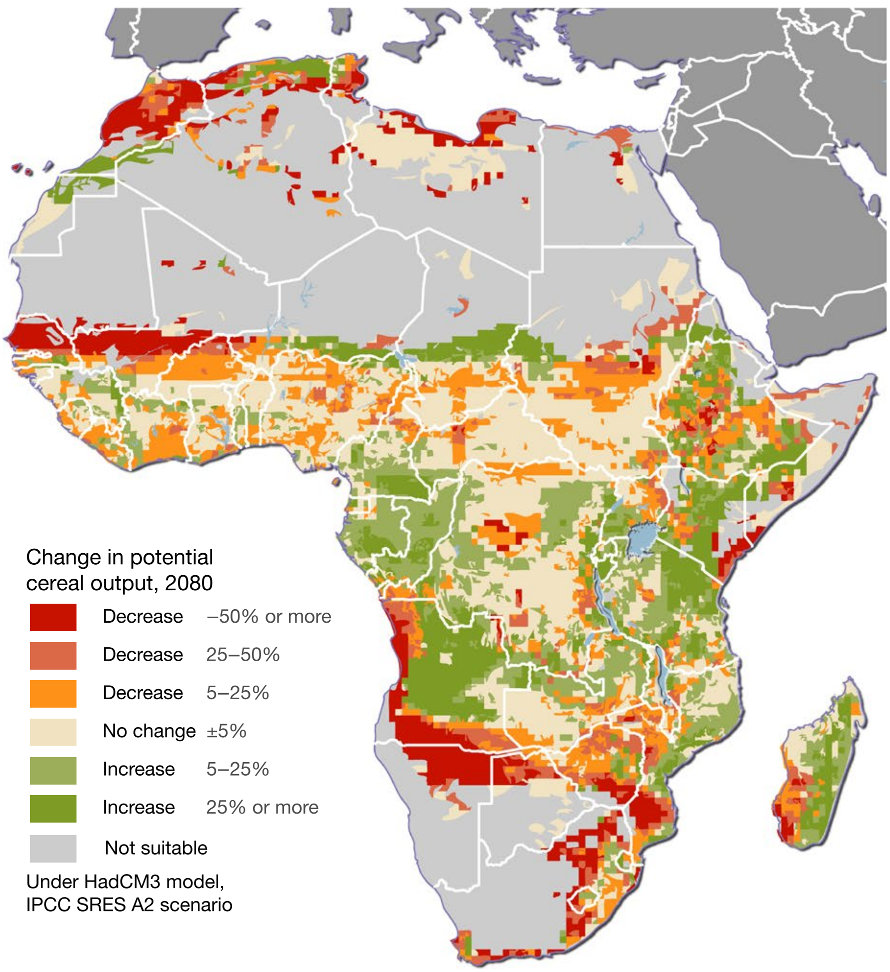

FIGURE 2 Impact of climate change on cereal production (Source: GRID-Arendal, 2008b)

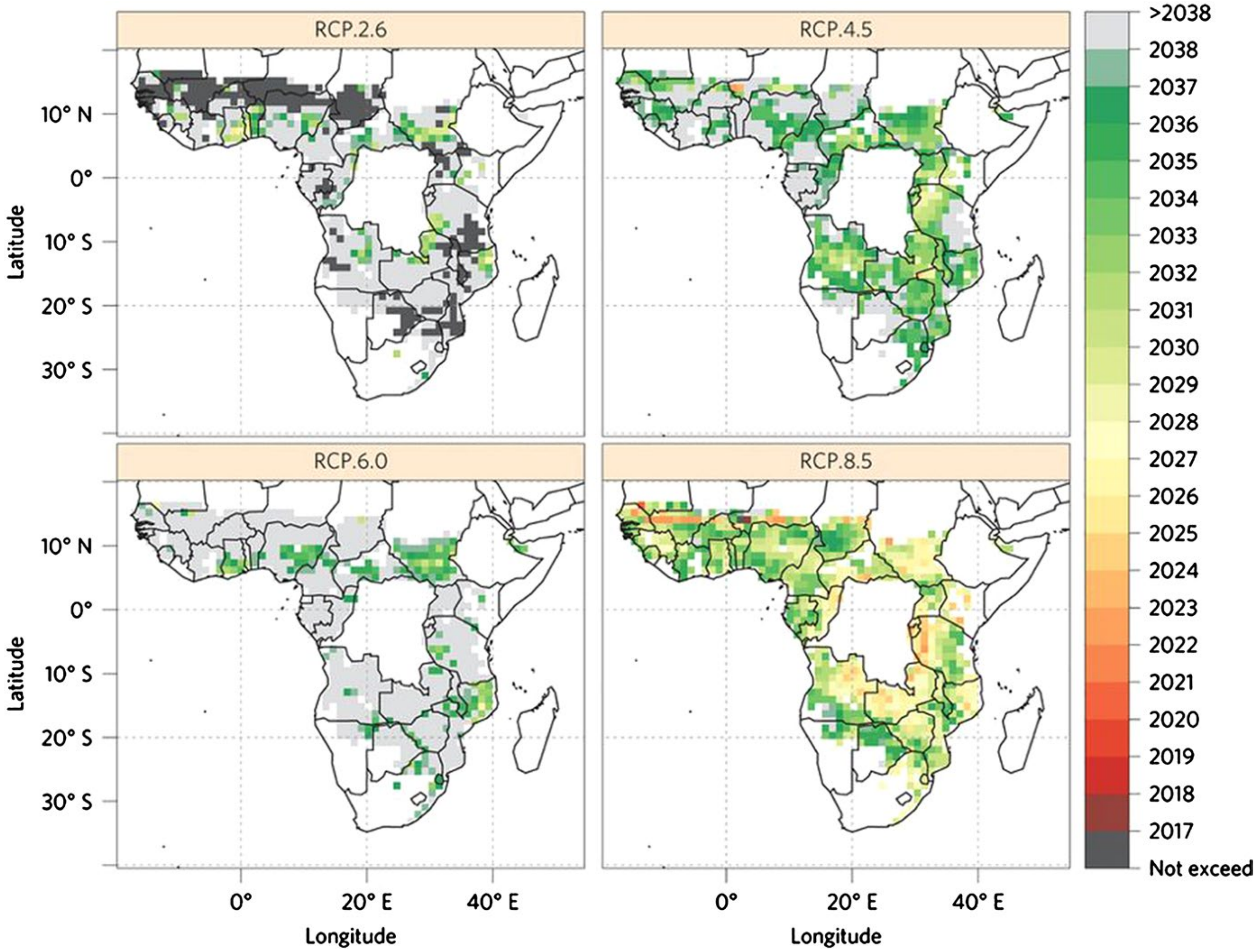

FIGURE 3 The emergence of new thermal environments in terms of the time at which climate change signal for crop duration is detected using (A) RCP 2.6, (B) RCP 4.5, (C) RCP 6.0, and (D) RCP 8.5 (Source: Challinor et al., 2016)

change adaptation, there should be significant improvements in crop breeding tailored to address both biotic and abiotic stresses. To supplement possible changes in management practices for adaptation, breeding (i.e., assessment and selection of suitable genetic diversity, and recombining the genetic resources into a new crop variety) should be done to produce varieties, which can give suitable yields under effects of stressful conditions such as high salinity, heat, and drought. Further exploration is required on how: (a) elevated carbon dioxide (CO_2) interacts with abiotic factors (such as sunlight, temperature, and soil fertility) and the effect of such an interaction on crop yield and/or harvest quality, and (b) elevation of CO_2 influences extent of biotic stress on crop growth and development. Population breeding in the form of an evolutionary participatory plant breeding needs to go hand in hand with breeding for resistance to biotic stresses (Ceccarelli et al., 2010). The preference of farmers for instance on the adequacy and relevance of crops could be taken into account. To accelerate genetic gain, marker-assisted breeding and genetic modification (i.e., biotechnology-based breeding technologies) will be essential. Because the application of biotechnology-based breeding technologies requires an extra investment in the understanding, genetic characterization, and phenotyping of complex adaptive traits for climate change conditions (Chapman, Chakraborty, Dreccer, & Howden, 2012), it could be supported through an international funding. For a number of African countries which are poorly represented in the GenBanks, there should be considerable efforts to conserve genetic resources in the near future. Global collaboration in science is a key to addressing food insecurity in the SSA.

