<ct>Agroecology: The Future of Sustainable Farming?</ct>

<ca>by Laura Pereira, Rachel Wynberg, and Yuna Reis</ca>

The world is entering a new geological epoch, the Anthropocene, where humans are believed to be responsible for having as much of an impact on the earth's system as geological processes themselves.[1] Given rapid anthropogenic change, scientists have defined a "safe operating space" for planetary systems, referred to as the nine planetary boundaries, that if exceeded could be disastrous for the earth and humanity. These are climate change, biodiversity loss, ocean acidification, the nitrogen and phosphorous cycles, chemical pollution, land use change, global freshwater use, and stratospheric ozone depletion. These planetary boundaries encapsulate the systems that have maintained the relatively stable environmental conditions in which humanity has thrived over the last 10,000 years.[2] These stable conditions have also enabled the growth of food and farming systems to an unprecedented level, characterized by the escalation of industrial agriculture.

Agriculture is not only dependent on biodiversity, freshwater, a reliable climate, and adequate nitrogen, phosphorous and other essential elements, but is also a significant driver of negative change in Earth systems. Industrialized agriculture, which is highly reliant on external inputs, contributes to chemical pollution through the use of pesticides and herbicides, changes nitrogen and phosphorous cycles through the addition of synthetic fertilizers, and typically relies on irrigation, thereby impacting freshwater stocks. It is also energy intensive, emitting almost one-third of all greenhouse gases, including methane, thereby contributing to climate change.[3]

Although the incidence of hunger has declined over the last decade through increased food production, this has been at a significant environmental cost. Furthermore, hunger is on the rise again, affecting 815 million people in 2016 largely due to the proliferation of violent conflict and climate-related shocks, which industrial agricultural production is unable to counter.[4] Industrial farming has led to increased focus on just a few energy-rich but micronutrient-poor staple crops, and the incidence of noncommunicable diseases such as diabetes caused through increased consumption of these so-called "empty calories" has become a leading cause of global mortality.[5] Agrobiodiversity, a critical contributor for healthy people and ecosystems, has been eroded and the innovative potential of underutilized species has been largely ignored.[6] Moreover, the livelihoods of many farmers remain precarious, with export-led economic models reducing imperatives for national food security, devaluing the role of farmers, and imposing inappropriate agricultural production approaches on smallscale farmers.

A new form of industrial agriculture is now emerging, packaged as "sustainable," and touted as the only way to feed the world's growing population and provide nutrition for the 795 million people who are still chronically undernourished.[7] Such approaches include supposedly alternative solutions such as "sustainable intensification," designed to intensify the use of land for food production,[8] and "climate smart agriculture,"[9] tailored toward agricultural solutions for a changing climate. However, the continued focus of such approaches on external inputs such as fertilizers and pesticides and hybrid or genetically modified seed frames them within the same technocentric paradigm of industrial agriculture. Indeed, it was similar tenets that underpinned the Green Revolution of the 1960s and 1970s that undertook to apply science to increase agricultural yields.

Whether or not these approaches have delivered food and nutritional security remains contested. While inroads have been made toward halving hunger by 2015, the prevalence of obesity has more than doubled since the 1980s to about 600 million people,[10] leading to a situation, especially in developing countries, where people carry the dual burden of being both obese and malnourished.[11] The search for alternative forms of agriculture that can alleviate the production challenge of global food security, while remaining within planetary boundaries, is clearly one of the greatest challenges facing humankind in the 21st century.

Altieri and Nicholls[12] argue that the basis for alternative agricultural systems should be the myriad of ecologically based agricultural approaches developed and practiced by at least 75% of the world's 1.5 billion smallholders, family farmers, and indigenous peoples. Key characteristics of these alternative farming systems, which fall broadly under the umbrella of agroecology, include the use of technologies based on ecological knowledge, a focus on family farming and local production, low levels of external inputs, and their diversified nature.

In this article, we argue that emerging economies, which we define as developing countries that are rapidly industrializing, present important opportunities for showcasing alternative agricultural development pathways that are contained within planetary boundaries and that demonstrate innovations that are societally desirable and ethically responsible. Using a review of key literature sources, we reveal that emerging economies show an interesting alignment of relatively high levels of public spending on agriculture, together with agricultural systems that have a large proportion of smallholder and/or family farms.

