Increasing Africa's Agricultural Productivity

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A report by the Pan Africa Chemistry Network

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About this publication

This report is intended for an audience of policymakers in Africa with an interest in the food security of the continent. It aims to highlight, in a non-technical way, the areas where research in the chemical sciences can contribute to increasing Africa's agricultural productivity in a sustainable way.

The RSC is committed to raising awareness of the role of chemistry in addressing global challenges and it is hoped that the report will be of interest to the wider scientific community and the public.

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The Pan Africa Chemistry Network (PACN) was set up by the RSC in partnership with Syngenta, with a special focus on the Millennium Development Goals aimed at advancing the chemical sciences across Africa. It represents an innovative approach to working with universities, schools, scientists, teachers, and students. A co-ordinated approach is crucial to success and the PACN is engaging with chemical societies throughout Africa, together with the Federation of African Chemical Societies. The PACN has established regional hubs in Ethiopia and Kenya and increased the existing collaboration with universities and other partners in South Africa. Two new centres of excellence in analytical chemistry have recently been launched in Nigeria with the support of partner Procter & Gamble.

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Background

Food security is an urgent global issue. The world population passed the seven billion mark in 2011 and it is expected to reach over nine billion by 2050. However, we only have limited resources with which to feed this growing population. In 1960, one hectare of land was available for the production of food for two people. By 2050, the same amount of land will need to feed more than six people.[1] Environmental stresses such as limited water availability, climate change and variability, as well as legacies from the unsustainable management of natural resources and poor agricultural practices (soil erosion and depletion of minerals), make feeding the population a complex and challenging target.

In Africa, the issue of food security is even more acute and is affected by a combination of factors. Across the continent millions of people still live in poverty. Some areas are prone to drought and many people have no access to clean drinking water. A recent report revealed that sub-Saharan Africa has 'the lowest drinking water coverage of any region' in the world.[2] Additionally, as is the case throughout the world, most of the population increase in Africa will be via the growth of urban populations.[3] A major revitalisation of agriculture in Africa is needed to underpin development ahead of the drivers of population increase, demographic change and climate change.

Supporting the development of research in the chemical sciences and strengthening its links with other complementary disciplines across Africa and beyond needs to be a key part of a long-term plan to ensure the future food security of the continent.

In November 2011, the Pan Africa Chemistry Network (PACN), sponsored by the Royal Society of Chemistry (RSC) and Syngenta, held the first PACN congress on agricultural productivity at the International Convention Centre in Accra, Ghana. The findings and recommendations in this report represent the discussions of the 150 scientists and practitioners who attended the conference from 16 different African countries, as well as from Europe, the USA and Asia, and from the delegates who participated in the post-conference workshop that was held at the RSC in London on 23 February 2012.

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Introduction

African economies rely heavily on agriculture. It is estimated that the contribution of agriculture to the gross domestic product (GDP) is as high as 75% in some sub-Saharan countries.[4] Many of the crops grown in Africa, such as sorghum and millet, are not commonly consumed as food outside of the region, which means that strategies to increase productivity for these crops need to be led by researchers in Africa.

Models used to predict alterations in agricultural productivity in relation to climate change show a likely future improvement in many regions in the northern hemisphere (eg Europe), but predict that productivity will not improve or decline in Africa.[5] Climate change and variability can have significant effects in a number of ways. Factors such as rainfall and average temperature directly affect the growth of crops, but it is often indirect effects, such as species adaptation to climate variability and change, that produce the most significant problems for agriculture. The problem is complex because the status of a species cannot be considered in isolation; other species with which they interact must also be taken into account. The predicted effects of climate change and variability will influence crop yields in different ways, with crops such as sorghum potentially being worse affected than wheat or rice by increases in atmospheric carbon dioxide.[6]

The nature of the farming system in Africa needs to be taken into account when considering ways in which productivity can be increased. New technologies for sustainably increasing crop yields are essential, and chemical scientists, working together with scientists from other disciplines, will be critical in delivering these.

A holistic approach that examines agriculture and its impacts on the environment is needed to achieve sustainable intensification. One way is to take the agroecosystem as a whole and examine the production of food in relation to the surrounding environment, taking into account all species interactions, and not only those relating to crop production. Chemistry can help us to understand agroecosystem function, in particular, nutrient cycles and the interactions within and between species via biosignalling.

While new technologies have a key role to play in increasing agricultural productivity, any strategy must also consider the socioeconomic conditions of the continent. The large majority of farming in Africa is carried out by smallholders, so solutions must be scalable, affordable and able to reach those who need them the most if they are to have a significant impact.

Key messages and recommendations

Increasing agricultural productivity needs scientific intervention. Fundamental research in chemical sciences, in partnership with other disciplines, will help to increase our understanding in areas like the interactions between crops and pests and how plants obtain and use nutrients from the soil. This research will help to develop the technologies that can deliver higher on-farm yields. Increasing Africa's agricultural productivity will require investment in multidisciplinary research, including the infrastructure to support this research.

However, a long-term strategy to improve yields sustainably requires a supporting environment that nurtures an appropriate socioeconomic climate. This section summarises the report's key findings. It highlights how the chemical sciences and changes in the socioeconomic environment can help to improve Africa's agricultural productivity.