2 | POVERTY AND FOOD INSECURITY

2.1 | General

Smallholder farmers (especially in the SSA) experience low crop production because of a number of biotic and abiotic challenges. Due to land degradation by human factors (such as deforestation and overgrazing), the soil is increasingly becoming infertile in many regions of the SSA. There are often serious climatic challenges for crops such as drought, waterlogging, and extremely high temperature, as well as constraints from pests, diseases, and weeds. According to Dinesh, Campbell, Bonilla-Findji, and Richards (2017), some of the possible innovations for adaptation in agriculture include agro forestry to diversify farms and enhance resilience, aquaculture to enhance nutrition and diversify incomes, stress-tolerant varieties to counter climate change, improving smallholder dairy for an enhanced income and greater climate resilience, solar irrigation innovation for expanding access to affordable irrigation and enhancing resilience. Digital agriculture from tailored advice to shared value with millions of farmers as well as climate-informed advisories to enhance production and resilience may also be helpful. Developments that are common in developed countries include weather index-based agricultural insurance and scaling up financing for climate change adaptation in agriculture. The implementation of the above innovations requires close collaboration between farmers, scientists, funders, and policy makers. The poverty status of the smallholder farmers becomes an important factor in such an implementation because of its linkage to food insecurity.

Household poverty in the SSA has been and still is rampant. By 1981, 53% and 74% of the total population in SSA lived on US$1.25 and US$2.00 per day, respectively. However, by 2005, still 51% and 73% of the total population in SSA lived on US$1.25 and US$2.00 per day (World Bank, 2008a). By 2013, countries listed in the Low Human Development category were 44, and 34 of them including the bottom ten were from the SSA (see the report of the United Nations Development Program http://hdr.undp.org/en/composite/HDI [accessed: 26th October 2018]). According to the update of the recent list of Human Development Index (HDI) ranking (see http://hdr.undp.org/en/2018-update [accessed: 26th October 2018]), the same 10 countries from the SSA (which were at the bottom of the HDI list in 2013), have continued to remain at the bottom of the HDI list even in 2018. As of March 2017, 29 out of the total 37 countries in the world that lacked resources to deal with critical problems of food insecurity (thereby requiring external assistance for food) were from Africa (Global Information and Early Warning System GIEWS, 2017). The largest proportion of food produced in the SSA comes from the smallholder farmers. About 80% of the African population affected by food insecurity live in the rural areas. More than 70% of the poor Africans that wholly depend on agriculture for their livelihood live in the rural areas (RPP, 2009), thus, there is the possible linkage between food insecurity and poverty. The actual farm yield in the fields of smallholder farmers is significantly different from the potential yield (note that potential yield is the yield obtainable based on crop growth that is not constrained by the impacts of harsh environmental conditions, lack of nutrients, and the effects of weeds, pests, and diseases). This difference between the potential yield and actual farm yield (also known as yield gap) in the SSA has implications on household food insecurity, which is instead linked to poverty. Poverty encourages food insecurity in a number of ways. Smallholder farmers lack knowledge on good farming practices. Furthermore, they cannot afford pesticides, herbicides, quality seeds, and fertilizers to boost crop production.

2.2 | Pest and diseases

The capacity of poor smallholder farmers to deal with invasions by pests and diseases is generally low. For instance, due to the low capacity to quickly deal with the recent devastation by the fall armyworm (*Spodoptera frugiperda*) in 2017, cereal yields in many countries of the SSA were (and are still in 2018) negatively affected. Apart from the infestation by the fall armyworm, the African smallholder farmers have also suffered from the invasion by a number of pests from other parts of the world. Recent cases of pests include the infestation of Banana in Mozambique by the new race of Panama disease from Asia, the widespread tomato leafminer from South America which came via Europe, and the spread of Maize lethal necrosis which was first noticed in Kenya in 2011 (Centre for Agriculture and Biosciences International CABI, 2018a). Apart from the invasive pests from foreign continents, there are a number of already existing devastating cases caused by insect pests, diseases, and weeds such as cotton bollworm (which attacks multiple crops), the native African armyworm (*Spodoptera exempta*), sorghum midge, maize stalk borers, sorghum stem borers, African rice gall midge, striga or witch weed (which attacks multiple crops), and many others (Africa Soil Health Consortium ASHC, 2015). The recent invasion by the fall armyworm was more widespread than the known infestations by other pests in Africa. In other words, the rate of invasion by the various pests tends to differ. Whereas some pests spread slowly, the invasion by others is fast. This affects the effectiveness of possible attempts to deal with the spread of the pests.

Figure 4 shows countries invaded by the fall armyworm based on information from CABI (2018b) (Figure 4A, D), International Maize and Wheat Improvement Centre CIMMYT (2017) (Figure 4B), and FAO (2017a) (Figure 4C). It can be seen that the number of countries affected by the pest increased with time. If maize is heavily infested by the fall armyworm, up to about 80% of the yield can be lost (CABI, 2018a). Furthermore, the notoriety of the fall armyworm in feeding on