We suggest that such countries are thus uniquely placed to avoid technological lock-in to industrial agriculture and to establish alternative agricultural pathways that maximize livelihood creation and sustainable food production. We argue that a preferred agricultural development paradigm for these contexts is that of agroecology, which we suggest is a type of inclusive innovation, given that the poorest and most marginalized both are engaged in and benefit from associated innovation processes.

By contrasting examples of agricultural development strategies in emerging economies, we illustrate how a sea change in these countries could pioneer alternative pathways for other developing countries. We conclude that there is great potential for inclusive agroecological innovations to help improve the livelihoods of small and resource-poor farmers. However, this will require greater recognition of agroecology in research programs, policies, and budgets.

<1>Agroecology as Inclusive Innovation</1>

Agroecology has gained prominence over the past 50 years, but its practices “are as old as agriculture itself.”[13] Wezel et al.[14] refer to agroecology as a science, a movement, and a set of agricultural practices, but at its core is the application of ecological concepts and principles for the design and management of sustainable agricultural systems. Agroecology integrates the study of the entire food system, encompassing ecological, economic, and social dimensions, and encourages practitioners to embrace the connectivity of systems, emphasizing unique, appropriate, and context-specific solutions.[15] Agroecology can therefore be said to be practiced by most small-scale farmers in the world—who are also typically among the poorest in the population.[16]

Agroecology is, however, more than the science and practice of agriculture. It is also a social movement grounded on the claims of food sovereignty, ecology, sustainability, gender, justice, farmer networks, land access, resilience, and resistance.[14,17] Viewed in direct opposition to the negative impacts of capital-intensive practices introduced in the so-called "Green Revolution," agroecology has grown as a social movement, stimulated especially by the financial and food crises in 2008.[18] Directed by local knowledge, and through the use of participatory methods and community engagement, the innovations of agroecological practices are receiving increasing recognition.[19]

While conventional views of innovation understand development as economic growth, inclusive innovation explicitly includes those who are excluded from mainstream development.[20] Despite growing support, agroecology continues to be marginalized in research and innovation policies. To become a legitimate alternative within the current research and development (R&D) context, agroecology needs to be incorporated into an alternative, more inclusive, innovation agenda.

Inclusive innovation refers to the production and delivery of innovative solutions to the problems of the poorest and most marginalized communities.[21] Small farmers with limited disposable income and little ability to attract innovation that is profit-driven form a particularly important potential "recipient" of inclusive innovation. Moreover, small farmers have the potential to engage actively in research processes that are appropriate to their needs.

In an agroecological paradigm, knowledge is regarded as collective and is obtained from networks of producers, consumers, and researchers; agroecology is therefore integrally bound to a high level of participatory knowledge exchange.[22] Moreover, the role of small-scale farmers is not confined to production, but extends to the marketing of the end product, "by emphasizing local commercialization and distribution schemes, fair prices, and other mechanisms that link farmers more directly and with greater solidarity to the rest of the population."[23]

Agroecology is strongly linked to the promotion of food sovereignty and is opposed to reliance on global markets; it seeks to advance and develop alternative distribution systems such as farmers' markets and local cooperatives.[24] It encourages integrative farming that takes the health of the agricultural system into account.[25] A key premise of agroecology is thus environmental sustainability, in that it is designed to allow producers to be more reliant on their own resources and less reliant on external inputs —thereby directly responding to the environmental challenges of the Anthropocene. Furthermore, the inclusion of local and traditional knowledge in the formulation of agrecological practices that are context specific extends the environmental awareness of the approach to include the knowledge of people whose lives and cultures are fundamentally interlinked with the landscapes in which they farm. Agroecology can thus be viewed as a legitimate innovation pathway within agricultural research systems that is more sustainable than the current dominant industrialist regime.[26]

<1>Challenges Facing Agricultural Systems in Emerging Economies</1>

While emerging economies face challenges of poverty, social inequality, and environmental degradation, they have more financial and infrastructural resources to deal with these problems than lower income nations. Furthermore, although their economies are diversifying, they retain large numbers of smallholder farming communities that maintain traditional farming systems.[27] Emerging economies such as those of Brazil, South Africa, India, and China still have areas of arable land for agricultural expansion but at the same time are rich in biodiversity, have increasing levels of environmental awareness, and have a developing body of environmental laws. Although their farming systems are diverse, they are typically dualistic, including both industrialized farmers and resource-poor farmers who practice low-input agriculture.

