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How can we feed nine billion people while reducing GHG emissions?

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Abstract — Global warming will have far-reaching consequences for agriculture that will disproportionately affect poor and marginalized groups who depend on agriculture for their livelihoods and have a lower capacity to adapt. Sustainable food security in a world of growing population and changing diets is a major challenge under climate change. A recent study estimates the annual costs of adapting to climate change in the agricultural sector to be over US$ 7 billion. Agriculture and related activities also contribute to global warming with agriculture estimated to account for about a third of global GHG emissions. This paper makes the case for heightened focus on agriculture if the triple challenge of adaptation, mitigation and food security are going to be achieved. It suggests four key areas for research and action: understanding trade-offs amongst adaptation, mitigation and food security; implementing accelerated adaptation strategies; enhanced climate risk management; trialling and testing agricultural mitigation options that don't compromise food security. In the conclusions we call for a new "green agriculture".

Keywords — Adaptation, agricultural practices, food security, mitigation

1 INTRODUCTION

To date, much of the interest in relation to climate change and agriculture has been on mitigation, but the focus is shifting. Mitigation actions in agriculture are indeed important as agriculture contributes nearly a third of global greenhouse gas emissions, through direct emissions [1] and as the main driver of land cover change [2]. However, since we know that global warming is unavoidable, much greater attention needs to be paid to adaptation [3,4]. Developed countries have resources and experiences that can be applied to adapting agriculture to climate change. It will be in developing countries where the biggest challenges arise.

Agriculture has some stiff challenges ahead. While adapting to climate change, and helping to meet mitigation targets, agriculture also has to address the fact that one billion people go to bed hungry every day [5]. On top of that, the global population will almost double by 2050, reaching 9 billion people. In addition, food consumption patterns are changing as the average person in the world gets richer and consumes more food and more meat: ultimately, this requires more land under agriculture, greater agricultural productivity and different diets, unless we will see major changes in consumption patterns.

In the international negotiations on climate change and in country strategies for climate change, adaptation and mitigation are often dealt with separately. This paper outlines the case for why much attention needs to be placed on agriculture in the coming years, and why agriculture has to be dealt with as a single entity if the triple win of adaptation, mitigation and food security are to be achieved.

2 IMPACTS OF CLIMATE CHANGE ON AGRICULTURE

Climate-related crop failures, fishery collapses and livestock deaths already cause economic losses and undermine food security, and these are likely to become more severe as global warming continues [6].

A major problem is that the current global climate models (GCMs) give rather different results, making planning difficult [5]. While there is quite a lot of agreement amongst models on how temperatures will change, there is little to no agreement for rainfall. In their recent monograph, [7] looked at scenarios for food security, farming and climate change to 2050, showing how for any particular region the two models give quite different

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predictions. Another problem with the GCMs is that they are ideally suited to exploring impacts over a fifty to hundred year period for large land masses, whereas farmers and those in agricultural development need information for specific areas for the next season and the next few decades. On top of the uncertainty in future climates, we have to add the uncertainty related to the impacts of climate change on pests and diseases. Many pests and diseases of crops and animals are sensitive to climate, and we can expect these to change in currently unpredictable ways. Some will become prevalent in areas where they were previously unknown.

Projections of higher temperatures and variable precipitation suggest that climate change is likely to seriously threaten many agricultural systems, which will be exposed to extremes that exceed their capacities to adapt. Scientists at the International Center for Tropical Agriculture (CIAT) in Cali-Palmira, Colombia are working on research to show which crops will be affected and where. Their project examines the likely impacts of climate change on the 50 most globally important crops. The results illustrate a general trend where, as the world warms, suitable growing areas will shift towards cooler temperatures at higher latitudes, where most developed countries are located. Therefore, while developed countries may gain substantial production potential, many developing countries—particularly those in food-insecure subtropical and tropical regions—will likely lose out. These anticipated yield reductions bode poorly for many small producers in these regions, who generally demonstrate lower adaptive capacity, due to common infrastructural, managerial, and market access constraints.

