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Use of Indigenous Knowledge as a Strategy for Climate Change Adaptation among Farmers in sub-Saharan Africa: Implications for Policy

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Authors' contributions

This work was carried out in collaboration between all authors. Author ENA designed the study, wrote the protocol, and wrote the first draft of the manuscript. Authors RNM and MNO managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The study discusses use of indigenous knowledge as a strategy for climate change adaptation among farmers in sub-Saharan Africa. The local farmers in this region through the indigenous knowledge systems have developed and implemented extensive adaptation strategies that have enabled them reduce vulnerability to climate variability and change over the years. However, this knowledge is rarely taken into consideration in the design and implementation of modern mitigation and adaptation strategies. This paper highlights some indigenous adaptation strategies that have been practiced in sub-Saharan Africa and the benefits of integrating such indigenous knowledge into formal climate change adaptation strategies. The study recommends the need to incorporate indigenous knowledge into climate change policies that can lead to the development of effective adaptation strategies that are cost-effective, participatory and sustainable.

Keywords: *Indigenous; knowledge; adaptation; strategy; climate change; farmers; sub-Saharan Africa.*

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1. INTRODUCTION

The importance of indigenous knowledge has been realized in the design and implementation of sustainable development projects, little has been done to incorporate this into formal climate change adaptation strategies. Indigenous knowledge has been defined as institutionalized local knowledge that has been built upon and passed on from one generation to the other by word of mouth [1,2]. It is the basis for local-level decision-making in many rural communities. Indigenous knowledge has value not only for the culture in which it evolves, but also for scientists and planners striving to improve conditions in rural localities [3]. The knowledge set is influenced by the previous generations' observations and experiment and provides an inherent connection to one's surroundings and environment. Therefore indigenous knowledge is transferable and provides relationships that connect people directly to the environments and the changes that occur within it, including climate change [4].

Climate change cannot be separated from sustainable development as sustainable development may be the most effective way to frame the mitigation question and a crucial dimension of climate change adaptation and impacts [5,6]. Integrating indigenous knowledge into climate change policies can lead to the development of effective adaptation strategies that are cost-effective, participatory and sustainable [7,8]. Adaptation methods are those strategies that enable the individual or the community to cope with or adjust to the impacts of the climate in the local areas. Such strategies will include the adoption of efficient environmental resources management practices such as the planting of early maturing crops, adoption of hardy varieties of crops and selective keeping of livestock in areas where rainfall declined.

However, incorporating indigenous knowledge into climate change concerns should not be done at the expense of modern/western scientific knowledge. Indigenous knowledge should complement rather than compete with global knowledge systems.

Local farmers in sub-Saharan Africa have been known to conserve carbon (C) in soils through the use of zero tilling practices in cultivation, mulching and other soil management techniques [9,10]. Natural mulches moderate soil temperatures and extremes, suppress diseases and harmful pests and conserve soil moisture. Before the advent of chemical fertilizers, local farmers largely depended on organic farming, which also is capable of reducing GHG emissions. It is widely recognized that forests play an important role in the global carbon cycle by sequestering and storing carbon [11,12]

Local farmers are known to have practiced the fallow system of cultivation, which encouraged the development of forests. It may be argued that with the growth in population, lengths of fallow have been reduced to the extent that the practice no longer exists in certain areas. However, one must not forget that the importance of forests have been recognized by traditional institutions to the extent that communal forest reserves were very common in traditional societies. Besides the fact that these well managed forests provided food and timber resources to the community, they also served as carbon sinks. It is recognition of the role of forests in climate change that has influenced participants of the Kyoto Protocol to allow countries to include carbon sequestered in forests in a country's emission requirements [13].

Agro forestry is another practice that has been very effective in carbon sequestration. It is a rational land-use planning system that tries to find some balance in the raising of food crops

and forests [14]. A practice similar to this has been described in south western part of Nigeria to raise shade tolerant crops such as *Dioscorea spp* and cocoyam in essentially a permanent forest setting [15]. In addition to the fact that agro forestry techniques can be perfected to cope with the new conditions that are anticipated under a drier condition and a higher population density, they lead to an increase in the amount of organic matter in the soil thereby improving agricultural productivity and reducing the pressure exerted on forests.