In 2014, the Food and Agriculture Organization (FAO) identified family farms—a sector that includes small- and medium-scale farmers, indigenous peoples, traditional communities, fishers, pastoralists, forest dwellers, food gatherers, and many others—as key players in sustainable food production. There are more than half a billion family farms in the world (approximately 90% of all farms globally), producing around 80% of the world's food on 70% of the agricultural land. Worldwide, farms of less than 1 hectare account for 72% of all farms, but they comprise only 8% of all agricultural land. In contrast, only 1% of all farms in the world are larger than 50 hectares, but these few farms control 65% of the world's agricultural land. In most countries, small- and medium-sized farms tend to have higher agricultural crop yields per hectare than larger farms because they manage resources and use labor more intensively. As a result, the share of small- and medium-sized farms in national food production is larger than the share of land they manage.[28] This contradicts the neo-liberal logic of scale and specialization, which argues that it is only by expanding the area of agricultural production and increasing production per hectare through technological advances that we will be able to “feed 9 billion by 2050.”[29]

Family farms are particularly significant in emerging economies. China and India, for example, account for 35% and 24% of the world’s approximately 570 million family farms,[30] respectively, while in Brazil, 78% of farms are less than 50 hectares.[31] In South Africa there are approximately 4 million small-scale and mostly subsistence farmers located in 2 million farming households.[32] In contrast, commercial agriculture in South Africa is controlled by a handful of large-scale farming units: in 2007, for example, just 0.3% of all farm units in South Africa produced 33% of all agricultural income.[33]

Small, family-managed farms play a critical role in food security, especially at the local level.[28] However, achieving sustainable and environmentally sensitive farming will require agricultural innovation that addresses the challenges these farmers face, including access to land and capital, secure land rights, appropriate extension and advice, and market access for excess produce.[34] Most current agricultural innovations are in contrast centered on improving yields from costly inputs like seeds, fertilizers, and pesticides.[8,35]

<1>Agricultural Research and Development</1>

Agricultural research and development systems have a significant role to play in meeting farmers’ needs sustainably.[36] There has been a sea change in agriculture research and development over the last decades, with an overall relative decrease in investment by high-income countries, an increase by middle-income countries (including China, Brazil, India), and a per-capita decrease by low-income countries.[28] Public agricultural research is increasingly being concentrated in just a handful of countries.[37] There has also been a shift in the balance between public and private contributions: In 2011 more than half of agricultural research in rich countries was being done by the private sector, and this upward trend of private-sector investment continues to be striking in middle-income countries, most notably China. This is evident of a trend to "off-shore" agricultural R&D to middle-income countries by multinational corporations that are headquartered in rich countries.[36]

The growing importance of middle-income countries is further evidenced in the figures that show global expenditures on public agricultural research and development concentrated in China, India, and Brazil, which account for 19, 7, and 5%, respectively. These three countries together with high-income countries account for 79% of global public spending on agricultural R&D, while the share of low- and middle-income countries is just 21%.[28] It is therefore noteworthy to discern the trends operating in these emerging economies, or BRICS (Brazil, Russia, India, China, and South Africa), to see what lessons can be learned for shifting agriculture R&D toward sustainable social and ecological outcomes in other developing countries where there are still high numbers of small-scale and family farms.