Many believe it will be extremely difficult to hold the increase in global temperature below 2 degrees Celsius [8]. A four degree warmer world would be devastating to agriculture in many parts of the world, and especially in developing countries. Thornton et al. [9] have analysed what agriculture and food systems in sub-Saharan Africa would look like in a 4°C+ world (Fig. 1). By 2090 agriculture in Sub-Saharan Africa would be heavily impacted, with almost all parts of Africa registering a decline in growing season length. This is a truly frightening scenario for a region of the world which is characterised by poverty and under-development.

Farmers are some of the first to acknowledge climate change, given what they perceive as its impacts on their practices and livelihoods. They talk of higher temperatures, strange weather patterns and new pests and diseases. Farmers have always had to adapt, and have always been at the mercy of the weather; but there is now a new urgency, given the predicted unprecedented rates of change. It is apparent that we will need accelerated adaptation.

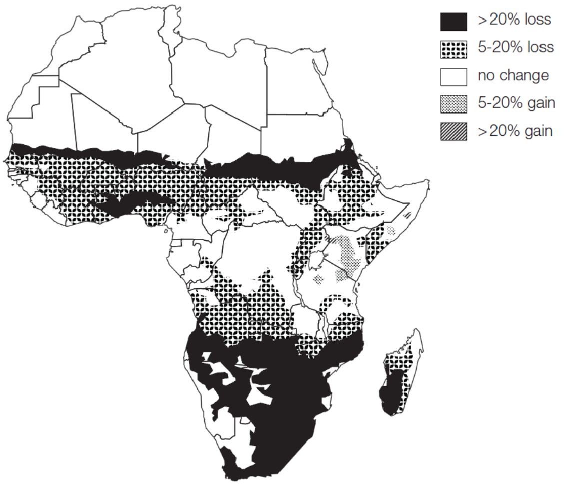

Fig. 1. Length of growing period in the 2090s compared with the present for a four degree warmer world under global climate change [9].

3 THE CHALLENGE OF FOOD SECURITY

Although estimates of food insecurity vary [10], the number of undernourished people already exceeds one billion and feeding this many people will require more than incremental changes [11]. Food production may need to increase by as much as 70% by 2050 when the global population will likely number nine billion. Food security depends not only on gross production of staples, but also on agriculture's ability to provide income for its practitioners in developing countries, a diverse and balanced food basket, and on the socio-economic factors that determine whether poor people, particularly women, are able to purchase, store, prepare and consume sufficient food.

Nelson et al. [7] and colleagues have simulated world food price changes for some of the main grain crops in response to climate change (Fig. 2). For this they use a complex simulation model of world agricultural systems and trade, with three scenarios (a baseline scenario with moderate income and population growth), a pessimistic scenario with low income growth and high population growth, and an optimistic scenario with high income growth and low population growth). World prices are a useful single indicator of the future of agriculture, with rising prices signalling the existence of imbalances in supply and demand and growing resource scarcity, driven by demand factors such as growing population and income or supply factors such as reduced productivity due to climate change

Their analysis shows that unlike the price declines of the 20th century, the first half of the 21st century is likely to see increases in prices. Increasing demand driven by population and income growth is greater than supply. The price increase called the economic growth effect is for a 2050 world with perfect mitigation (i.e. where climate change is not an impact on agriculture). Income and demographic changes between 2010 and 2050 result in price increases that range from 10% for rice in the optimistic scenario to 54% for maize in the pessimistic scenario. These substantial increases show the pressure under which the world's food system finds itself, even without climate change. With climate change, price increases more or less double, ranging from 31% for rice in the optimistic scenario to 100% for maize in the baseline scenario.