Local knowledge is vital for preserving bio-diversity, which is considered a very successful adaptation strategy. Through the World Bank, gene banks have been established to preserve genetic information of local varieties or indigenous species. Genetic traits of these species and the knowledge of cultivars may prove instrumental in future breeding programs to introduce resistance against pests or diseases or endurance for harsh climatic conditions. A major criticism of this initiative is that preserving genetic traits without preserving the knowledge of the husbandry may prove futile as the seeds and clones stored in seed banks do not carry the instructions on how to grow them [16]. Hence, these gene banks should cooperate with farmers and communities who still cultivate local varieties to preserve such essential knowledge and skills in situ.

Local farmers in sub-Saharan Africa have developed several adaptation measures that have enabled them to reduce vulnerability to climate variability and extremes. One important step in reducing the vulnerability of a climatic hazard is the development of an early warning system for the prediction or forecast of the event [17]. There is a wealth of local knowledge based on predicting weather and climate. A study of weather knowledge in various parts of the sub-Saharan Africa reveals the wealth of knowledge that farmers possess. These farmers have developed intricate systems of gathering, prediction, interpretation and decision-making in relation to weather. These systems of climate forecasts have been very helpful to the farmers in managing their vulnerability to a very great extent. Farmers are known to make decisions on cropping patterns based on local predictions of climate and decisions on planting dates based on complex cultural models of weather.

It is anticipated that climate variability and change in sub-Saharan Africa will have overwhelming impacts on agriculture and land use, ecosystem and biodiversity, human settlements, diseases and health and water resources. With respect to agriculture and land use, climate change will likely elicit a significant change in agricultural production both in terms of the quantum of products as well as the location or area of production. For example, the change is expected to lead, among other things to a shift in rainfall belts. Since agriculture is largely rain-fed in the sub-Saharan Africa, this will be accompanied by a shift in the traditional areas of production of certain crops with all the possible negative consequences that this may bring to the local people [18].

Temperature increases and decline in rainfall for example, will cause ecological stresses that could impair the functioning of ecological systems particularly in terms of plant growth and development. Settlements will similarly be affected as difficult conditions force people to move to marginal lands. The impacts of such diseases that luxuriate under high temperatures may in all probability be amplified under a changing climate driven by increased temperature. For example, it is anticipated that there will be a marked increase in the scourge of malaria across the sub-Saharan Africa. Water resources will be similarly affected as surface and ground water depend on moisture from precipitation hence, reduced precipitation will lead to decline in local water supply in many areas. The magnitude of these impacts in the various human systems will be influenced by the level of their vulnerability to climate change [19].

At farm level, the practice of organic agriculture is one of the most important measures for adaptation to climate change by farmers. Organic agriculture is a holistic production management system which enhances agro-ecosystem health, utilizing both traditional and scientific knowledge [20]. It prevents nutrient and water loss through high organic matter content and soil covers, thus making soils more resilient to floods, drought and land degradation processes. In organic agriculture, soil fertility is maintained mainly through farm internal inputs (organic manures, legume production, crop rotation), rejection of energy demanding synthetic fertilizers and plant protection agents with less or no use of fossil fuel [21].

The process of organic agriculture, being a holistic approach in climatic change adaptation can be classified as two major kinds of modification in the production systems: (a) increased diversification and (b) protecting sensitive growth stages by managing the crops to ensure that these critical stages do not coincide with very harsh climatic conditions such as mid-season droughts [22]. In Nigeria, adaptation strategies perceived by farmers as appropriate include: crop diversification using different crop varieties, varying the planting dates, harvesting dates, increasing the use of irrigation, increasing the use of water and soil conservation techniques, shading and shelter, shortening the length of the growing season and diversifying from farming to non-farming activities. Rural women are involved in both farm and non-farm occupations in order to cope with challenges of climate change [23]. Some strategies that serve as an important form of insurance against rainfall variability are: increasing diversification by planting crops that are drought tolerant and/or resistant to temperature stresses, taking full advantage of the available water and making efficient use of it, and growing a variety of crops on the same plot or on different plots, thus reducing the risk of complete crop failure since different crops are affected differently by climate changes [24]. Such farm-level adaptations aim at increasing productivity and dealing with existing climatic conditions and draw on farmers' knowledge and farming experience.