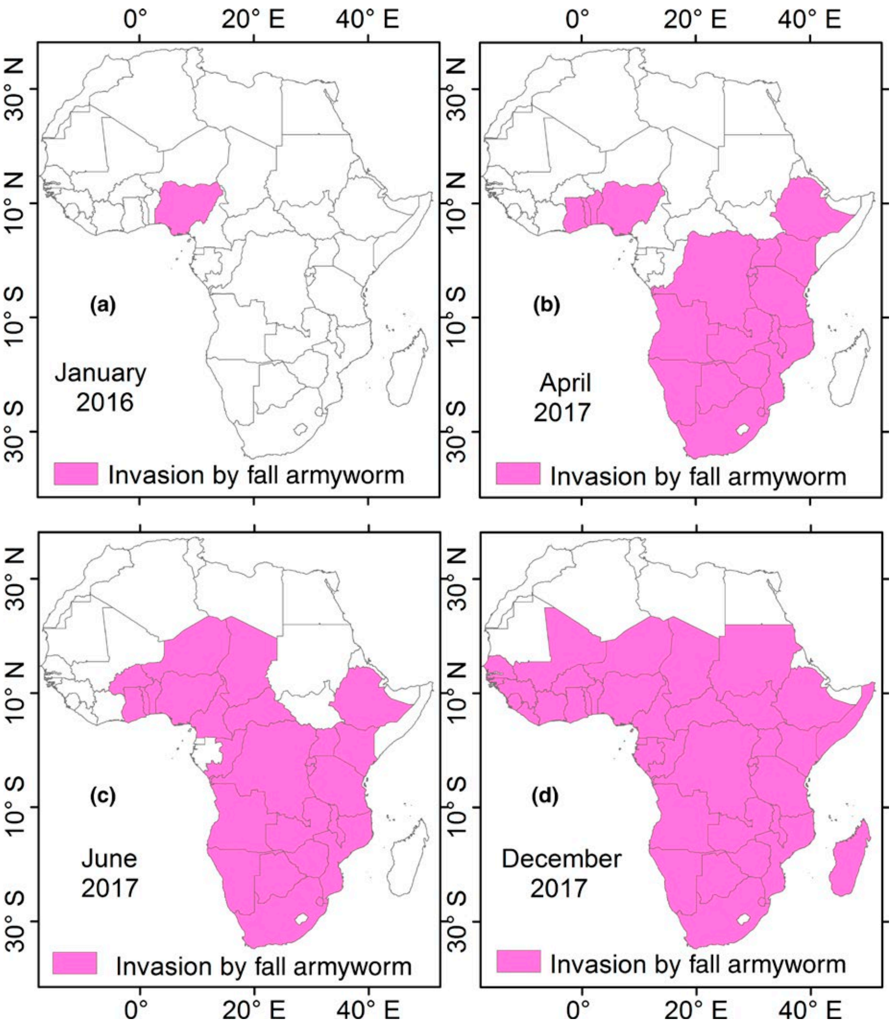

FIGURE 4 Countries invaded by fall armyworm as of (A) January 2016, (B) April 2017, (C) June 2017, and (D) December 2017

several plant species such as maize, sorghum, and sugarcane can compound food insecurity due to the huge losses in cereal crop yields of smallholder farmers across the continent.

To deal with the invasions by the fall armyworm, a number of suggestions resulted from an international meeting in Nairobi (Kenya) in 2017, which produced a framework for action with FAO as the overall coordinator. The suggested actions included the following: getting various stakeholders organized, establishment of research and development, supporting the farmers, and so on [see http://www.fao.org/3/a-bs183e.pdf (accessed: 10 March 2018)]. Farmers are encouraged to: conserve the fall armyworm's natural enemies (such as spiders and ants), use hands for squashing the pest's eggs and larvae, adopt careful and/or regulated use of pesticides, etc. Although pesticides are used against the fall armyworm in Brazil (The Guardian, 2017), FAO discourages this practice in Africa to prevent environmental poisoning. In order to promote scientific advances in dealing with the fall armyworm, funders and the government in SSA could support research and development. These advances may include developing genetically modified (GM) cereal crop varieties resistant to the worm, new biological methods, and so on. The use of GM crops is already being applied by America's farmers (The Guardian, 2017). However, most of the African countries except South Africa have banned GM crops (The Economist, 2018). This might be due to the issue of perception that genetic modification of crops can be harmful. If GM crop varieties are to be developed, the bans need to be lifted, and this can be done based on unanimous decision of the government across the SSA. Furthermore, developing biological methods (such as viruses that can attack the fall armyworm) is a costly venture and may take a lot of time. However, related work (like decoding of the genome of fall armyworm) is already being done (see, for instance, Cheng et al., 2017). Therefore, technical and financial support from international organizations or institutions outside Africa would be required to reinforce contributions from the government in Africa. Collaboration between the scientific researchers in Africa and those from other continents working on the fall armyworm could be highly encouraged and financially supported.

According to Dinesh et al. (2015), crop pests already account for approximately 1/6th of farm productivity losses in

Africa. However, under future climatic conditions, Africa is predicted to realize an increase in crop pests and diseases (FAO, 2009a; IPCC, 2014) because climate change will lead to: (a) alteration of crop resistance to insect damage (Dermody, O'Neill, Zangerl, Berenbaum, & DeLucia, 2008) and (b) changing the response of pests and pathogens (Gregory, Johnson, Newton, & Ingram, 2009). Therefore, in a climate changing context, an Integrated Pest Management (IPM) can generally be adopted by the smallholder farmers. One key reason for the adoption of an IPM is the reduced use of chemicals, which in turn increases food safety (given that reduced level of food safety is a big issue in food security across the world). According to the ASHC (2015), an IPM comprises four steps including identification, prevention, monitoring, and control. For an identification of the pest or diseases, knowledge of the key signs and symptoms is required. In the prevention step, a number of activities can be undertaken some of which include removal of infected plant material, adoption of good field practices, and the use of disease-resistant varieties or disease-free seed. To reduce further spread or losses, monitoring can be done to take note of any pest or disease as early as possible. In the control procedure, both cultural approaches (like removal of infected plants) and the use of appropriate pesticides can be adopted. At the control stage of the IPM, smallholder farmers require technical and financial support from the government or funders.

2.3 | Quality seeds or planting materials

Poverty also limits the smallholder farmers from affording high-quality seeds and/or planting materials. Despite the varying food demands in the SSA, farmers mainly rely on indigenous crop varieties that are known to exhibit low yields especially under stressful environmental conditions. Furthermore, farmers have a common practice of reusing planting materials from previous harvests for subsequent cropping cycles. When the planting materials from previous harvests are infected with viruses, their reuse leads to accumulation of viruses in the crops over subsequent cropping cycles. The reuse of planting materials infected with viruses increases the impacts of related diseases, for instance, lowering yield, reducing vigor or sprouting ability, increasing disease incidence or severity, and this process is called degeneration. If, for instance, by reusing infected planting materials, a measure such as yield, disease severity or incidence, sprouting ability, etc., is quantified in a number of successive cropping cycles, the amount by which such a measure varies with cropping cycle comprises a degeneration rate. Generally, degeneration rates can be influenced by a number of factors such as climate variability, soil fertility, and farming practices. Nevertheless, to check on degeneration, there should be measures to ensure planting materials for the smallholder farmers are quality-assured. Scientists at the various Agricultural Research Institutes across the SSA could expand breeding programs for research on seed or crop varieties to enhance their resistance to pests and diseases as well as harsh environmental conditions such as drought, waterlogging, and high temperature. To do so, an adequate financial support of the government and international funders is required. It was remarked in The New York Times (1985) that lack of improved crop varieties that could produce high yields in the harsh and variable climatic conditions is one of the factors responsible for food insecurity in Africa. However, presently a number of stress-tolerant crop varieties exist in Africa. For instance, several varieties of maize, beans, and cassava have been bred and released by the CIMMYT, see http://www.cimmyt.org/ (accessed: 26th March 2018)] through collaboration with various National Agricultural Research Institutes of different countries in the SSA. The adoption of stress-tolerant crop varieties can lead to an increase in yields. For instance, in Zimbabwe climate-resilient maize translated into an income of US$240 per hectare equivalent to 9 months of extra food (Lunduka, Mateva, Magorokosho, & Manjery, 2017). By adopting stress-tolerant maize across 13 countries in Africa over a 7-year period, both yield gains and an increase in yield stability could potentially generate income of US$ 362 million - US$ 590 million (Kostandini, Abdoulaye, & La Rovere, 2013). However, the main problems are that the new varieties are too few, subject to counterfeit, and a number of smallholder farmers: (a) do not have access to the new crop varieties and (b) cannot still afford the cost of purchasing the seeds or planting materials of the new crop varieties (even if the prices are subsidized). Besides, the priorities of the smallholder farmers seem not to be incorporated into the development of the new crop varieties. In some areas, the new crop varieties are not readily accepted and adopted by the smallholder farmers. This, therefore, requires participatory breeding (Ceccarelli et al., 2010) in which collaboration between scientists and local farmers is critical in developing varieties that suit farmers' preferences. Of course, even the new crop varieties can still degenerate, though at different rates possibly slower than those for the indigenous types. To check on degeneration of crops, the smallholder farmers can replace degenerated planting materials with those which are virus-free. Even in this case, programs are needed to quantify degeneration rates for the various crop varieties across the different agroecological zones and provide necessary information on when replacements of degenerated planting materials should be made.