1. Inorganic fertilisers are an essential tool to help improve crop and soil nutrition

Access to finance is a major barrier to increasing fertiliser application. African governments need to improve access to finance for smallholders. Alternatives, such as the use of nitrogen-rich plants to enhance nutrient content are a useful supporting strategy but they cannot be used alone. Chemical scientists have a role in undertaking research into the natural mechanisms that govern these processes, thereby generating information that can help to tailor the use of fertiliser inputs to best effect.

2. Coherent multidisciplinary research programmes are required to develop new crop protection strategies

Alongside biological scientists, chemical scientists will help to develop methods for integrated pest management which take account of changes in natural interactions between species as a result of climate change. Research funding should take account of the multidisciplinary nature of the challenges that are associated with increasing agricultural productivity. Chemical inputs for crop protection can only be managed sustainably by introducing and enforcing a sensible regulatory framework. Chemical scientists need to work with governments to make sure that such regulations are pragmatic and can attain the goal of increasing productivity sustainably. It is the role of learned societies to facilitate opportunities for scientists to engage with policymakers to achieve this. The RSC should work with senior chemical scientists in Africa to identify opportunities to engage with policymakers.

3. Policies to increase agricultural productivity must take account of water usage

Chemical scientists must work with governments to develop robust standards for practices such as the recycling of water for agricultural use. Developing the technologies to achieve this in practice requires chemical scientists to work with engineers. Organisations like the RSC have a role in facilitating communication between scientists, engineers and policymakers.

4. The chemical sciences have a role in improving land management

The management of land is critical to the growth of crops and, by association, the long-term livelihood of farmers and their families. There is a challenge for chemical scientists in making existing technologies (eg soil monitoring tools and methods for remediation) scalable and affordable so that they can be used by smallholders as part of an ongoing land management strategy. The RSC needs to provide opportunities for researchers to communicate with agencies that work closely with smallholders. The PACN should look to deliver focused workshops that examine specific areas of chemical science that can improve agricultural productivity by bringing together researchers and those who work closely with farmers (eg to develop analytical tools for farming). Alongside this, policies are needed that encourage farmers to invest in sustainable farming practices and educational extension services that disseminate knowledge to farmers. The availability of long-term land leases would encourage sustainable practices and should be a priority for local authorities.

5. The implementation of technology must address the needs of the end user in African agriculture (smallholders)

In some cases, the chemical technologies that can help to increase Africa's agricultural productivity already exist, but they are not reaching the end user. Agronomists should continue to embed the practices that will ensure that smallholders can use these technologies to best effect. Extension services are an important mechanism to communicate new practices to farmers, and they should go hand-in-hand with technological advances. Non-governmental organisations that have active links with both smallholders and researchers have an important role in facilitating this. The RSC should examine existing programmes and identify areas where it can contribute knowledge to help ensure that chemical technologies for agriculture reach those who need them.

6. Funding schemes should encourage multidisciplinary collaboration between scientists in Africa and the rest of the world

International partnerships need to be driven by African scientists. Also, collaboration between African scientists is needed as they are uniquely placed to understand the social, economic and cultural drivers that affect the uptake of technology. Networks such as the PACN can help to bring together scientists across Africa and the world to provide forums for generating international collaborations. Additionally, the PACN should alert researchers within the network to funding opportunities and use its hubs in Africa to disseminate up-to-date information on funding calls.

7. Educating the next generation of researchers is vital

This will allow Africa to build its research capacity and establish the correct sequence of long-term scientific advice for extension services. Building research capacity in Africa is essential both in terms of training researchers and infrastructure development (laboratories and equipment). African governments must invest in the scientific skills pipeline from school education through to research at university level. Organisations such as the PACN have a role in supporting skills development with specialised initiatives, such as teacher training and workshops to develop researchers' skills, including skills in communication and scientific writing.

1 Crop and soil nutrition

Fertiliser use in sub-Saharan Africa is far below the global average. In 2008, an average of just over 200kg of fertiliser per hectare was applied to arable land in the UK. In Ghana, the corresponding figure was just 6.4kg per hectare.[7] External nutrient application is essential to ensure that adequate amounts of phosphorus and nitrogen are available to crops.

1.1 Use of fertilisers

The depletion of soil nutrients is known to reduce crop yields. A reduced crop yield will, in turn, result in reduced soil cover, leaving the soil exposed and open to the effects of weathering and accelerating the process of soil erosion. Whilst the use of manures and other organic fertilisers can help to increase organic matter in soils, on their own they contain insufficient inorganic nutrients to meet the needs of crops. In addition, the use of organic fertilisers may not be practical for some smallholder subsistence farmers because farmers are often unable to farm both livestock and crops due to land constraints. Even where this is possible, it can prove labour-intensive so although organic fertilisers have a role in agriculture, they should be used alongside inorganic fertilisers.

The application of greater amounts of inorganic fertiliser will help to address deficiencies in two key nutrients, nitrogen and phosphorus (see *Nutrients for plants*). However, alongside measures to help smallholders gain access to the vital nutrients needed to boost yields, a long-term strategy for monitoring and managing soil health in Africa is needed.

Increasing the application of nitrogen and phosphorus fertilisers should lead to increased agricultural productivity. Of course, such increases need to be managed carefully to minimise any negative environmental impacts. The chemical sciences have an important role in developing appropriate formulations of fertilisers that decrease run-off and increase nutrient use efficiency. These technologies must be backed up with suitable extension services to ensure that farmers are able to use such inputs correctly and with crop protection strategies that maximise yields, but minimise any negative effects on the ecosystem.