However, in continuous coping with extreme weather events and climatic variability, farmers living in harsh environments in the regions of Africa, Asia and Latin America have developed and/or inherited complex farming systems that have the potential to bring solutions to many uncertainties facing humanity in an era of climate change. The farming systems have been managed in ways that enables the small farming families to meet their subsistence needs in the midst of environmental variability without depending much on modern agricultural technologies [25].

Developmental projects are known to have been created, funded and managed by outside resources and introduced into rural communities with the hopes and promises of impacting their lives. These projects did not take into consideration the culture of the people and resulted in low participation and success rates [26, 27, 28]. As a result of these failures, there was a growing interest in the incorporation of local knowledge and traditions to increase project participation rate and provide environmentally sound approaches to development. Although research is gradually recognizing the importance of indigenous knowledge systems in developmental studies, the value of indigenous knowledge in climate change studies has received little attention.

Climate change adaptation projects can learn from the experiences of other developmental projects by recognizing the value of indigenous knowledge systems. Two major problems that can be identified as obstacles to integrating indigenous knowledge into formal climate change mitigation and adaptation strategies are: recognizing the need to, and how to actually integrate indigenous knowledge into formal western science.

Indigenous knowledge adds value to climate change studies in the following ways. First, indigenous knowledge systems create a moral economy. It identifies a person within a cultural context, therefore providing decision-making processes or rules of thumb to be followed based on observed indicators or relationships within events [29, 30]. Members of communities act within these rules to maintain security and assurance or risk isolation from their community. In an uncertain and biased world, these rules provide people with a sense of community belonging and stability. Second, indigenous knowledge is increasingly exhibiting a resemblance with scientific methods as many ideas in indigenous knowledge that were once regarded as primitive and misguided, are now seen as appropriate and sophisticated. Third, indigenous knowledge systems provide mechanisms for participatory approaches. A major requirement for the sustainability of any project is that the local population must be seen as partners in the project with joint ownership. This is best achieved when the communities effectively participate in the design and implementation of such projects. Fourth, indigenous knowledge systems share the same guiding principles with sustainable development framework with 3E concerns-Economy, Equity, and Environment [31]. The essence of most climate change projects is to reduce poverty and ensure sustainable development. This can be facilitated by the integration of indigenous knowledge into climate change policy. Fifth, indigenous knowledge systems can facilitate understanding and effective communication and increase the rate of dissemination and utilization of climate change adaptation options. Sustainable land and water management combined with innovative agricultural technologies could help farmers adapt to climate change impacts [32]. New knowledge, technology and policy for agriculture have never been more critical and adaptation strategies must urgently be applied to national and regional development programmes in order to reduce vulnerability among rural farmers.

The paper therefore reviews use of indigenous knowledge as a strategy for climate change adaptation among farmers in sub-Saharan Africa under the following sub-headings, which also forms the specific objectives of the study:

1. Water and land resources usage as indigenous adaptation measures.
2. Land tenure issues and adaptation to climate change in sub-Saharan Africa.
3. Use of climate-proof crops and pests control methods.
4. Climate change and rural farmers; and
5. Adaptation indigenous knowledge practices used by farmers.

The paper is a review paper and it relied heavily on secondary data from current literature and observations on climate change in the study area.

2. WATER AND LAND RESOURCES USAGE AS INDIGENOUS ADAPTATION MEASURES

Water is critical for agriculture across the semi-arid tropics [33]. Although rainfall predictions remain uncertain, scientists agree that climate change will reduce water availability and storage, and warmer temperatures will increase the amount of water needed by crops. Improving crop production in these regions largely depends on better capture and storage of rainwater. But rainwater harvesting and storage technologies remain underdeveloped. And we know little about the economic viability of such systems-implementing them may well require financial investment beyond the capacity of most rural communities [34].