2.4 | Cost of fertilizers

Smallholder farmers, the majority of whom are very poor, cannot afford fertilizers to boost crop production. On the fact that Africa is hit hardest by global warming despite its low greenhouse gas emissions, Kifle (2008) remarked that many regions of Africa that once had fertile soil are now without rain, and the future is not bright. In response to variations in temperature and precipitation, Africa is predicted to experience an altered soil fertility under future climatic conditions (FAO, 2009a). Despite Africa being the world's lowest consumer of fertilizers, the African soils suffer from severe degradation, which is worsening due to the impacts of climate change (The Initiative for the Adaptation of African Agriculture IAAA, 2016). Soil degradation in Africa is as a result of several human activities such as deforestation, overgrazing, bush burning, overexploitation, and poor farming methods. Therefore, an integrated system of soil fertility management could be adopted in the SSA. An integrated management of soil fertility (especially if adapted to the high variation of local conditions in Africa) is vital to support soil regeneration and improve productivity (IAAA, 2016). According to Rockström and Barron (2007), an integrated soil and fertility management while putting dry spell mitigation into perspective can improve water productivity and potentially increase yield by more than double. Training on an integrated soil fertility management could be organized for smallholder farmers at community-based level, especially in rural areas. Some of the existing initiatives on soil fertility in Africa include the following:

- the large-scale science-based research-in-development with focus on putting nitrogen fixation to work for smallholder farmers in Africa (N2Africa) [http://www.n2africa.org/ (accessed: 26th August 2018)] supported by Bill and Melinda Gates Foundation,
- the African Soil Health Consortium (ASHC) [https://africasoilhealth.cabi.org/ (accessed: 10th March 2018)] supported by Bill and Melinda Gates Foundation,
- Optimizing Fertilizer Recommendations in Africa (OFRA) [https://africasoilhealth.cabi.org/ (accessed: 16th March 2018)] supported by the Alliance for a Green Revolution in Africa (AGRA) Soil Health program,
- the "Green Revolution in Africa" [https://agra.org/ (accessed: 15th March 2018)] led by the Alliance for a Green Revolution in Africa,
- Soil Fertility Initiative (SFI) [https://uia.org/s/or/en/1100049256 (accessed: 11th February 2018)] jointly financed by FAO, International Bank for Reconstruction and Development, and World Agroforestry Centre.

Projects or initiatives (ASHC, OFRA, AGRA, SFI, N2Africa, and others) on soil fertility in Africa are crucial for addressing food insecurity challenge. Therefore, technical support and funding could be continued for such initiatives. If possible, these initiatives should, in a participatory way, involve large number of smallholder farmers in the rural areas while incorporating the farmers' priority needs. Taking into account some of the farmers' choices for instance, adequate crops to plant, cropping systems, and selection of sowing dates can form an important adaptation strategy to climate change (Waha et al., 2013).

2.5 | Cost of irrigation

Because the smallholder farmers are mainly poor, they cannot afford the cost of irrigation. In fact, compared to the 37% and 14% in Asia and Latin America, respectively, only 5% of the total cultivated area of the SSA is irrigated (World Bank 2008b). This is probably due to household poverty, and it explains why rainfed cropping system is mainly practiced in the SSA. However, due to climate variability, rainfall is increasingly becoming unreliable to meet the crop water requirements. The use of small-scale irrigation for the smallholder farmers would greatly contribute to reduction in food insecurity. According to the United Nations (2012), crop yields from rainfed cropping systems are on average 2.7 times lower than those obtained under irrigation. Traditionally, buckets, shadoof, and calabashes are used for small-scale irrigation systems. A modern system might comprise motorized pumps driven by solar energy. Other irrigation technologies in the SSA include treadle pumps, communal river diversion, and small reservoirs. These technologies all have the potential to boost crop production. For instance, in the SSA, the use of motor pumps can potentially expand the amount of agricultural land irrigated during the dry season to 30 million hectares (which is four times the current area) (Xie, You, Wielgosz, & Ringler, 2014). However, the cost of acquisition, installation, operation, and maintenance of the relevant irrigation technologies cannot be afforded by the majority of the smallholder farmers at household level. There is so much arable land in the SSA (in fact, about 95% of the total cultivated land) where irrigation is not practiced. To maximize this irrigation potential, adequate technical and financial support could be given to smallholder farmers. To do so, smallholder farmers could be organized in groups at village levels. To such groups, the government, through their financial support (or donor funding), could distribute water pumps to facilitate small-scale irrigation. To enable some farmers afford the cost of acquiring certain technologies, the government in each country of the SSA could, in their national trade policy, greatly reduce taxes on the importation (and perhaps even allow duty-free importation) of irrigation equipment. Furthermore, several microfinance services could be provided at the disposal of local farmers for the necessary support through provision of agricultural loans. Infrastructure (such as roads) could be improved in the rural areas to allow smallholder farmers easily and cheaply transport their produces and access markets. Adequate technical information regarding small irrigation could also be readily provided to the local farmers.

It is apparent that irrigation of crops depends on the availability of either surface water or groundwater. Climate change will greatly affect the availability of water for crop production (IPCC, 2014). Under future climatic conditions, dry (wet) areas are expected to become drier (wetter) than their present states. Besides, the severity and frequency of extreme weather events such as drought and high temperature may increase. Therefore, if irrigated production area needs to be expanded to close yield gap, it could be done in a sustainable way (van Ittersum et al., 2016). However, apart from irrigation, other measures like the use of improved crop varieties (with good yield even under stressful environmental conditions) remain important for crop production under future climatic conditions. Measures that enhance water use efficiency (such as field surface management through rainwater harvesting, the use of mulches to reduce evaporation from soil, etc.) could be adopted. Furthermore, it may be vital to note that subsidizing of irrigation schemes can instead increase unemployment, thereby exacerbating poverty for many. Therefore, alongside subsidizing of irrigation schemes, the government could promote and support contributions from livestock products, and non-farm income-generating activities for local or rural population.