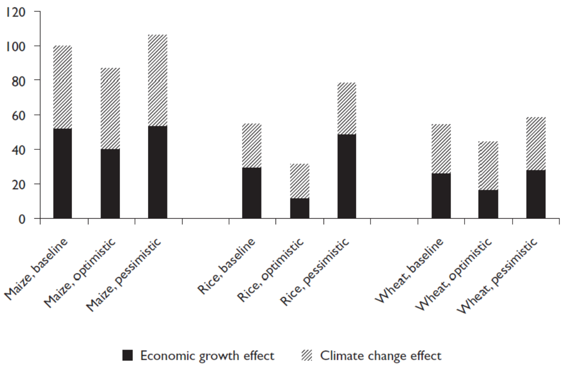

Fig. 2. World price increases for selected crops under various scenarios, 2010–2050 (percent change from 2010), with the climate change effect being a mean of four climate change scenarios: CSIRO and MIROC models for each of A1B and B1 scenarios) [7].

What we don't see in these results are the impacts of extreme weather events (e.g. droughts, heat waves). Many climate scientists suggest that extreme events will be more frequent and more severe. Such events will drive food price spikes. The food-price spike of 2008 led to food riots and political change in several countries.

4 AGRICULTURAL GREENHOUSE GAS EMISSIONS

Agriculture and related activities contribute to global warming, by generating greenhouse gas (GHG) emissions and altering the land surface. Agriculture is estimated to directly contribute to about 15% of global GHG emissions and for around 30% if the indirect impacts of agriculture on land cover change are included, agriculture being the leading cause of forest conversion (Fig. 3)[12]. Around 80% of agricultural emissions, including deforestation, occur in developing countries.

Smith et al [1] show that agricultural lands occupy 37% of the earth's land surface and account for 52% of global anthropogenic methane emissions and 84% for that of nitrous oxide. Land cover change contributes carbon dioxide (Fig. 4). Agriculture is different from many sectors in that it contributes to three GHGs, with complex trade-offs between what is emitted under different agricultural development pathways. For instance, intensification of agriculture, which often increases N_2O emissions, can reduce the demand for land, which can reduce deforestation and thus reduce $C0_2$ emissions. However, if intensification is successful, the local response is often expanded production rather than land-sparing [2].

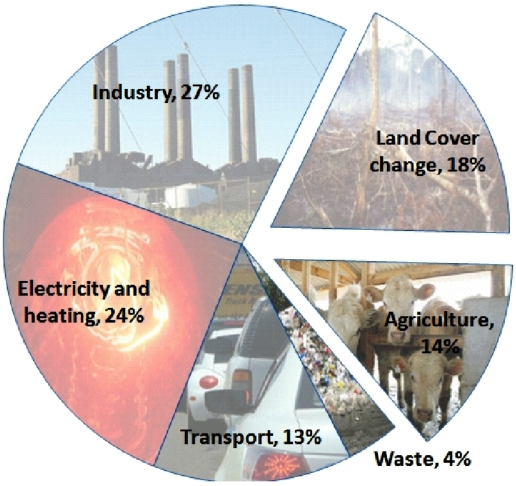

Fig. 3. Greenhouse gas emissions across all sectors, showing the contribution of agriculture (the direct emissions) and land cover change (indirectly contributed by agriculture) [13].

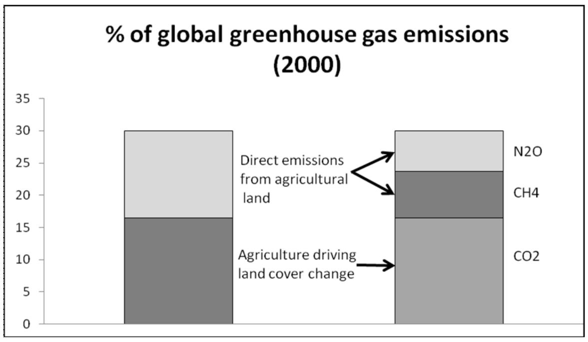

Fig. 4. Contribution of agriculture to the warming potential of greenhouse gas emissions (expressed as a percentage of total anthropogenic emissions from all sectors) [13].