China accounts for more than one-third of the world's small farms, while having the largest and most decentralized public agricultural research and development system.[38] It has been said that in China, agriculture is too important for it to be taken over by the market.[39] This sentiment is reflected in its agricultural research system; since

2006, the modernization of agriculture has been at the forefront of research coming out of public universities.[40] Chinese government investment in agricultural research and development doubled from 2001 to 2008, far exceeding that of any country except the United States, with commitments expected to increase further.[38]

Brazil too has one of the most well-developed and well-funded agricultural research systems in the developing world, ranking third in terms of public agricultural research and development investments after China and India.[37] Brazil's total public agricultural research and development spending has increased substantially over the last decade, with an increase of 46% between 2006 and 2013 largely due to growth at EMBRAPA (Brazilian Agricultural Research Corporation) and in the higher education sector. In 2013 Brazil's agricultural research intensity was the highest in Latin America, at 1.82% of spending as a share of agricultural gross domestic product (GDP).[41]

Public agricultural R&D expenditures in South Africa fluctuated considerably between 2000 and 2008, largely due to shifts in government funding to the Agricultural Research Council (ARC). Nevertheless, South Africa's investment level is high compared with most other Sub-Saharan African countries: The country invested $2.02 for every $100 of agricultural output in 2008, compared to intensity ratios in Ghana, Uganda, and Kenya of $0.94, $1.24, and $1.43, respectively. Government contributions are the primary source of funding for agricultural research and development, but private companies, of which many are subsidiaries of multinational companies, also conduct agricultural R&D in South Africa, focusing on seed and fertilizer research.[42]

What sets emerging economies apart is that they have a development challenge to improve the livelihoods of many smallholders farmers, while also having a significant allocation of research and development funding for agricultural research. However, there remains a question as to whether the enabling research environment is addressing the conditions that small farmers in these emerging economies face or whether it is more oriented toward meeting the demands of large-scale industrialized agriculture. This argument is supported by the dualistic agricultural nature of many emerging economies. How research funds should be allocated to address the challenges of producing sufficient healthy food for a growing population under environmental stress remains a challenge under competing concepts of sustainability. Many suggest that an increased emphasis on agroecology could provide a viable alternative to conventional agriculture that not only meets the needs of smallholder farmers but also mitigates some of the environmental impacts associated with industrial agriculture.[3] In the next section, we expand on the importance of validating agroecological innovations by contrasting it to genetically modified or biotechnology innovation, referencing examples from South Africa and Brazil. We show that incorporating inclusive innovation in the agricultural sector could have profoundly positive impacts for creating more sustainable and just food systems.

<1>Public Investment in Agriculture: Agroecology and Biotechnology</1>

The genetic modification of crops, mired in controversy, forms an integral part of contemporary forms of industrial agriculture, with debates centered on its ability to resolve global food security.[37,43] When it was still a breakthrough innovation, genetic engineering became "locked in" as the main technological regime shaping agricultural research, largely due to its scientific approach of positivism and reductionism fitting within larger political and economic trends. The central role of experts removed from the context and knowledge of most of the world's farmers stands in stark contrast to the principles of inclusive innovation. Utilizing an innovation systems framework to demonstrate how agricultural research systems function as a selection device that influences science and technology choices, Vanloqueren and Baret show that once established, there is a strong tendency for a dominant technological paradigm to persist.[44] In this case, the agriculture research system is locked in to an industrial paradigm, despite calls for fundamental changes in the orientation of agricultural knowledge, science, and technology.[45]

Modern biotechnology is resource and knowledge intensive, and thus requires high levels of investment with expectations of high returns. It is for this reason that genetically modified (GM) crops are strongly oriented to production for global markets, with little to no regard for context specificities or needs.[46] Despite this, the growth rate of biotechnology is much faster in developing countries and emerging economies in particular: The five lead developing countries in biotech crops are China and India in Asia, Brazil and Argentina in Latin America, and South Africa in Africa[47] (see Box 1).<TQ>Box 1</TQ>

In contrast, agroecology, as with inclusive innovation technologies, seeks to find solutions that are appropriate to the local context. A major challenge for agroecology is to ensure not just the generation of new knowledge, but the wider diffusion of this knowledge to diverse locations and settings. This is a general difficulty for inclusive innovation, which is disadvantaged compared to standardized innovation, because of its need to be locally appropriate.