1.2 Soil and plant science

Soil science research will build up knowledge on the state of Africa's soils and will be the basis for long-term gains in agricultural productivity. As a discipline, soil science presents technical challenges; soil is not uniform in its composition and therefore the processes that occur in it can vary greatly according to its spatial distribution making them challenging to study and model. Soil science combines aspects of biology, chemistry, geology and engineering but chemistry plays a central role in many areas such as monitoring pH, determining nutrient content, and mineral and structural studies.

There has been progress in large-scale mapping of soil quality across the African continent. The Africa Soil Information Service initiative was launched in 2009 with funding from the Bill and Melinda Gates Foundation and the Alliance for a Green Revolution in Africa (AGRA).[8] It aims to provide a single large-scale resource which will accurately map soil conditions across the continent and provide a unique reference tool to help predict changes in soil properties. The programme uses a range of tools to monitor soil at selected field sites. Many of these tools involve chemical techniques, such as near-infrared spectroscopy, to help determine the amount of carbonaceous matter in the soil. These are combined with spatial analysis techniques like digital soil mapping to provide a thorough physiochemical analysis of a given area of land. However, there is a challenge in developing simple, cheap, portable technologies on a scale that can be used by farmers to monitor soil within their own smallholdings. There are also challenges in the development of practical remediation treatments for degraded soils that can be used on a smallholder scale.

While direct application of inorganic fertilisers will help to increase productivity, underpinning chemical and biological research can help to make sure that the benefits of such inputs are maximised. One method of helping to enrich soil nitrogen content is the planting of legumes, either in rotation or by intercropping. The roots of legumes bear nodules that host nitrogen-fixing bacteria, such as *Rhizobium*, which convert atmospheric nitrogen into nitrogen-containing compounds that can be used by plants. Research directed towards understanding the mechanisms by which such bacteria convert nitrogen will allow better management of soil nitrogen content.

By understanding what affects the action of these bacteria, fertiliser application can be tailored to work alongside these naturally occurring processes. Other important complementary strategies include genetics and plant breeding. New research into breeding varieties of crops that exhibit faster root nodule growth has the potential to lead to the development of crops that can fix nitrogen more efficiently, and therefore improve overall yield.

Nutrients for plants

Direct application of inorganic fertiliser to crops is an efficient technique to ensure an adequate supply of nutrients in the correct form. Nitrogen is an essential element in plants that is found, for example, in DNA and chlorophyll. Whilst nitrogen is abundant in gaseous form in the atmosphere as nitrogen gas (N_2), this is of no direct use biologically and must be converted (or 'fixed') into other forms, such as nitrates, which plants are able to incorporate into their primary metabolism. Plants themselves are not able to fix atmospheric nitrogen but the process can be carried out by bacteria that live in soils or within root nodules of legumes (eg *Rhizobium*).

Phosphorus is another essential element for plants which is also found in DNA as well as, for example, in the molecules that are key components of cell membranes. Phosphorus needs to be available in a form that can be used by the plant, such as phosphate which is the form used in most inorganic fertilisers. In some soils, up to 80% of available phosphorus is present in forms that plants cannot take up and use in their metabolic processes.[9]

Recommendations

- Increased fertiliser inputs (nitrogen and phosphorus) are needed to increase agricultural productivity. African governments need to support financial schemes to facilitate this.
- Other agricultural strategies, like improved crop varieties and seeds and the planting of legumes in rotations, should also be examined but their application needs to be integrated in order to sustainably achieve higher crop yields. Learned societies like the RSC should develop ways to ensure advice delivered via extension services for farmers is based upon sound science. The RSC could do this by creating opportunities for African scientists to engage with policymakers.
- Coherent research strategies across scientific disciplines are needed to develop methodologies that work at the farm level. Research into the natural mechanisms that govern nutrient cycling in the environment will require the input of chemical scientists, biologists and geoscientists. The RSC has a role in identifying the specific areas that require collaboration and provide opportunities for chemical scientists to interact with other disciplines. It also has a role in facilitating the interaction of public and private organisations to address the issue of how to revitalise Africa's soils.
- To improve crop nutrition, funding for research programmes in soil science is needed. This includes funding from national governments in Africa as well as collaborative international research funding.

2 New crop protection strategies

Increased fertiliser inputs are essential if Africa's agricultural productivity is to improve, but appropriate crop protection strategies are also important. Scientific advances can contribute to the development of such solutions: synthetic insecticides, fungicides and herbicides have all been critical to protecting crop yields. It is estimated that up to 40% of the world's food would not exist without crop protection products.[10]

Providing access to good seed varieties which are suitable for use in a particular climate is a fundamental step in improving crop yield. Treating seeds to ensure that they have the optimum physical and chemical properties to survive in a particular climate is an example of the way in which yields may be enhanced (see *Seed treatment*).