Most agriculture adaptation options have a positive impact on water resources and management. Improved cropland and grazing management can increase water storage and infiltration, reducing loss through runoff and leading to greater water availability in the soil and enhancing ecosystem water balance [35,36]. This is true also for manure application and, in general for other approaches that maintain or increase soil organic matter [37]. Additionally, conservation agriculture often reduces evaporation from the soil, especially in drier environments. Since the combined water loss through runoff and evaporation often leaves less than half of the rainfall (or irrigated water) available for crops, the adoption of these technologies can increase crop yields and food production. Other technologies are more explicitly related to water management, example water conservation and harvesting and efficient irrigation can effectively increase the soil carbon pool [38]. Terraces and contour farming also have great impacts on water, providing for storage of rainfall and discharging excess runoff through a drainage system [39]. Nevertheless, in areas where water management focuses on drainage to lower water tables for crop and forage production, such as organic soils that tend to be highly fertile, there is the risk of exposing soil organic matter to aerobic decomposition, promoting substantial losses of soil carbon [40]. Other practices increase or maintain water quality: technologies that sequester carbon in grassland soils tend to maximize vegetative cover and reduce water induced erosion and sediment load [41]. Enhanced soil moisture should also reduce vulnerability to low rainfall and drought conditions, thus increasing the capacity of farming systems to adapt to climate change. Much of the concern over water resources in agriculture stems from a lack of moisture to maintain crop or forage production at optimal levels. This issue is particularly acute in dry land agricultural systems. Irrigation is the most common and direct way for producers to reduce water stress to crops and forage grasses, but improved cropland and grazing management have also been viable alternative strategies to improve soil water regimes. Also, in much of the world maintaining adequate moisture during extreme events is perhaps the most important aspect of adapting to future warmer climates. About 95 per cent of water in developing countries is used to irrigate farmlands, policies to improve irrigation efficiency are also critical. Research is needed on water flows and water quality and infrastructure needs to be improved [42].

A wide variety of traditional and innovative rainwater harvesting systems is found in Africa's Sahel zone. In semi-arid areas of Niger, small-scale farmers use planting pits to harvest rainwater and rehabilitate degraded land for cultivation of millet and sorghum. The technology improves infiltration and increases nutrient availability on sandy and loamy soils, leading to significant increases in yields, improved soil cover and reduced downstream flooding [43].

Farmers harvest water from rooftops and divert water from natural springs into tanks. This ensures that they have a substantial amount of water stored up. In case of a drought, the stored water will be able to sustain them for about five months depending on the volume of the tank. The water is also used for supplementary irrigation of vegetables and crops. Some farmers dig infiltration pits along contours. Water collects in the pits during the rainy period. When the weather becomes dry, as in the case of a short period of rains, the water infiltrates underground and is used by the plants. Crops can grow up to maturity by using this conserved moisture. Farmers' experience shows that even if there are only five days with rain in the whole rainy season, the crops will reach maturity using conserved and harvested water in the pits [44]. Farmers practicing dry season agriculture harvest rain water and conserve it in basins or wells. In the dry season, the water conserved in the wells and basins is used for irrigation. Combinations of indigenous and scientific techniques have the potentialities of contributing to productivity and also sustaining the farming system.

Crops are grown under a range of water management regimes, from simple soil tillage aimed at increasing the infiltration of rainfall, to sophisticated irrigation technologies and management. However, about 80 percent of the estimated 1.4 billion ha of crop land worldwide is rain-fed and accounts for about 60 percent of global agricultural output. Under rain-fed conditions, water management attempts to control the amount of water available to a crop through the opportunistic deviation of the rainwater pathway towards enhanced moisture storage in the root zone. However, the timing of the water application is still dictated by rainfall patterns and not by the farmer [45].

About 20 percent of the world's cropped area is irrigated, and produces about 40 percent of total agricultural output [46]. Higher cropping intensities and higher average yields account for this level of productivity. By controlling both the amount and timing of water applied to crops, irrigation facilitates the concentration of inputs to boost land productivity. Farmers apply water to crops to stabilize and raise yields and to increase the number of crops grown per year. Globally, irrigated yields are two to three times greater than rain-fed yields. Thus, a reliable and flexible supply of water is vital for high value, high-input cropping systems. However, the economic risk is also much greater than under lower input rain-fed cropping. Irrigation can also produce negative consequences for the environment, including soil salinization and nitrate contamination of aquifers.

Growing pressure from competing demands for water, along with environmental imperatives means that agriculture must obtain "more crops from fewer drops" and with less environmental impact. That is a significant challenge, and implies that water management for sustainable crop production intensification will need to anticipate smarter, precision agriculture. It will also require water management in agriculture to become much more adept at accounting for its water use in economic, social and environmental terms [47].

Prospects for sustainable intensification vary considerably across different production systems, with different external drivers of demand. In general, however, the sustainability of intensified crop production, whether rain-fed or irrigated, will depend on the adoption of ecosystem approaches such as conservation agriculture, along with other key practices, including use of high-yielding varieties and good quality seeds, and integrated pest management.