There is thus a tension between locally appropriate sociotechnical configurations, and standard technologies like GM that seek to be widely applicable. However, proponents of inclusive innovation believe this challenge can be overcome with the right support and effort.[48] The role of agricultural research systems in emerging economies is key in realizing this shift, but their agricultural innovation systems remain configured toward global solutions to meet market demands. This conflicts with agroecology's ideology that runs counter to global integration and market orientation. Reconciling these opposing forces remains a challenge.

Given the importance that smallholder agriculture plays in emerging economies like Brazil, China, India and South Africa, as well as the environmental stresses to which agriculture needs to adapt, alternative agricultural solutions must be institutionalized and it makes sense for these countries to be leaders. Movements toward the institutionalization of agroecological processes are afoot, and there are processes whereby these more inclusive approaches can be made to compete with biotechnology and other industrial agriculture paradigms (see Box 2).<TQ>Box 2</TQ> Increasingly, policy recommendations for achieving global food security within planetary boundaries are advocating for mainstreaming more inclusive and diverse approaches to agricultural, and therefore to agricultural research.[3,45,48]

Recommendations for Institutionalizing Agroecology in Emerging Economies

> <ext>A global environment favourable to agroecology must be created … This means not only a more balanced allocation of resources in agricultural research, but attention to the larger framework that influences science and technology choices.[49] </ext>

There is growing potential for increasing South–South cooperation in agricultural research between countries with larger public-sector research institutes, like Brazil and China, and smaller national agricultural research institutes in countries facing similar agroecological challenges but with more limited research capacity, like Mozambique, Ghana, and Zimbabwe.[28] As agricultural research agendas are increasingly being set by emerging economies that retain agriculture as a significant contributor to economic growth, the agricultural paradigm in which research is undertaken in these countries is of paramount importance. The agricultural R&D pathways that these emerging economies take are likely to set the trajectory of both global agriculture and those of lower-income countries. Such trends are especially relevant given that lower-income countries are seen increasingly as sites for the growth of industrial agriculture – as witnessed by the expansion of commodity crops such as palm oil and coffee in these countries (See Phalan et al 2013, Robiglio et al 2014). The negative social and ecological implications of this model, whereby smallscale sustainable farmers are forced to contend against the power of global capital as it takes over productive land for its own financial benefit, has been pointed by researchers who advocate for a need to engage with a different, transformative paradigm (Lahsen et al 2016, Sawyer and Lahsen 2016, Pereira and Drimie 2016, von Bormann and Gulati 2016, Freeth and Drimie 2016).

Demonstrating the validity and economic potential of agroecology is critical in such contexts. Along with an emphasis on the low inputs required for agroecology, and the fact that much R&D already occurs on farmers' fields, drawing on centuries of local knowledge and experimentation, agroecology has the potential for enabling a positive transformation towards a more equitable, environmentally sustainable and socially just agriculture. Validating local knowledge, and bringing it into formal training and extension programmes, could be an extremely effective and low-cost way to ensure the stronger uptake of agroecology in resource-poor settings.

The key message from this article is that emerging economies provide an important space and leverage opportunity for strengthening agroecological practices that are well suited to the challenges facing smallholder farmers in these countries, and are also more environmentally sound. With increased public investment into agroecological research and an enabling policy environment, it is possible that developing countries can leapfrog industrial agriculture systems and move toward an inclusive innovation agenda in the agricultural sector that is based on agroecological principles.

<bio>Laura Pereira is a postdoctoral researcher with the Bioeconomy Chair in the Department of Environmental and Geographical Sciences (EGS) at the University of

Cape Town, South Africa. Rachel Wynberg is Bio-economy Research Chair and Associate Professor, EGS, at the University of Cape Town, South Africa.
Yuna Reis is at The Brazilian School of Public and Business Administration from Fundação Getulio Vargas (FGV EBAPE), Rio de Janeiro, Brazil.
</bio><AQ>Please review BIO info and confirm if correct or edit as needed; provide position for Reis, if appropriate.</AQ>