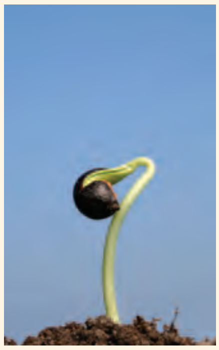
New strategies in pest control need to take account of the consequences of environmental change. In particular, we need to be prepared for species to respond to changes in climate in different ways. The reactions of a particular pest species are driven, to varying extents, by the other species with which it interacts. Possible changes that need consideration include:

- a change in climate that may induce faster population growth rates of pests and pathogens;
- the range expansion of invasive species, or pests targeting new crops;
- the loss of possible genetic sources of disease resistance as wild relatives of crops may disappear;
- changes in soil fertility and increased soil erosion that can affect the natural capacity of soils to control soil-borne pests and diseases;
- the potential for decoupling between pests and their natural enemies.

Crop protection strategies need to examine possible pest behaviour under a host of different scenarios as a result of climate change and variability. Climate variability depends upon location and demonstrates the need for local scientists to address such problems at a regional level. A combined approach, known as Integrated Pest Management (IPM) is needed because it brings together the chemical and biological aspects of crop protection. By using biological and chemical techniques to probe the differences in species response, technologies can be developed to exploit such synergies at the farm level (see *Case study B – Allelopathy in action*).

Seed treatment

Seed treatment involves applying an ingredient (like a crop protection chemical, usually a fungicide or an insecticide) to the seed prior to sowing. This forms a protective layer around the seed during its initial growth. As the seed germinates, the active ingredient is absorbed by the emerging roots and is distributed throughout the tissues of the plant, giving protection from pests via the soil and the air.[11] Seed treatment is a preferred technology because it allows smaller quantities of chemicals to be used than when they are applied as foliar sprays. It is therefore not only economical but leads to a lower impact on non-target organisms.



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Research approaches using semiochemicals

Semiochemicals are signal chemicals that organisms such as plants and insects use to communicate with each other. They can be divided into different classes. Pheromones convey signals between members of the same species and may, for example, be used as an alarm signal to alert others to a predator. Allelochemicals, by contrast, convey signals between different species. An example would be the chemicals given off by plants to deter insect pests. When one organism is influenced by chemicals emitted by another, this is referred to as an allelopathic effect. An understanding of semiochemicals and the ways in which they operate is useful because it can sometimes be exploited to develop novel and sustainable pest management methods.

Nature has developed elegant mechanisms that allow insects to find appropriate host plants for feeding and breeding. Plants emit complex mixtures of volatile chemicals which can be difficult to distinguish. However, receptors in insect antennae are not only sensitive to the combination of chemicals in a mixture, but also the ratio in which they are present, making them highly sophisticated analytical systems.[12]

A system known as gas chromatography coupled electrophysiology has been developed to build an understanding of the chemical communications between insects and plants. The complex mixture of the volatile chemicals given off by a specific plant is split into individual components. These are then passed one by one over an insect antenna, and those that trigger a response can be identified.

This piece of equipment is a key tool in the research programmes of organisations such as the International Centre of Insect Physiology and Ecology (ICIPE) in Kenya.[13] Its aim is to help alleviate poverty, ensure food security and improve the overall health status of rural and urban poor through the management of harmful and useful arthropods associated with plants, animals and humans while preserving the environment.

The integration of such natural biological systems with a known analytical chemistry technique provides a powerful tool with which to understand the action of those semiochemicals that relate to crop protection. The development of such chemical and biological analytical systems is essential in helping to develop new strategies in pest management.

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Recommendations

- Research addressing the challenges of managing pests under a changing climate needs to be multidisciplinary to address all aspects of the challenge. The RSC will work with researchers to facilitate new collaborations. The PACN should organise targeted workshops to bring researchers across disciplines together in Africa with those who work closely with farmers (eg non-governmental organisations) to address specific challenges in African agriculture.
- Technology for managing pests, which stems from fundamental research, must address the practical needs of smallholders which differ vastly from the requirements for farmers working on a larger scale. The RSC must enable communication between researchers and organisations that work closely with farmers to make sure that this information exchange takes place.
- Policymakers need to work with chemical scientists to put together robust, practical legislation to guide the use of crop protection chemicals. Such legislation must be backed up with provision from local authorities of adequate extension services. Through the PACN, the RSC has a role in equipping African scientists with the skills needed to engage with policymakers and those that deliver extension services. This will ensure the spread of best practice whilst taking account of local conditions.

3 The link between food and water

The challenge of managing water involves several different sectors, so it is essential to develop partnerships between governments, the private sector, the scientific community and the media. The chemical sciences have a role in assessing and improving water quality but this area also requires careful co-operation from other stakeholders. Many governments are not making wise investment decisions about water: it is not easy to evaluate the costs and benefits of water, which makes it difficult to price. Cross-border policies to help manage water sources between different nations are essential.

In 2009, the PACN organised an international conference on sustainable water which brought together almost 200 researchers, policymakers and technologists from 18 different countries. The report from this meeting, *Africa's Water Quality: A Chemical Science Perspective*,[14] summarised the conclusions and recommendations which emerged from the meeting. It represents the opinions and knowledge of some of Africa's best scientists and practitioners in the field of sustainable water research and development. Many of the key observations relate to the area of agriculture.

It is important to consider joint policy and research strategies for sustainable food and water and sanitation: agriculture represents 70% of the water withdrawals across the globe and the water needs to be fit for purpose.[15] The recycling of water for agricultural purposes is one method of meeting consumption needs; however, clear standards need to be developed for the treatment and subsequent reuse of water and this can only be done with policymakers working in conjunction with scientists.