2.6 | Quality education

Smallholder farmers are mainly too poor to afford quality education. The link between poverty and food insecurity is reinforced by lack of relevant education. According to Africa 24 Media (2011), less than 70% of rural children in Africa have access to education. In rural areas, enrollment of children is poor, and teachers are few in number and not that well organized or resourced. The government in each country of the SSA could aim at making primary and secondary education free to both girls and boys. There are already some few countries like Uganda in which primary and secondary education is at reduced cost in government-owned schools. The main challenge is that the children from private schools tend to perform better than those in government schools (with free primary or secondary education). Despite the free access to education, government could ensure high quality of education. Furthermore, the education needs to be relevant for sustainable development. Also important to note is that rural schools tend to perform more poorly than those from urban areas. In many countries of the SSA, it is common to have trained teachers unemployed in urban areas, yet there are fewer than expected numbers of teachers in the rural schools. There should be clear actionable policy regarding recruitments and deployments of teachers in both urban and rural areas. To attract teachers in rural schools, the government could ensure that in each rural school, the facilities, services, and utilities (electricity, hospitals, accommodation, classroom, leisure, school resources, and so on) are highly comparable to those in the teachers' quarters of urban areas. Teachers in rural areas could also be offered similar opportunities for promotion or professional advancement. Another fact is that the performances in schools from some regions are always far better than those of other areas of the same country. Furthermore, teachers in schools in a particular area tend to originate from the same region and probably speak similar or related language. In other words, the deployment of teachers tends to be characterized by nepotism, tribalism, and corruption. Nevertheless, in each country some regions will always (year in, year out) be poorer than others. For instance, according to Uganda Poverty Assessment Report of 2016, in 2006, about 68% of the poor people (whose income falls far below that for poverty line) in Uganda lived in the Northern and Eastern regions. However, in 2013, this number increased from 68% to 84%, yet in other regions (like the Central and Western regions), poverty was reducing. In a related fashion, the situations of food insecurity or illiteracy will always tend to vary across the different regions of a country. Such cases which also exist (to varying extents) in the different countries of the SSA can be ascribed to marginalization that dates back to the colonial era. Rural developments relevant for education as well as the deployment of teachers in schools across various regions of a country must be governed by a clear policy that ensures zero tolerance to nepotism, tribalism, and corruption.

2.7 | Poor farming practices

Poverty limits food production because it encourages the use of outdated techniques or poor farming practices, which cannot significantly improve farm gains. Poor farming practices have a huge contribution to food insecurity in the SSA. Some of the poor farming practices of the smallholder farmers in the SSA include deforestation, overcultivation, overgrazing, and monoculture. Overcultivation of a particular piece of land leads to loss of soil fertility and increases the susceptibility of soil to erosion. Monoculture (the practice of producing one type of crop in a particular field at the same time) when practiced year after year increases the vulnerability of the crop to pest and diseases. While adding diversity in time, crop rotation can reduce susceptibility to pests and diseases and improve soil fertility through nitrogen fixation (planting of legumes). Furthermore, to increase local biodiversity in space, polycultural practices such as intercropping and multicropping can reduce susceptibility to pests and diseases. Deforestation and overgrazing lead to soil erosion, thereby depleting the soil nutrients necessary for healthy crop growth and development. To avoid creation of gullies in the fields following erosion, terracing can be done. On a separate note, for regions which are semiarid and dry subhumid, crop production is constrained less by rainfall totals than by variable rainfall, dry spells, and droughts (Rockström et al., 2007; Wani, Sreedevi, Rockström, & Ramakrishna, 2008). Despite the intermittent rainfall characterized by variability which is difficult to predict, most of the smallholder farmers do not take precautions to minimize water losses from the fields. On the one hand, improved crop varieties can be planted under harsh environmental conditions. On the other hand, field practices such as the use of organic mulches and tied ridges can reduce the field susceptibility to soil erosion and can also retain soil moisture something that would be valuable during water stress. On another note, the practices of burning crop residues and slashed grasses from the smallholder farmers' fields are common in the SSA. The use of crop residues or manure as organic fertilizers is a probable practice in sustainable farming, which can reduce the need for chemical fertilizers. Weed management is often poor in the fields of smallholder farmers. The weeds compete with crops for nutrients and light, thereby affecting the biomass formation by crops. In drought-prone areas, weeds compound water stress by transpiring water that would be available for crops. In the fields of most local farmers, the spaces between crops are always far different from those that might be optimal for crop productivity. In summary, the farmers generally lack knowledge on: an integrated weed management, IPM, and integrated soil management. Through extension services, there could be general sensitization of the smallholder farmers (in rural areas) on good farming practices, training, and/or demonstrations on recommended farming practices especially those that do not require money.

2.8 | Crop losses

Smallholder farmers lack capacity to minimize crop losses. Both quantitative and qualitative reductions in crop yield which can occur in either the field (pre-harvest) or during storage (post-harvest) as a result of biotic or abiotic factors comprise crop loss (Oerke, 2006; Savary, Teng, Willocquet, & Nutter, 2006). Crop loss can also be taken as the decrease in value and financial returns of the crop (Nutter, Teng, & Royer, 1993). Pre-harvest losses are due to pest and diseases, soil infertility, and poor farming practices. Yield losses due to weeds are commonly faced by smallholder farmers of the developing or least developed countries (FAO, 2009b). Compared to the case when no pest control practices are applied, global crop losses due to weeds and pests can be as high as 80% (Oerke, 2006). For the case of the SSA, it remains possible that such a loss could even go higher than 80%. To minimize pre-harvest losses, the smallholder farmers could be trained on IPM, strategies to select pest- or disease-resistant and drought-tolerant cultivars, and practices that can increase water use efficiency and improve on soil fertility. Post-harvest losses arise as a result of several challenges right from the time of harvest to decision by the consumer on whether to discard the food. These activities include an inadequate drying of the crop, bulk storage without sorting and grading of the produce, improper storage facility, insects, rodents, poor mode of transportation of the produce, and inadequate food processing. Due to spoilage and infestation, the amount of food lost while being transported to the consumers is massive (FAO, 2011). In a tropical climate, the problem of wastage when compounded by poor infrastructure can be as high as 40%–50% (Spore, 2011). Most growers tend to believe that many problems can arise as a result of challenges before harvest. However, the losses due to post-harvest systems in the SSA are so high that their minimization could always be taken into account. For instance, considering only Maize in Uganda alone, of an annual volume loss of 215,243 metric tons, post-harvest losses comprise 17.58% on average. For many countries (like Mozambique, Malawi, Somalia, Tanzania, Eritrea) in the SSA, the annual average (or weighted average of the seasons) of the post harvest losses for Maize over the period 2003–2010 were about 20% or more (see the African Post-harvest Losses Information System via http://publications.jrc.ec.europa.eu/repository/bitstream/111111111/15877/1/lbna24712enc.pdf [Accessed: 18th October 2018]). Extension services or initiatives to sensitize and train smallholder farmers on how to minimize pre- and post-harvest losses are crucial to address food insecurity challenge and could therefore be strengthened and supported across the SSA by the government or funders.

3 | POLICY ON POVERTY ALLEVIATION AMID CLIMATE CHANGE

Often, anthropogenic factors play a role in the emission of greenhouse gases. Greenhouse gas forcing is the dominant cause of global warming (IPCC, 2013). By influencing climatic and/or atmospheric factors including rainfall, surface water runoff, temperature, and CO_2 fertilization, climate change will greatly modify crop productivity and even lower the agricultural potential in Africa (World Bank, 2007). Climate change represents a significant threat to the current African crop production systems and therefore farmers' livelihoods (Müller, Cramer, Hare, & Lotze-Campen, 2011). Presently, about 1 out of 3 people in the SSA is undernourished (The Borgen Project TBP, 2016). However, compared with the present, the proportion of undernourished population will increase by 25%–90% due to warming of 1.2–1.7°C by 2050 (Lloyd, Kovats, & Chalabi, 2011). According to the information provided on the 3rd June 2011 via http://www.cgiar.org by the Consultative Group on International Agricultural Research (CGIAR), several regions in Africa and South Asia that exhibited the highest food insecurity were found to be the ones where farming activities will be drastically impacted upon by climate change.