5 KEY ACTIONS TO ACHIEVE THE TRIPLE CHALLENGE IN AGRICULTURE

Agriculture faces three inter-related challenges. The sizeable emissions from agriculture must be reduced. The disastrous impacts of a warming world on agricultural production must be avoided. And agriculture must ensure global food security. Considerable attention to the agricultural sector is needed if this triple challenge is to be achieved. This section outlines four priority areas for research and action: understanding trade-offs; implementing accelerated adaptation strategies; enhanced climate risk management; trialling and testing agricultural mitigation options.

5.1 Improved understanding of trade-offs and synergies of different agricultural development options

Each agricultural practice, and, at a broader level, different agricultural development pathways have different outcomes for mitigation, adaptation and food security. Tools are needed for genuinely integrative *ex ante* assessment, thereby combining adaptation and mitigation agendas, and exploring synergies and trade-offs among outcomes. These assessments need to be done at different scales. For example, global and regional levels are needed to decide which regions of the world are best suited for agricultural mitigation while not compromising food security. Different sets of tools will be needed for national decision makers so that climate finance can be appropriately directed to actions. And another suite of tools is needed at household and landscape levels, to assess viability and performance of different adaptation and mitigation options, which can subsequently be tested in farmers' fields.

Interlinked with the need for such tools is the imperative to downscale climate model outputs to temporal and spatial scales that are appropriate for biophysical and socio-economic modelling. Outputs from global climate models are not in the form required for linking with crop models, for example.

5.2 Implementation of accelerated adaptation strategies

The good news is that many of the solutions to agricultural productivity problems are available [14,6]. In addition, in most developing countries, there are very large yield gaps (the gap between current productivity and the known potential of a crop). By removing the yield gaps with known technologies – such as improved crop, soil and water management practices and stress-tolerant varieties – we go a long way to increasing food production. Of course, we have to address the reasons why these technologies are not used today. Climate change provides a massive and urgent incentive to intensify efforts to disseminate the fruits of past research, to adapt it to farmer contexts in different developing countries, and to put in place the necessary policies and incentives. The benefits of adopting many of the existing technologies could be sufficient to override the immediate negative impacts of climate change.

Farmers, ranchers, and fishers have long adapted to annual climate variability and passed on that knowledge from generation to generation. However, the scope of climate change may change the conditions in a certain area more quickly and more drastically than traditional adaptation methods can handle. Centuries-old coping mechanisms may be insufficient. As the temperature rises in one cool area (A), it will resemble a warmer climate (B), whose climate will also transform into another (C). Andy Jarvis and colleagues at the International Centre for Tropical Agriculture (CIAT) are developing a system they call the analogue method, which hopes to use current and past climatic data, as well as projections into the future, to identify and connect these sites. The aim is to combine this method with farmer-to-farmer exchanges, as well as via a web-based platform. This would then create a knowledge chain through which strategies and farming information could be passed down and shared. This will allow technologies currently practiced successfully in one region to be transferred to other regions, as climate changes and climate belts migrate.

But as dangerous climate change threatens, it will not be enough to merely adapt current practices and apply current knowledge. We need to stay ahead of climate change – and to do that we need to push agricultural science to new frontiers. Climate change promises novel conditions. We need to take rapid strides to understand what is going to happen to our farming systems, and what will be needed to maintain and expand food production. We will need to breed for the new conditions. We will need to devise practices that adapt to climate change, while also helping meet mitigation targets. We will need new techniques to get more crop per drop, as water becomes an even more scarce resource.

5.3 Implementation of climate risk management strategies

Many believe that the spectre of the future can be seen in the unprecedented heat waves, droughts and floods of recent years. There is no need to wait for progressive climate change – the climate today is already having significant negative impacts on the livelihoods of farming households around the world. Extreme weather events are not new phenomena, and farmers have developed various ways of coping with them. But poverty limits options. Thus, in extreme events farmers without insurance may be forced to sell off their assets, such as animals and farming equipment, thus hampering future production. In addition, climate risk limits investment – farmers are not willing to invest their time and money into agriculture if there is a high risk of loss [15]. Extreme events and the associated risk play a significant part in keeping farmers in developing countries poor.