Training farmers to manage land effectively to make best use of rain-fed agriculture can be achieved by evaluating the land and soil conditions and implementing appropriate strategies. For example, creating terraces where rainfall run-off can be targeted towards crops.

However, alongside this, there is also a role for scientific advances. Since 2008, the African Agricultural Technology Foundation has implemented the Water Efficient Maize for Africa programme.[16] This programme has used a combination of biotechnology and breeding programmes to trial access to drought-tolerant maize across several African countries. Further research to examine whether such methods could be applied to other crops could also be beneficial.

Recommendations

- The use of effective land management concepts (eg terracing) to increase the productivity of rain-fed agriculture should be promoted via extension services. Those who plan these should work closely with scientists to agree techniques that are practicable and beneficial.
- Funding bodies should engage with scientists to determine future research targets in this area. Research on molecular tools for improving drought resistance in maize should be extended to other crops.
- Policymakers must work with scientists to define clear standards for water re-use for agriculture. Learned societies like the RSC have a role in facilitating such interactions.

4 Land management

Land management is a key consideration in improving agricultural productivity, not just in Africa, but globally. Future agriculture will continue under the assumption that there is little or no new land for food production.[17] Some land that has been used for agriculture has become degraded over the years due to poor farming practices (eg poor tillage, over-application of fertiliser), leading to lower yields. A lack of consistent land management policies has meant that soil has become depleted due to years of farming without replenishment of minerals and soil organic matter. Short-term leasing of land to smallholders means that they are not encouraged to invest in the long-term health of the land that they cultivate. A combination of equipping farmers with the correct tools to manage their land and leasing policies that support this are needed.

4.1 Land use for non-food production

There is growing interest across the world in biofuels and the cultivation of biomass for this purpose. However, any planned use of land for non-food agriculture must recognise that food production is the priority. Biomass can offer a range of opportunities, beyond fuels, for the production of valuable 'platform chemicals'. Platform chemicals are small molecules which constitute the building blocks that can be used to develop more complex compounds for use as starting materials in plastics, detergents and medicines.

Crops such as cocoa, coffee and tea have been important for the financial empowerment of farmers for decades. The use of waste from agricultural produce for fuels and platform chemicals could present a similar opportunity. Options include processing biomass waste streams from crop production (eg husks, stalks and stems). Careful use of land and resources is essential to implement this successfully in the long-term alongside food production. One approach would be to grow specific crops for platform chemicals on marginal lands that cannot be used for food.

4.2 Empowering smallholders

The chemical sciences have a supporting role in providing tools to assist land management. Parameters such as the pH of soil and nutrient concentrations can be determined using analytical techniques. By investing in scientific research to map and predict soil conditions (see *1.2 Soil and plant science*), local communities will have a powerful tool to manage their land. Smallholders will be able to get the best from their land by differentiating between agricultural and marginal lands. Interpreting the knowledge gathered through schemes such as the Africa Soils Information Service can enable the strategic farming of lands with increased agricultural potential. Such mapping can also be used to determine which lands would benefit most from remediation treatment and which specific nutrient inputs are required to improve soil health. As land quality is improved, farmers will grow crops of higher value, leading to economic empowerment within smallholder communities.

4.3 Enabling economic growth

Agriculture is a large component of GDP in many African countries. The opportunities in African agriculture to produce starting materials for other industries alongside food are vast. Coupling this with research into the efficient use of chemical processes to generate platform chemicals could open up a new area of economic growth. There is also the potential for scientists to develop crop varieties with higher sugar and oil content which could satisfy both food and energy applications. However, these opportunities can only be realised with changes to policy and access to the technology that can assist farmers with practical land management.

Recommendations

- African policymakers at a national and regional level need to revise land tenure policies to encourage farmers to invest in the health of their smallholdings.
- Science and technology programmes that can inform land management policy (eg monitoring soil, remediation programmes for degraded land) need to be incorporated into advice and technologies that can be used at farm level. There is a challenge for scientists to make these fit-for-purpose, but the RSC must take steps to ensure that organisations that work closely with farmers are aware of progress on this to make sure that technologies reach those who need it.
- Using scientific data to inform smart land management policies will help to achieve a less labour-intensive production system. African scientists need to work with policymakers to turn this data into a tool that farming communities can use to help make the best long-term use of their land.
- Land management policies with a long-term vision will lead to opportunities to grow crops of higher value for applications such as fuel and platform chemicals.
- There is an opportunity for African scientists to couple such long-term land management strategies with related chemical sciences research into how agriculture could lead to commodities for economic benefit.

5 The African context

This report has outlined some of the areas where science and technology can help Africa to increase its agricultural productivity. However, research and development of new technologies cannot be adopted in isolation. There are a range of other socioeconomic and cultural factors, specific to Africa, that must be addressed to ensure that the technologies described in the previous chapters have maximum impact.

5.1 Understanding African agriculture

Most agriculture in Africa is carried out by smallholders and, as such, any new technological advances must be suitable for use at this level. Similarly, a number of Africa's major crops are specific to particular regions, eg sorghum and millets. The challenges and solutions associated with increasing the yields of these crops should be led by African scientists.

5.2 Collaboration and co-operation

Collaboration between scientists of different disciplines, and in different places, is essential in contributing to new advances. Co-operative ventures between African scientists and scientists outside of Africa are important to facilitate knowledge exchange, and the input from African scientists should drive the collaborations between laboratories.