Given that agriculture (which is the key source of subsistence in the SSA) will be mainly negatively impacted upon (at various locations) by the climate change, the progress for food security under future climatic conditions requires a careful planning. Although Africa is the least contributor of greenhouse gas emission, it remains the most vulnerable continent to the impacts of climate change (IAAA, 2016; Niang et al., 2014). Besides, Africa is also the least prepared continent for weather-related risks, which exacerbate its already existing food insecurity challenge (IAAA, 2016). This clearly indicates that the focus of policy makers in the SSA could be directed toward increasing capacity for adaptation instead of reducing the emission of greenhouse gases. Even if the SSA is the least contributor of greenhouse gases, its local people will, due to their vulnerability, suffer heavily from poverty compounded by climate change impacts on socioeconomic conditions. Some would consider that the greatest contributors of greenhouse gases might be tasked to boost the capacity of poor people from the SSA in adapting to climate change impacts. Because there may be no consideration of such a liability risk, poverty alleviation in the SSA qualifies for concern at a global scale. When it comes to funding for climate change programs in Africa, it is unfortunate that apart from the slow release of funding for adaptation projects by the developed countries, the principle of common but differentiated responsibilities and respective capabilities emphasized in the Kyoto treaty has not been consistently applied (FAO, 2009a). One typical way to reduce the emissions of greenhouse gases for the SSA is by minimizing the rate of conversion of forests into farming fields. However, as highlighted before, boost in crop production in the SSA has mainly stemmed from expansion of agricultural farms. Therefore, to avoid negative effects of environmental malpractices such as deforestation and burning of forests (for expansion of arable land for production) on the carbon cycle, agricultural intensification with expedited yield and enhanced production quality could be adopted in the SSA. If agricultural intensification fails while expansion of arable land for production is being avoided, the key option for the SSA will be massive importation of food to meet future demand. The question of whether the importation of food to meet future demand will be feasible or should be avoided in a climate changing context must be of global relevance. The same question is also relevant in a social context. Import of low-cost food by SSA has a deleterious socioeconomic effect. For the continents apart from Africa, other measures for reducing the emission of greenhouse gases can be adopted, something which may also still negatively impact on the livelihoods in Africa if not undertaken in a carefully planned way. For instance, a rapid transition toward the low carbon economy (also referred to as decarbonization of economy) can destabilize the international markets. Transition to low carbon economy can affect the timing and extent of investments in agricultural systems something which has implications for capital accumulation. Instability of international food markets may imply failure to meet the dire food demand in the SSA, and this is a worrying situation for food security.

While climate change poses a major threat to agricultural potential and, therefore, complicates any measures taken to reduce poverty, agriculture remains critical in rural poverty alleviation. History holds that the success of industrialization in most countries depended on agriculture (Hazell, Poulton, Wiggins, & Dorward, 2007). It would be vital, therefore, to put in place risk management measures and strategies for the protection of social and economic conditions. Furthermore, the main challenges in SSA such as illiteracy, poverty, and food insecurity are generally in the rural areas, yet the international financial institutions have reduced their support to rural areas (FAO, 2006). Financial support from funders coupled with mutual agreement on accountability between government and the funders would be supportive to establish developments in the rural areas in a bid to curb poverty and build adaptation capacity. This could be done with a considerable focus on the roles of women who are directly involved in reduction of household poverty and food insecurity. This is because, in the SSA, crops to provide household food are mainly grown by women.

Illiteracy, food insecurity, and poverty are tightly linked to one another. Malnourished and food-insecure children have reduced cognitive abilities and poor school attendance. On the other hand, lack of education reduces productivity and earning capacity, thereby increasing vulnerability to extreme poverty and hunger; in other words, hunger and lack of education are facets of extreme poverty (FAO, 2006). In many (if not all) countries of the SSA, illiteracy is higher among women than men and the gap is likely wider in rural than urban areas. One of the Millennium Development Goals was to promote gender equality and empower women by eliminating gender disparity in all levels of education. Again, the Sustainable Development Goal (SDG) number 5 (SDG5) was set to achieve gender equality and empower all women and girls. Nevertheless, even in the present, in rural areas where gender inequality continues, women are generally and culturally burdened with the labor-related support (such as domestic chores and provision of food) for the functioning of families. Therefore, it is important that the various appropriate ministries in each country of the SSA work in collaboration on poverty alleviation, increasing access to quality education in rural areas, and reduction in food insecurity. Frameworks through which women in the rural areas can be empowered in their smallholder farming could be devised. Women in rural areas could be trained on good farming practices and empowered with management or key roles in seed distribution systems. Apart from providing relevant infrastructure and facilities required, the government could ensure free access to good quality education especially at primary and secondary levels to both girls and boys without disparity. This should be the case in both rural and urban areas. Of course, the education must also be relevant for sustainable rural development. Women need to be given equal opportunities for job, earning, and poverty alleviation. For the youth in rural communities, informal training tailored toward self-employment could be organized.

The impact-oriented adaptation strategy for climate change could be linked with poverty alleviation (at household level, if possible). Focus should be directed toward poverty alleviation in rural areas. In the opinion of this paper's author, one of the strategies for poverty reduction entails the consideration of an engaged civil society in which there is a clear space for consultation on policy regarding poverty alleviation. The need to incorporate priority needs or interests of the poor people (Driscoll & Evans, 2005) should be considered in such a consultation. The poor people (who are, actually, the subject matter) tends to be, in many cases, not well represented in the poverty reduction policy making or strategies. Some of the priority needs of the poor include food, health care, shelter, education, electricity, and employment. Compared with other regions of the world, the SSA has the highest percentage of the population that is food-insecure. About 80% of the people in the SSA live without electricity and instead rely on firewood, charcoal, or dung for cooking (TBP, 2016). The African continent has about 40% of the total global population that lack access to clean water; and due to poverty, more than 500 million people suffer from waterborne diseases (TBP, 2016). Due to an inadequate health care, poor sanitation, and hygiene, there are many deaths of babies from Malaria, and a lot of women still die during childbirth or pregnancy. The number of the unemployed people is high in the SSA. Besides, the job markets in the SSA are characterized by lower-than-expected quality jobs, thereby leaving minimal number of the employed people who can afford to save for retirement. In summary, for poverty alleviation in the SSA, strategies that address both the causes and consequences of poverty must be established and/or strengthened.

There are a number of challenges regarding food distribution. Traditionally, producers sell directly to the consumers. On the other hand, the tendency to collect food at a selected central location with subsequent distribution to potential market areas is on the increase. However, according to the World Bank (2012), some of the obstacles to African trade in food staples comprise variable import tariffs and quotas, export and import bans, restrictive rules of origin, and price controls. These factors make food prices volatile and market conditions uncertain. It seems reasonable that governments in Africa could come up with (or strongly implement) policies that can encourage regional food trade. Borders could always be open for food to be supplied to poverty-stricken homes that need support. Another trade-related problem is lack of competitive markets for food staples. Clear policy that attracts private investors to boost crop production by empowering farmers through provision of capital and machinery is desirable. Policy on food distribution networks can be tailored toward increasing benefits to the local farmers or consumers to guarantee sufficient amount of household food at the right price.