Policymakers will need to assess accurately the relative contributions of rain-fed and irrigated production at national level. If rain-fed production can be stabilized by enhanced soil moisture storage, the physical and socio-economic circumstances under which this can occur need to be well identified and defined.

With regard to institutions, there is a need for re-organization and reinforcement of advisory services for farmers dependent on rain-fed agriculture, and renewed efforts to promote crop insurance for small-scale producers. A sharper analysis of rainfall patterns and soil moisture deficits will be needed to stabilize production from existing rain-fed systems under climate change impacts.

Stern noted that better land and crop management are equally important. There are already some promising and economically viable technologies to reduce risk of crop failure, improve soil fertility and increase productivity under variable climatic conditions [48]. These include methods to reduce agricultural inputs, such as fertilizer micro dosing and smarter application of pesticides, as well as technologies for minimizing soil disturbance such as reduced tillage, conservation agriculture and crop rotation. Revising planting dates, plant densities and crop

sequences can help cope with delayed rainy seasons, longer dry spells and earlier plant maturity that are already being observed across parts of Africa including Malawi, Mozambique, Zambia and Zimbabwe. However, a key challenge will be how to integrate modern scientific knowledge into indigenous knowledge system in order to safeguard biodiversity for food and agriculture. This can be enhanced by taking into consideration the local knowledge of indigenous people before developing appropriate modern technologies to suit the needs of the end users. Modern scientific knowledge should complement indigenous knowledge rather than replacing it. This will in turn help to achieve better results in coping with challenges of climate change.

The major sources of land based adaptation from agriculture according to IPCC are described below [49]:

- Improved agronomic practices generate higher inputs of carbon (C) residue, leading to increased soil carbon storage [50]. Such practices include using improved crop varieties, extending crop rotations, avoiding use of bare fallow and using cover crops.
- Integrated nutrient management can reduce emissions on-site by reducing leaching and volatile losses, improving nitrogen (N) use efficiency through precision farming and improving fertilizer application timing [51].
- Increasing available water in the root zone through water management can enhance biomass production, increase the amount of above-ground and the root biomass returned to the soil, and improve soil organic carbon concentration. Soil and water conservation measures such as the construction of soil or stone bunds, drainage measures and irrigation constitute important aspects of water management.
- Tillage management practices with minimal soil disturbance and incorporation of crop residue decrease soil C losses through enhanced decomposition and reduced erosion. Systems that retain crop residues tend to increase soil C because these residues are the precursors of soil organic matter.

3. LAND TENURE ISSUES AND ADAPTATION TO CLIMATE CHANGE IN SUB-SAHARAN AFRICA

Some of the recent climate change literature examines issues of vulnerability and adaptation including the challenges and opportunities for support to collective action to improve land use systems and livelihoods resilience [52, 53]. Current assessments of the challenges of adaptation however focus on the scope for substitution of existing crops with more drought tolerant species and varieties, adaptive research for dry land crops to develop more suitable varieties, land use management and agro forestry to improve water retention and promote crop diversification, improve credit availability, crop insurance, improved weather forecasting and introducing payments for avoided deforestation / reforestation by small farmers to substitute for loss of farm income [54]. Secure land rights for dry land farmers provided either on a farm household or community basis are likely to increase the incentives for investment and people to invest in and take advantage of these types of adaptation.

Quan and Dyer noted that the effects of climate change and variability are felt through changes in natural ecosystems, land capability and land use systems [55]. Increasingly, these changes will place diminishing supplies of land under greater pressure, for both productive use and human settlement. As a result land issues and policies are key considerations for adaptation planning, which will need to strengthen land tenure and management arrangements in at risk environments, and secure supplies and access arrangements for land for resettlement and changing livelihood demands.

The land tenure implications of climate change impacts on agriculture are also difficult to predict. Although not a simple consequence of climate change, but of development and population pressures and political economy, increasing scarcity of good quality agricultural land will increase land pressure and competition, further weakening the asset base of the poor in the absence of guarantees of tenure security. Combined with decreases in crop productivity this would hasten the exit of the poor from agriculture. Thus, in addition to facilitating adaptations to changing rainfall conditions, another set of challenges for land policy is to facilitate migration, diversification and exits from agriculture, and how best to secure the tenure rights, or provide alternative settlement and compensation for those affected. There arises the need to strengthen resilience on situ, building on existing adaptations, including established strategies involving seasonal mobility [56].