This calls for greater attention to climate risk management for agriculture. This will have immediate benefits – in forthcoming seasons – while also preparing agriculture for future climate change. Climate risk management includes the systematic use of climate information in planning and decision making from farmers to regional food security agencies, use of climate-informed technologies that reduce vulnerability to weather variability and uncertainty, and climate-informed policy and market-based interventions that transfer risk from vulnerable populations.

Climate information services can link into the explosion in communications technologies that is occurring, also in developing countries. A number of pilots have been initiated where meteorological services are striving to reach farmers with relevant weather information. But, in general, the power of cell phones for these purposes has not been tapped. Some interesting index-based insurance schemes have been piloted – and scaled up in countries like Mexico and India. In this approach insurance is purchased for specific risks that are defined by reference to measured weather conditions. Insurance is automatically paid out when the weather index goes below an established level. The insurance company does not need to visit farmers' fields to assess losses and determine payouts; instead it uses data from, for example, rain gauges near the farmer's field. As well as reducing costs, this means that payouts can be made quickly – a feature that reduces or avoids distress sales of assets. Such a product potentially enhances the capacity of farmers, banks, micro-finance lenders and agro-based industries to take risks. ICICI Lombard in India have scaled up such products from trials in the early 2000s to over 500,000 clients today. In Mexico, risk insurance products are well-developed, especially focussing on the smaller farmers, and now some 8 million hectares of farmland are covered by traditional and index-based products. Livestock risk-insurance is being trialled in Kenya, and insurance for coastal dwellers – with production activities in fisheries, plantations and crops – are being trialled in India.

5.4 Trialling and testing technologies and incentives to promote reduced GHGs from agriculture

Agricultural practices can significantly reduce emissions by sequestering carbon in the soil or above ground biomass (for example in agroforestry or woodlots, or by reducing nitrous oxide or methane emissions). But intensified production (with potentially greater emissions at the farm level) may reduce emissions overall if areas with high carbon biomass, such as forests, are spared. We need to therefore look across the rural landscape at agriculture, forestry and degraded lands to understand drivers of land-use change, and the net emissions from the landscape.

Given that the world's poorest depend on agriculture and related natural resources to meet their basic needs, pro-poor mitigation options will be needed in many parts of the world. There is a need for mitigation options that have a positive impact on livelihoods, otherwise unacceptable trade-offs may occur. Carbon markets are unlikely to provide significant benefits to smallholder farmers in the near run and are highly uncertain, but livelihood options that produce mitigation co-benefits and carbon finance schemes that provide additional incentives should help farmers to meet both livelihood and environmental objectives.

In the livestock sector, reductions could be quickly achieved in tropical countries by modifying production practices [16]. For example, switching to more nutritious pasture grasses, supplementing diets with even small amounts of crop residues or grains, restoring degraded grazing lands, planting trees that both trap carbon and produce leaves that cows can eat, and adopting more productive breeds can all be employed relatively quickly to reduce emissions. Such changes could increase the amount of milk and meat produced by individual animals, thus reducing emissions because farmers would require fewer animals.

Fertiliser use is a major source of emissions (and other polluting effects). While it is expected that fertiliser use will have to increase in some countries (e.g. in sub-Saharan Africa) in others use could be more judicious. China is the world's largest producer and consumer of synthetic nitrogen and phosphorus fertilizers, accounting for about a third of global manufacture and use. A recent paper suggests that fertiliser use could be reduced with huge gains for mitigation and environmental outcomes [17], but Chinese farmers perhaps cannot make savings without more labour and better irrigation technology.