Currently, the collaboration and exchange of ideas between scientists within Africa seems to be at a lower level than that of scientists outside of Africa. But African scientists are uniquely placed to share knowledge on the application of technology with respect to social, economic and cultural drivers. The PACN needs to continue to encourage collaborations, through the use of its shared facilities and through targeted research meetings which bring together scientists across disciplines.

5.3 Education

Opportunities to educate the next generation are intrinsically linked to Africa's agricultural productivity. By improving access to fertiliser and seeds, improving land management practices and restoring poor-quality land, smallholders can move from subsistence farming to growing crops in surplus or of higher economic value, leading to greater economic empowerment. This will allow access to education for their families, providing opportunities for future generations.

Alongside this, the role of education in inspiring the next generation of African scientists should also be strengthened to build capacity. Organisations like the PACN have a role in helping to facilitate mentoring for young African researchers by encouraging the development of skills such as scientific writing and applying for academic grants. One way that this can be achieved is by the PACN acting as a broker between young researchers in Africa and more experienced researchers across the world. The PACN, in collaboration with organisations like INASP (the International Network for the Availability of Scientific Publications), works to deliver programmes to train African researchers in skills like scientific writing.

The PACN should review its training provision to ensure it meets the needs of African researchers and, where necessary, implement new courses: for example, training scientists in how to engage with policymakers.

5.4 Building research capacity

A major barrier to scientific development in Africa is the fact that many scientists do not have access to the instruments and other equipment they need. A shortage of equipment not only makes it difficult to carry out high quality research but also complicates the training of the next generation of scientists. Sustained funding is critically important and governments must invest in the appropriate scientific infrastructure to enable growth in areas such as agricultural research.

The 'hub-and-spoke' model which is designed to encourage the sharing of facilities between researchers in neighbouring countries, can help to solve the problem of access to equipment and fosters links and an exchange of ideas between African scientists. The PACN has established centres of excellence, using such a model, as a means of providing training facilities for scientists from across the region. To date, four centres of excellence in chemical sciences have been established: one in Kenya (Jomo Kenyatta University of Agricultural Technology, Nairobi), one in Ethiopia (Addis Ababa University) and the recently announced centres in Nigeria (Lagos University and Ibadan University). These provide focal points for the training of scientists from across the region and are furnished with specialist equipment to facilitate this. Workshops to train researchers in each country, and neighbouring countries, in key chemical analytical techniques, such as the use of gas chromatography-mass spectrometry (GC-MS) instruments, provide an active opportunity for researchers to develop their analytical skills. The PACN can build on this by collecting data on the use of its facilities. Such data could help to provide policymakers with evidence of the need for such facilities.

5.5 Regulation and extension services

The use and enforcement of legislation to guide the use of chemical inputs in much of Africa is inadequate. Governments need to work with scientists to develop robust guidelines for the use of fertilisers and crop protection agents. This will ensure that future usage of chemical inputs is not only beneficial, but is also sustainable and has a minimal negative impact on the environment. Organisations like the RSC can act as a broker to provide access to a wealth of scientific expertise to ensure that policy is based upon sound scientific evidence.

In conjunction with this, the role of extension services should be prioritised. Extension services provide two important functions. Firstly, they are needed to ensure that new technologies to increase agricultural productivity reach the farmers they need to serve. The introduction of such technologies must be sensitive to the experiences of farming communities and their traditional agricultural practices. Secondly, the introduction of new technologies must include information regarding safe and effective use in relation to the environment to help improve yields and minimise negative impacts.

5.6 Finance, markets and infrastructure

Farmers across Africa need access to appropriate financial schemes and markets to help make agriculture a viable livelihood in the long-term. Such access would help smallholders to increase fertiliser inputs, obtain high quality seeds, and modern, safe crop protection chemicals. Policies that help increase access to markets are also needed: for example, better transport infrastructure and access to appropriate post-harvest storage systems. Careful choices in employing long-term technological solutions in areas such as post-harvest storage can only be made with sound scientific advice.

Most African agriculture is carried out by smallholder farmers.

Recommendations

- Researchers must consider the needs of end users (smallholders) when developing new technologies for Africa. The RSC, through the PACN, needs to provide opportunities for researchers to communicate with agencies who work closely with smallholders to ensure that scientists understand the needs of farmers.
- Extension services that provide local guidance to farmers on the use of new techniques for farming are essential to ensure the correct and sustainable adoption of new practices.
- Maintaining appropriate laboratory facilities for training and research is essential. The use of the 'hub-and-spoke' model can provide a cost-effective method for providing such infrastructure across a region. The PACN has already established four centres of excellence, but they must build on this by ensuring that these facilities are receiving maximum usage for both research and training courses in these regions.
- Collaborations between scientists of different disciplines and in different countries can lead to innovative solutions for improving agricultural productivity. Governments in both developing and developed nations need to continue to commit funding for such research programmes.
- Developing the research base in Africa requires attention along the entire skills pipeline. Provision of good science education at school level will inspire the next generation of scientists. However, this needs to be followed up with appropriate provision at university level, as well as support for the continuing development of researchers. The RSC can build on the workshops it currently arranges by organising opportunities for young African researchers to be mentored by more senior African researchers.