Problems of increasing climate variability are already currently experienced by Africa's farmers, The IPCC Working Group found that in the Sudano-Sahel region of Africa, persistent below-average rainfall and recurrent droughts in the late 20th century have constricted physical and ecological limits by contributing to land degradation, diminished livelihood opportunities, food insecurity, internal displacement of people, cross-border migrations and civil strife. Some impacts of climate change may already be visible. Precipitation has fallen by 50-150mm per season from 1996 to 2003 in East Africa, which has brought on a subsequent fall off of long-cycle crops [57].

Africa's dry land farmers and pastoralists face serious implications including the decreased viability of rain-fed dry land farming, changes in the geographical ranges within which arable farming and cattle raising are feasible (including possible increased opportunities as well as constraints for pastoralists in some regions), and overall increased land and water competition in dry lands. These are all issues for which Africa's dry land farmers have already been adapting to some degree to current and recent patterns of climate variability, which under climate change, are likely to be exacerbated. However, the adaptive responses required to future climate change should not in principle be very different from existing adaptations to climate variability except in scale and pace at least in the medium term and excepting extreme climate change impact scenarios. In view of this, much can be learnt from understanding how farming populations and the formal and informal institutions which shape and regulate land and resource use have responded and adapted to these changes – and in practice the changes have surely gone wider than the agricultural systems [58].

Current assessments of the challenges of adaptation however focus on the scope for substitution of existing crops with more drought tolerant species and varieties, adaptive research for dry land crops to develop more suitable varieties, land use management and agro forestry to improve water retention and promote crop diversification, wider crop insurance, improved weather forecasting and introducing payments for avoided deforestation/reforestation by small farmers to substitute for loss of farm income [59].

The survival and effective adaptation of indigenous groups therefore requires not only guarantees of tenure security over dwelling places and key livelihood and cultural resources, but guarantees of access rights to resources over wider areas, and where these also have other legitimate users, negotiated arrangements for the protection, management and sustainable use of the resources in question.

The principal land tenure policy implications of climate change risks to indigenous groups are therefore to reinforce policies, legislation and mechanisms for the practical guarantee of indigenous land and resource rights, including the provision of indigenous title, but also through legally enforceable frameworks for negotiated access and management rights to natural resources over the broader areas which constitute indigenous territories.

4. CLIMATE-PROOF CROPS

Changes in growing seasons in the tropics can also to a large degree be adapted by redeploying existing improved crop varieties that can cope with a wide range of climatic conditions. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has developed pearl millet hybrids that can cope with temperatures of 40 degrees celsius and deliver normal yields with limited water. Short duration varieties of chickpea and pigeon pea mature in 65–75 days and so can escape terminal drought at later stages of growth. What is needed now is a better understanding of the physiological mechanisms underlying heat tolerance such that more effective screening techniques for desired traits can be developed; wider gene pools to develop climate-proof crops should also be identified [60].

Kenya's Ministry of Agriculture launched high-yielding drought and disease-resistant varieties of maize, sugarcane and wheat. The seeds developed by the Kenya Agricultural Research Institute (KARI), are marketed by seed companies in Kenya, Congo, Sudan, Tanzania and Uganda [61]. However, lack of information can be a barrier to better climate change adaptation. Many farmers are expected to benefit from the existing drought resistant maize varieties.

Many farmers prefer the use of indigenous grains such as millets and sorghums that are more drought-resistant than maize and also produce high yields with very little rain. Farmers also prefer specific crop varieties for drought seasons, such as an indigenous finger millet variety as it ripens fast, and an early maturing cowpea (*Vigna unguiculata*) variety. Generally, in areas with little moisture, farmers prefer drought-tolerant crops (like *Cajanus cajan*, sweet potato, cassava, millet, and sorghum), and management techniques emphasize soil cover (such as mulching) to reduce moisture evaporation and soil runoff. These varieties that exhibit high genetic variability have a huge untapped potential to be grown in many marginal environments of Africa and elsewhere threatened by climate change. These examples are of great significance because they help the resource-poor farmers living in marginal environments, providing the basis for adaptive natural resource management strategies that provides the opportunity for diversification of cropping systems which lead to greater stability and ecological resiliency under climatic extremes.