Governance in the various countries of the SSA needs to strongly embrace transparency, accountability, and integrity. Possible frameworks that exist to unify government priorities in agriculture and food security could be formed and/or strengthened. A typical example of such a framework is the Comprehensive Africa Agriculture Development Programme (CAADP) formed from the agreement (in a meeting of 2003 in Maputo) that requires allocation of at least 10% of public or national expenditures to the agricultural sector. However, the pace of compliance with the Maputo declaration was so low (CAADP, 2015) that the CAADP's first target of 6% annual growth in agricultural gross domestic product (GDP) was not achieved. Eventually, to sustain CAADP momentum, there was the Malabo Declaration of 2014 to, among others: (a) halve poverty by 2025, (b) boost intra-African trade in agricultural commodities and services, (c) end hunger by 2025 through doubling the current agricultural productivity levels and through halving the current levels of post-harvest losses by the year 2025 (FAO, 2017b). Apart from the need for technical and financial support to implement or achieve such promising targets of the Malabo Declaration, cooperation and coordinated efforts are required among the various stakeholders including farmers, financial institutions, research institutions, policy makers, and others. Whereas financial support from donors can be required especially to be directed toward attracting innovative entrepreneurship schemes for boosting employment, the policy makers and local stakeholders in the SSA could embrace opportunities to make tough choices that can push poverty alleviation steps off the starting level. This would provide a firm platform to realize the SDG number 1, which emphasizes the end of poverty in all its forms everywhere. According to information found on the link https://sustainabledevelopment.un.org/sdg1 (accessed: 26 March 2018), intensified focus should be directed to the SSA to alleviate suffering and to build resilience of the population still living in extreme poverty by boosting their incomes. Extreme poverty is mainly in the rural areas. Therefore, the focus of ending poverty could be first, as highlighted before, be directed at the household level in the rural areas.

Impacts of climate change are of concern to multiple sectors such as water resources, agriculture, fishery, tourism, forestry. This can generate serious conflict of interests from the policy makers or stakeholders of the various sectors. However, climate change should be considered as a component of the broad challenge of sustainable development (Banuri & Opschoor, 2007; IPCC, 2001). Therefore, in the case where possible conflicts may arise with respect to poverty alleviation or boosting food production and support for economic growth, differences in priorities could be first addressed before allocation of resources for various possible adaptation measures.

Natural resources can be used to generate opportunities for poverty alleviation (Figure 5). This can be possible through coordinated support between policy makers, investors, and international donors. Some natural resources are shared by various countries; for instance, Lake Victoria is shared among Uganda,

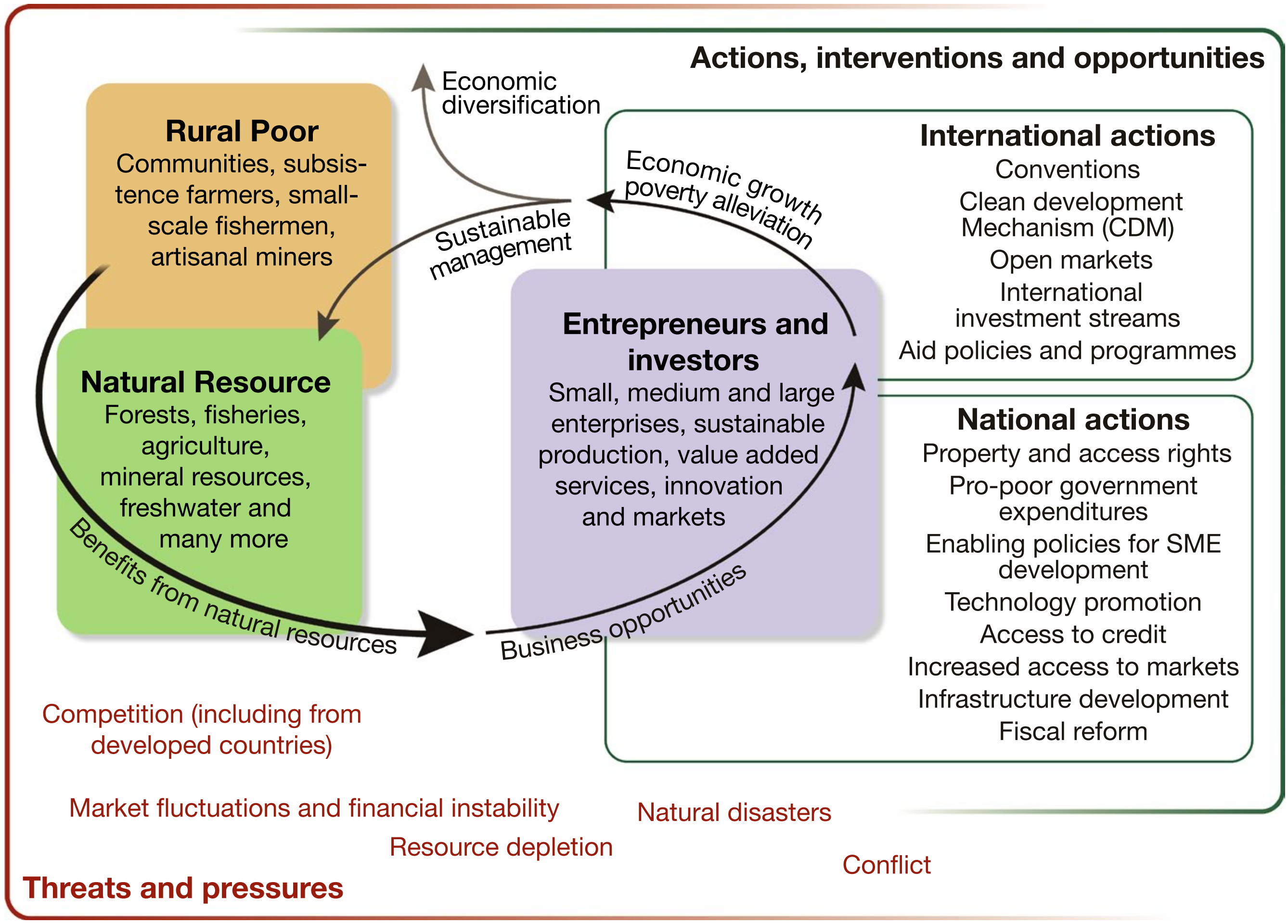

FIGURE 5 The use of natural resources for poverty alleviation (Source: GRID-Arendal, 2008c)

Kenya, and Tanzania in East Africa, while River Nile runs through several countries in Africa, and the Nile basin extends in 11 countries including Uganda, Kenya, Tanzania, Rwanda, Burundi, Democratic Republic of Congo, Sudan, South Sudan, Ethiopia, Eritrea, and Egypt. For natural resources that are shared among countries, a framework that promotes cooperation among countries with clear strategies to eliminate possible differences that could arise in terms of political or socioeconomic setting needs to be formed and/or adhered to. The opportunities to alleviate poverty could be undertaken in a way that ensures sustainability of the natural resources. To promote business opportunities across the SSA given the available natural resources, policy makers need to eradicate conflicts, which are responsible for displacements of the local population.

4 | SCIENCE SUPPORTED BY POLICY

According to Challinor et al. (2016), crop duration will become significantly reduced as early as 2018 in some regions. This will cause potential reduction in yield for most parts of Africa (Climate Change, Agriculture and Food Security CCAFS, 2016). The process of developing, delivering and adopting new varieties by the farmers can take up to 30 years (Challinor et al., 2016) making adaptation-related farming potentially too slow to keep up with climate change. In development and dissemination of new varieties, policy makers from the various countries across Africa need to: (a) embark on speedy variety testing and approval, (b) address the possible factors that lower rates of adoption by the smallholder farmers, and (c) ensure little or no restriction to accessibility of the new seeds by the smallholder farmers as well as both private and public seed systems. Genetic modification would be crucial to speed up some of the processes involved in development of new crop varieties. However, the question of whether the existing ban on the GM crop varieties by many African countries should be lifted remains a political and scientific question to be answered given the need to minimize food insecurity by adapting to climate change impacts on crop production.