<box title>Box 1: Biotechnology in South Africa and Brazil</box title>

In South Africa, genetic engineering is extremely successful as a technological paradigm in agricultural research. South Africa was seen as the gateway to African markets and the government decided that genetic engineering was part of its future agricultural path, and there was immense pressure to commercialize new products and to open new markets, given European resistance to the technology. A model evolved whereby multinational gene companies typically financed research, and partnered with local research facilities to develop and promote GM crops. This laid the crucial foundation for the rapid adoption of GM crops in South Africa, where by 2013, 2.9 million hectares of land had GM crops.[50]

In Brazil state support of large commercial farmers and agribusiness is strongly associated with foreign capital, monocultures, GM crops, and biotechnology.[51] Genetic engineering attracts most of Brazilian research resources and is having a transformative impact on agriculture. In 2003, Brazil became the fourth largest producer of GM crops in the world, and by 2010 it was the second largest, with 25.4 million planted hectares.[46] However, whilst this growth had a positive effect on the country's economy, it had negative consequences for livelihoods and biodiversity. For instance, in the Brazilian cerrado region- an area of huge geographical and cultural significance- widespread agribusiness has degraded vital ecosystem services that are critical not only for the wellbeing of Brazilian citizens, but also for agricultural viability (Lahsen et al 2016). This destruction had led to a concerted effort from civil society actors to access decision-making platforms in order to mobilise how to halt the erosion of this biome that is of such economic and environmental importance not only to Brazil, but also to neighbouring countries (Sawyer & Lahsen 2016).

<box title>Box 2: Agroecology in Brazil and South Africa</box title>

The growth of agroecology as a resistance movement in Brazil has generated new technological, cognitive, and sociopolitical innovations and has consequently enabled the re-imagining of a new political scenario.[17] The movement creates the possibility for renewed science and technology structures to serve an innovation mind set that encompasses the diversity and demands of family farmers, the wide variety of ecological processes within agroecological farming, and the complexity (social, cultural, political, and economic) of each agricultural production unit. After more than 20 years of social movement mobilization, the Brazilian government has started to invest in agroecology innovation and to hear marginalized voices. EMBRAPA recognized agroecology as a science in 2004,[52] and as of 2015, the federal government had invested 65 million Brazilian Reais (around 20 million USD) in organic and agroecology research, innovation, and technological extension through PLANAPO (National Plan for Agroecology and Organic Production), which was strongly negotiated for by La Via Campesina.[53] However, although PLANAPO is regarded as an achievement for social movements, many civil society organizations (CSO) believe they had less influence over the policy as compared to agribusiness and other private actors (See example of CSOs in the cerrado by Sawyer and Lahsen 2016)).

In South Africa, the survival of agroecology as an agricultural strategy is similarly dependent on its adoption by smallholder farmers and the success of civil society movements in advocating for change. Although embryonic, positive accounts are emerging, linked to ongoing nongovernmental organization (NGO) support for farmer-led approaches that embrace diversity and sustainability and to the growing mobilization of farmers and civil society organizations who are concerned about the escalating erosion of agricultural diversity, depleted soils, and variable climate (Pereira & Drimie 2016; von Bormann & Gulati 2016; Freeth & Drimie 2016). At a historic food sovereignty assembly in March 2015, more than 50 organizations initiated the South African Food Sovereignty Campaign and Alliance to “Break the power of food corporations, establish a constitutional right to food, build food sovereignty from below, based on small scale farming and agroecology, not industrial agriculture.”[54] Although such initiatives are not yet on the same scale of those in Brazil, they suggest a growing resistance and restlessness among stakeholders who have historically been marginalized.

ORCID

Laura Pereira 0000-0002-4996-7234

Rachel Wynberg 0000-0002-2984-9759

http://orcid.org/ http://orcid.org/

Laura Pereira is a postdoctoral researcher with the Bio- economy Chair in the Department of Environmental and Geographical Sciences (EGS) at the University of Cape Town, South Africa. **Rachel Wynberg** is Bio-economy Research Chair and Associate Professor, EGS, at the University of Cape Town, South Africa. **Yuna Reis** is at The Brazilian School of Public and Business Administration from Fundação Getulio Vargas (FGV EBAPE), Rio de Janeiro, Brazil.

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