5. PEST CONTROL METHODS

Developing technologies to help farmers control pests remain important. Climate change could have positive, negative or no impact on each pest. There is need for better models to

assess their global impact as most pest population prediction models have different spatial and temporal scales than global climate models [62]. Pests are usually controlled by cultural practices, natural enemies, host plant resistance, biopesticides and synthetic pesticides. But many of these control tactics are highly sensitive to the environment and climate change may render them less effective. It may alter the interactions between pests and their host plants, directly affecting resistance to pest control. For example, there are indications that stem rot (*Sclerotium rolfsii*) resistance in groundnut is temperature dependent, while in Kenya resistance to sorghum midge (*Stenodiplosis sorghicola*) breaks down under high humidity and moderate temperatures.

The traditional techniques used for pest control include use of hoe for weeding, intercropping and rotation patterns and pest resistant seed varieties. At germination stages, indigenous techniques such as hoe-weeding are applied while at later stages is complemented by the use of pest control chemicals as the crop grows. The implications of integrated pest management techniques are that the costs and side-effects of pest chemicals can be minimized. The uses of integrated techniques for pest management help to overcome the limitations which results from using indigenous and scientific techniques separately. Studies carried out by ILEIA and Goodell confirms this fact [63, 64].

There is an urgent need to identify and develop crops that can resist pests under variable climates. ICRISAT has started work in this area, developing mildew-resistant pearl millet in India, wilt-resistant high-yielding pigeon pea in Malawi, Mozambique and Tanzania, and rosette-resistant groundnuts in Uganda.

6. CLIMATE CHANGE AND RURAL FARMERS

Climate change will have a substantial impact on the lifestyles and livelihoods of indigenous people because of the effects on the variety of wild and remote areas where they live and the natural ecosystems. These include: polar areas, where melting ice sheets affect fish and wildlife populations; mountain environments, where glacial melt creates particular hazards such as glacial lake outbursts, and affects alpine ecosystems and water supply; remaining tropical forests. This is threatened with long term drying trends causing changes in natural resource availability and utilization; dry land environments, where pastoralist groups are reliant on mobile access to fragile grazing and water resources spread over wide distances and highly dependent on rainfall availability; and coastal wetlands and low lying island threatened by sea level rise [65].

Indigenous groups can be particularly vulnerable to climate change hazards because they face widespread discrimination and exclusion from and degradation of land and natural resources on which they depend, often as a result of government failures to recognize the legitimacy of their land and territorial rights. In this context in which indigenous people's livelihoods and cultural survival are already under threat, they also face the direct and indirect impacts of climate change on the ecosystems which have formed the traditional basis of their livelihoods.

7. ADAPTATION INDIGENOUS KNOWLEDGE PRACTICES USED BY FARMERS

Adaptation is an adjustment made to a human, ecological or physical system in response to a perceived vulnerability. Specifically, IPCC described adaptation to climate change as adjustment in natural or human systems in response to actual or expected climatic stimuli

and their effects which moderates harm or exploits beneficial opportunities [66]. Adaptation is an important component of climatic change impact and vulnerability assessment and is one of the policy options in response to climatic change impacts [67, 68]. Adaptation to climatic change is therefore critical and of concern in developing countries, particularly in Africa where vulnerability is high because ability to adapt is low [69]. In agriculture, adaptation helps farmers achieve their food, income and livelihood security objectives in the face of changing climatic and socio-economic conditions including climatic variability, extreme weather conditions such as droughts and floods and volatile short term changes in local and large-scale markets [70]. Farmers can reduce the potential damage by making tactical response to these changes.

According to Brussel, adaptive measures to climatic change in agriculture range from technological solutions to adjustments in farm management or structures and to political changes such as adaptation plans [71]. Continuing, the author categorized agricultural adaptation options into technological development, government programmes and insurance; farm production practices, and farm financial management. The first two categories are principally the responsibility of public agencies and agri-business and adaptation here could be thought of as system-wide or macro scale. The last two categories mainly involve farm level decision making by farmers. In the short run, autonomous farm level adaptation may be sufficient but in the longer run, adaptation in the form of technological and structural changes will be necessary. This will require planned strategies based on analysis of local and regional conditions [72].