Appendix: Case studies

This section includes case studies written by speakers from the first PACN congress on agricultural productivity. They provide a series of examples highlighting the role of chemistry and other scientific disciplines in helping to develop methods to improve agricultural productivity in Africa and the future opportunities for growth to which they can lead.

Case study A
Soil science educational programme[18]

Bashir Jama

The Alliance for a Green Revolution in Africa (AGRA) is an organisation that improves the productivity of Africa's smallholder farmers through programmes that address changes in agricultural policy and improvement in agricultural technologies. It also provides practical help in the form of access to tools, markets, information and finance.

For soils, the overall strategy is one of combining organic and inorganic sources of nutrients. A cornerstone of AGRA's work is the provision of training and extension services to ensure that smallholders are equipped to manage their own land successfully. A key reason for setting up these services is to ensure that Africa can train future soil scientists who will monitor, evaluate and develop new strategies to maintain healthy soils in Africa. Since 2010, AGRA has implemented a series of MSc- and PhD-level courses in soil science and agronomy with nine partner universities across Africa, as part of its ongoing Soil Health Programme. By the end of 2011, 86 students had been enrolled onto these courses, around half of which are women. The target is to achieve 170 MSc and PhD students trained in 13 countries through this programme by 2014/2015.

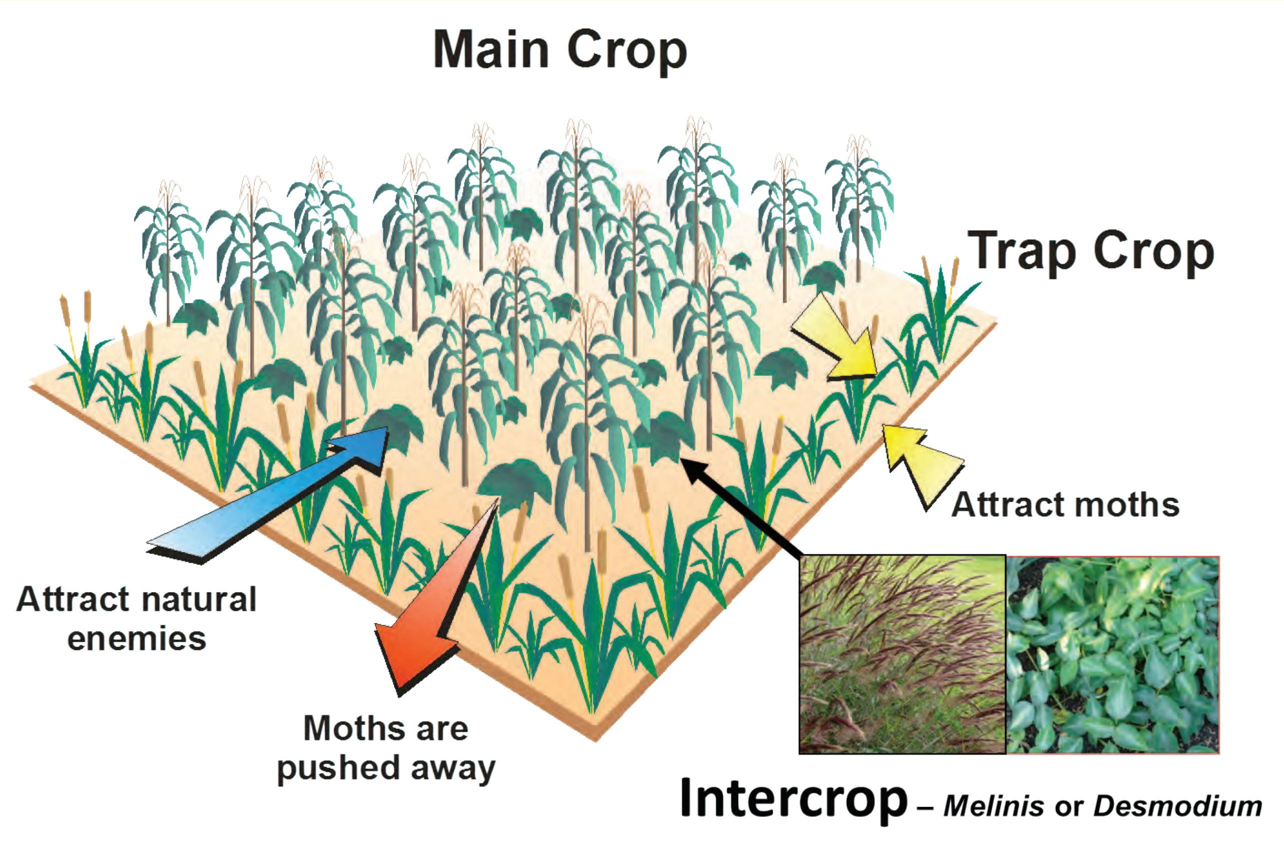
In Ghana, the programme is hosted in the Department of Crop and Soil Sciences in the Faculty of Agriculture at the Kwame Nkrumah University of Science and Technology (KNUST). The students are drawn from five countries in the West Africa region – Ghana, Nigeria, Mali, Burkina Faso, and Niger. The course focuses on basic scientific training in the understanding and monitoring of soil processes, but also equips students with the knowledge to develop practical strategies for soil and water management. The training that students receive includes basic chemical analytical techniques such as: monitoring pH and nutrient content; soil-water interactions; nutrient availability and soil microbiology; but also topics like Geographical Information Systems (GIS) and remote sensing and agribusiness models for Africa. This dual approach of combining scientific training with a careful understanding of the practical context will provide African scientists with the rounded education needed to increase agricultural productivity across the continent. An expansion of programmes like this which recognise the link between basic scientific research and agriculture is needed to drive forward a long-term approach to increasing agricultural outputs.