Institutional capacity building is another important area that requires focus. An increased expenditure is needed to support science and development. As highlighted before, global collaboration could be vital for scientific research relevant for food security. Support needs to be provided for education and training at various levels such as undergraduate, postgraduate, doctoral, and postdoctoral levels. Here, girls or women should be given equal opportunity and access to the education. The acquired science and technology skills should be put into practice. In other words, quality jobs should be provided to reverse the rampant tendencies of Africans seeking employment opportunities in other continents. Furthermore, it is a common practice that the educated leave rural for urban areas in search for employment opportunities. However, the creation of jobs should be done in such a way as to attract employment even in the rural areas.

How the scientists can directly reach and interact with the smallholder farmers regarding the need to improve crop production should be well established or strengthened. In this line, Participatory Plant Breeding (PPB) can be preferred to the Conventional Plant Breeding (CPB). CPB is mainly done by trained breeders in laboratory or controlled environments. In CPB, the local farming conditions are not clearly understood for consideration in a case-specific way. However, PPB comprises the involvement of farmers at different stages of a plant breeding. In PPB, participation of the farmers in, for instance, selection of the germplasm, provision of fields where to host trials, choice on which plants are superior to warrant further breeding consideration, decision of what and how seed activities should be done, can enhance breeding efficiency. Participation of farmers in breeding (with a considerable focus on the roles of women in growing food crops) is a critical step of adoption of new crop varieties. To ensure interactions between locally based scientists and farmers, increased support is required for extension services.

Predictions on climate change are now becoming more abundant than they were in the past. However, there are still some gaps that the policy makers could fill. Across the SSA, there is a general lack of long-term and high-quality observed data on weather conditions (Onyutha, 2018b). The observed data are required for calibration of climate models before predictions of future climatic conditions. Thus, the policy makers in Africa need to increase investments in weather data collection. Furthermore, clear policy on data sharing should be made and adopted to permit data access by researchers in support of scientific research.

There should be a systematic coordination for planning of adaptation measures. Platforms on which the policy makers could obtain influential scientific advice given by scientists from various institutions or networks could be established and/or strengthened. The financial cost and/or benefit of adopting a possible strategy for crop production by smallholder farmers given the scientific information could also be explored.

5 | POLICY SUPPORTED BY SCIENCE

To address food insecurity challenge, scientific information to be provided should be relevant for actionable policy. According to Donatti, Harvey, Martinez-Rodriguez, Vignola, and Rodriguez (2017), lack of scientific and technical information hinders policy makers from developing policies that help smallholder farmers adapt to climate change. It is well known that crop varieties that will enhance future food production are needed (Burke et al., 2009; Mba et al., 2012). For the development of the new crop varieties, a number of factors are important to be considered, for instance, CO_2 fertilization, high soil temperature, extreme air temperature, prolonged dry condition, and waterlogging. These factors affect crop growth or development in different ways. For instance, high soil temperature promotes fungal growth, thereby threatening the health and survival of seedlings (Patz, Olson, Uejo, & Gibbs, 2008). An increase in the mean temperature shortens crop duration and reduces the time required for biomass accumulation or yield despite the available rains and solar radiation (Asseng et al., 2015; Bassu et al., 2014). Based on the specific crop type and the region, an assumption of CO_2 fertilization may even reverse the direction of impacts (Serdeczny et al., 2016). While C3 crops should benefit from elevated CO_2 (Serdeczny et al., 2016), the benefits for C4 crops (such as maize and sorghum) may currently be overestimated (Roudier, Sultan, Quirion, & Berg, 2011). Extreme climatic conditions can alter the ecology of plant pathogens (Patz et al., 2008). Breeders and seed companies should clearly explain the benefits and cost associated with their varieties, with reference to probable climatic challenges.

Whether and how crop production in Africa can be improved to a significant level that meets the future food demand could also be addressed by the scientists. In the opinion of this paper's author, relevant information that the scientists could attempt to provide comprises:

1) vulnerability of the various agroecological zones to climate change impacts,
2) impacts (per hectare) of climate change on production of both indigenous and improved crop varieties when planted in each agroecological zone,
3) comparison of crop durations in the present and future climatic conditions for the various agroecological zones,
4) climate change impacts (if any) on soil quality and/or fertility in the various agroecological zones,
5) climate change effects on incidence and/or severity of diseases for different crop varieties suitable for each agroecological zone,

6) comparison of degeneration rates of the various crop varieties for the present and future climatic conditions in each agroecological zone,
7) the amount by which climate change impacts on rainfall, temperature, alteration in soil fertility, and CO_2 fertilization (when considered both individually and jointly) will affect crop yields across the various agroecological zones,
8) scientific strategies that the smallholder farmers could adopt with respect to (1–7),
9) the financial costs and/or benefits of adopting such strategies in (8),
10) the questions of how and to what extent will the climate change alter the distribution of agroecological zones in Africa? What will be the implications of such changes on food security in the various agroecological zones?

There are various uncertainty sources, which influence results of climate change impact investigations. Uncertainties are majorly due to: modeling of various processes (model uncertainty), chaos in the climate system (internal variability), and future greenhouse gas emissions and their associated effects on the climate system (scenario uncertainty). Further uncertainties are due to the influence from the selection of: downscaling methods, generation of climate models, emission scenario, secondary models (like the crop models) which simulate climate change impacts based on the outputs of climate models, etc. Results from several models that simulate climate change impacts as well as evaluations of the intermodel differences should be considered (Onyutha, 2016). In studies on the investigation of climate change impacts, multiple GCMs should be applied to generate a range of projections to limit the influence of errors and uncertainty in one model (Tebaldi & Knutti, 2007). The choice of the downscaling method can be made on a case-by-case basis in line with the objectives of the climate change impact investigation (Onyutha, Tabari, Rutkowska, Nyeko-Ogiramoi, & Willems, 2016). A critical area for improvement in the scientific information on climate change impacts is the focus on estimating and reporting uncertainty to policy makers. The scientists should attempt to elaborate on what implications the uncertainties would have on expenditures related to climate change adaptation measures.

6 | CONCLUSION

Climate change impacts on agriculture compound the challenge of increasing food supply to meet future demand of the projected high African population. To plan measures for adaptation to climate change impacts, linkages among food insecurity, poverty, and illiteracy should be considered. An improvement in adaptive capacity should be made highly localized to household levels and importantly tailored toward empowerment of women. Efforts on yield gap closure should be supplemented with tackling challenges regarding food distribution, promotion of non-farm income-generating activities, and unification of government priorities in agriculture and food security. Science–policy interfacing is crucial in planning and implementation of adaptation measures with respect to the climate change impacts. Governance in the sub-Saharan Africa should strongly embrace transparency, accountability, and integrity. Several sources of uncertainties exist in prediction of future climatic conditions. These uncertainties influence results of climate change impact investigations. Therefore, estimates of uncertainties in predicting future climate and their implications on expenditure related to adaptation should always be made in an integrated way and reported to support actionable policies. Continuous advances toward improvement in climate models, for instance, by refining spatial and temporal scales and by increasing capacity of the models to reproduce natural variability in observed long-term climatological variables like rainfall (Onyutha, Rutkowska, Nyeko-Ogiramoi, & Willems, 2018) should be promoted and supported through an adequate investment in climate science. Global collaboration (especially in science) is key in ensuring food security in SSA. In summary, this paper can be considered as an incentive to address the challenges of food insecurity in Africa while putting science–policy interfacing (and global collaboration) into perspective.

CONFLICT OF INTEREST

The author declares no conflict of interest and no competing financial interests.

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