The short-term adaptation measures for climate change by farmers include: crop insurance for risk coverage, crop/livestock diversification to increase productivity and protection against diseases, adjusting the timing of farm operations to reduce risks of crop damage, change crop intensity and adjust livestock management to new climatic conditions, food reserves and storage as temporary relief, changing cropping mix, permanent migration to diversify income opportunities, defining land use and tenure rights for investments [73]. On a long term note, the author stated the following as best adaptation options for climate change: development of crop and livestock technology adapted to climate change stress, develop market efficiency, irrigation and water storage expansion, efficient water use, promoting international trade, improving forecasting mechanisms, institutional strengthening and decision-making structures.

Brussel highlighted the possible short to medium term adaptation practices to changes in climate by farmers to include: (i) adjusting the timing of farm operations such as planting or sowing dates and treatments; (ii) technical solutions such as protecting overheads from frost damage or improving ventilation and cooling systems in animal shelters; (iii) choosing crops and varieties better adapted to the expected length of the growing season and water availability and more resistant to new conditions of temperature and humidity; (iv) adapting crops with the help of existing genetic diversity and new possibilities offered by biotechnology; (v) improving the effectiveness of pest and disease control through for instance better monitoring, diversified crop rotations, or integrated pest management methods; (vi) using water more efficiently by reducing water losses, improving irrigation practices and recycling or storing water; (vii) improving soil management by increasing water retention to conserve soil moisture and landscape management such as maintaining landscape features providing shelter to livestock; (viii) introducing more heat-tolerant livestock breeds and adapting diet patterns of animals under heat stress conditions [74].

With the realization of declining soil quality and productivity, several indigenous management practices have evolved over the years to conserve the soil. Some of these practices include: bush fallowing, organic manuring, intercropping, crop rotation, agro forestry and conservation tillage. Bush fallowing involves the use of natural fallows to regenerate or restore soil fertility by the farmers. In some areas, leguminous plants are used for quick restoration of soil fertility. Example, *Centrosema* spp is used to fix nitrogen into the soil in order to improve its fertility [75].

The application of compost, animal waste and domestic wastes to soil is referred to as organic manuring. This helps to maintain soil microbial activities and promote absorption of nutrients by plants. Farmers use this practice to improve soil fertility. Intercropping is a practice of cultivating more than one type of crop on a piece of land at the same time. This practice removes the risk of total crop failure as well as providing good soil cover that minimizes soil erosion. Farmers also use conservation tillage (minimum and zero tillage) to respond to rapid soil deterioration and degradation caused by conventional tillage under harsh climatic environment and fragile soils. This system has the advantage of conserving the soil because of minimal disturbance [76]. It therefore becomes pertinent for integrated approach to be developed in order to guarantee adequate food production and at the same time conserve the soil in the face of challenges of climate change.

8. CONCLUSION AND RECOMMENDATIONS

Indigenous knowledge practices have been employed successfully in adapting to climate change impacts among farmers in sub-Saharan Africa. However, it is important to note that not all indigenous practices are beneficial to the sustainable development of a local community; and not all indigenous knowledge can a priori provide the right solution for a given problem. Therefore, before adopting indigenous knowledge, integrating it into development programs or disseminating it, practices need to be scrutinized for their appropriateness just as any other technology. In addition to scientific proof, local evidence and the socio-cultural background in which the practices are embedded also need to be considered in the process of implementation and evaluation.

Organizing local people for projects to enhance agricultural resiliency to climate change must make effective use of traditional skills and knowledge, thus improving prospects for community empowerment and self-reliant development in the face of climatic variability. There is need to adopt the bottom-up participatory approach that encourages the highest level of local participation in climate change programmes designed for the rural communities as this provides valuable insight into how communities and households interact and share ideas and allows the intended beneficiaries to develop the skills and practices necessary to forge their own path and sustain the projects. Incorporating indigenous knowledge into climate change policies can lead to the development of effective adaptation strategies that are cost-effective, participatory and sustainable. There is the need therefore to integrate this local knowledge into formal adaptation policies. Institutional support is also needed in the form of information on cropping patterns; credit; crop insurance and government subsidized seeds. In the event of a dry season or drought, institutional support should be provided mostly in the form of a loan waiver in order to help the farmers cope with the effects of climate change. Institutional support, as well as increased access to education, information and technology and sustainable agricultural development could improve the overall resilience of smallholder farmers and strengthen their efforts to withstand the overall impacts of changes in climate variability and long-term climate change.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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