Case study B
Allelopathy in action the 'push-pull' system[19]

Tony Hooper and Charles Midega

As a result of a long-standing collaboration between The International Centre for Insect Physiology and Ecology (Kenya) and Rothamsted Research (UK), a strategy was developed to reduce stem-borer insect pest damage to subsistence-grown maize in smallholder and low-input farms. This comprises planting a highly attractive trap crop (Napier grass) around a maize field. The volatile chemicals from this trap crop act as a 'pull' by attracting pest insects away from the maize. In addition, an intercrop, *Desmodium uncinatum*, is grown in rows within the maize. This intercrop produces volatile chemicals that repel pest insects and therefore act as a 'push'. This pest management strategy is known as 'push-pull' technology or 'Vuta Sukuma', and although it requires training it is suitable for application to smallholder farms.

This strategy has proved successful in reducing pest insect damage, and a further substantial benefit is that the *Desmodium* also prevents parasitic *Striga* weeds (commonly known as witchweeds) from attacking and destroying maize plants. Experiments have shown that *Desmodium* protects maize through an allelopathic mechanism whereby chemicals in the *Desmodium* roots are exuded into the soil and inhibit *Striga* development. Some of these chemicals have been identified and research is ongoing to provide an intercrop plant that can protect maize against *Striga*. But unlike *Desmodium*, which is a cattle forage legume, the new plant would be useful as a crop for human consumption. Approximately 50,000 farmers now employ 'push-pull' technology on their smallholder farms and the creation of this technology, which was transferred successfully to resource-poor farmers through extension work, was made possible by the award of long-term research funding to African and European research laboratories.



The push-pull system.

Case study C
Towards a sustainable cocoa economy

Paul Hadley

Cocoa is a very important crop in the humid and sub-humid regions of sub-Saharan Africa. Between 2009 and 2010 more than half of the world's cocoa was produced in the Ivory Coast and Ghana.[20] However, cocoa production in the future will require improvements in biological, chemical and agricultural practices.

Cocoa farming presents a number of challenges. For the farmer, it must provide a long-term income, whereas at the landscape level, it must be carried out in such a way that, for example, soil conditions are not degraded. Demand for cocoa continues to increase but many consumers now also demand that it is produced sustainably. Technically, one of the major challenges is to provide the cocoa farmer with new and improved cocoa varieties. Cocoa seeds have a lifespan of only a few days once removed from the pod, so new methods for handling and distributing plants are required if cocoa farmers are to have access to new breeding material.

Research on cocoa has resulted in a wealth of information that can help to provide tools for improving productivity. The complete genome map for cocoa was published in 2009. This information provides a valuable basis for the development of molecular-level tools that can improve the efficiency of plant breeding programmes. The development of new molecular tools will require collaboration between plant scientists, molecular biologists and biochemists. These tools could help to address the long-term needs of farmers by improving the quality, productivity and resistance to insects and diseases of the cocoa germplasm, and ensuring that cocoa trees are resilient to the effects of future climate change in the regions where it is grown.

A key challenge with such an approach is that many national research institutes across Africa do not have co-ordinated breeding programmes with access to molecular genetics tools. At the smallholder level, cocoa farmers have little or no access to seedlings of local 'improved' varieties, suggesting that while there is a need for more research in Africa, there is also a need to construct a knowledge pipeline from scientific research to the farmer.

Case study D
Sustainable chemicals: the role for agriculture

James Darkwa

Whilst agriculture for food production is important, the prospects for agriculture in areas such as fuel and production of bulk and fine chemicals should not be underestimated. For much of the developing world, especially in Africa, the issue of food security will take precedence over the use of crops in fuel and the production of chemicals. Such opportunities will not be realised unless avenues to increase agricultural productivity can be found.

Crops such as sugar cane, palm oil and corn are prime sources of food in most developing countries but are also crops that can provide fuel and commodity and fine chemicals. Sugar cane and corn are prime sources of ethanol, a fuel additive and fuel in its own right. Brazil is a leading country in the deployment of biofuels. As well as cultivating sugar for biofuel production, the country has now developed industrial-scale technology to convert ethanol into ethylene, a starting material for the production of polyethylene.

Both sugar cane and corn can be converted by fermentation into *d,l*-lactide which can be used to make biodegradable polylactide for numerous applications in plastics, medical dressings and fabrics. Corn and other crops are sources of vegetable oils that contain fatty acids for conversion to biodiesel. Glycerol, a by-product from the production of biodiesel, has tremendous potential as a starting material for a number of commodity and fine chemicals. [21]

A productive agricultural sector can help to secure a sustainable chemical industry. Chemistry research can therefore be directed at finding ways to further improve agriculture productivity that will allow the use of crops both for food and as starting materials for commodity and fine chemicals. Research should also be directed at examining waste streams from agriculture to extract starting materials that can be converted to substances of great benefit. Such smart use of chemistry can help to balance the need for food and the opportunities for economic growth.

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