Conservation agriculture is a promising approach for achieving mitigation objectives. It is based on minimal soil disturbance (reduced or no tillage), combined with organic matter retention (returning crop residues to the soil) and diverse crop rotations. As well as reducing erosion and improving soil structure and soil–water dynamics, this approach also saves on labour, time, fuel and machinery. The combination of reduced soil disturbance and increased retention of crop residues also results in increased carbon storage. A good example of the effectiveness of conservation agriculture is the rapid spread of 'zero tillage' technology in South Asia's rice–wheat systems [18].

While many technologies and practices for reducing greenhouse gas emissions are known, they are, in general, not widely practiced. And, from a farmer's perspective there are often valid reasons, e.g. some new technologies require extra labour. We need to identify the policies, institutional arrangements and incentives that will be needed to increase uptake of such technologies and practices. A number of finance mechanisms and incentives exist or are likely to be developed to support agricultural mitigation. Carbon markets exist and offer real benefits, yet smallholders may not be able to participate effectively, e.g. due to high transaction costs. Consumers are increasingly interested in low net emissions food and may be willing to pay a premium, however the standards and benefits available to smallholder farmers remain unclear.

6 CONCLUDING REMARKS: TRANSFORMING AGRICULTURAL DEVELOPMENT

Our knowledge about the role of carbon dioxide for global temperatures goes back over 100 years, to the Swedish Nobel Prize winner Arrhenius. But it has only been in the last few years that climate change has got the attention it deserves, though there has been little concrete action to reduce greenhouse gas emissions. Given the difficult-to-attain targets for emissions that will have to be met to control global warming, all sectors will need to contribute to mitigation efforts, including agriculture.

When one examines the dimensions of the 'safe operating space' for humanity [19], it is obvious that agriculture is a key driver in pushing the globe beyond the safe boundaries on a number of dimensions. Furthermore, agriculture has to accomplish some seemingly contradictory outcomes: food security, mitigation and adaptation. While there are win-win-win technologies and practices, in many cases there are trade-offs (Fig. 5). If agriculture is going to rise to the triple challenge, and is going to contribute to keeping the globe in a safe operating space, a very different kind of agriculture is needed – a "green" agriculture. What this will look like will differ from region to region. In many developed countries, perhaps subsidies to agriculture will be reduced but farmers will be paid for supplying "environmental services" such as carbon and clean water. In parts of Asia a green agriculture may result in reduced use of fertiliser but without compromising food security. In forest-agriculture landscapes, perhaps climate finance will provide the incentives for farmers to intensify production in the context of strong forest governance. In much of sub-Saharan Africa fertiliser use will inevitably increase but hopefully accompanied by high fertiliser use efficiency through very targeted application and careful inorganic-organic management.

The solutions lie in many different endeavours, from making scientific breakthroughs in the area of downscaling climate models, to promoting accelerated agricultural adaptation, to strengthening institutions and policies, amongst others. Climate change policy is often compartmentalised in mitigation and adaptation areas of activity. Agriculture is where the two agendas come together and agriculture has to be dealt with as an integrated sector. Having an integrated approach allows for a clear focus on the triple challenges and to balancing trade-offs.

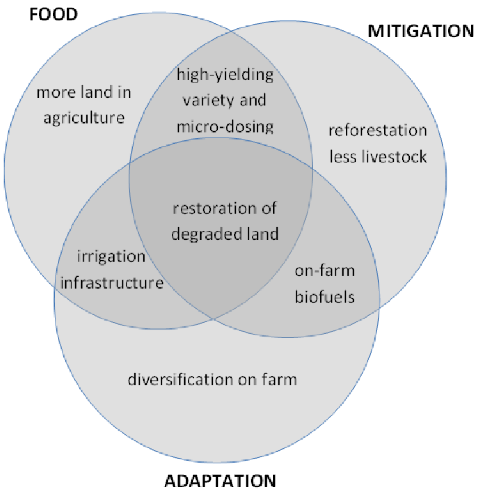

Fig. 5. The triple challenges faced by agriculture: food security, mitigation and adaptation. While win-win-win technologies and practices do exist, more often than not trade-offs will occur. [20].

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