Scaling up agroforestry requires research ‘in’ rather than ‘for’ development
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Recent high-level policy papers call for scaling-up agroforestry to sustainably increase agricultural production and maintain environmental services. Evidence suggests that this will not be achieved by wide scale promotion of a few iconic agroforestry practices. Instead, three key issues need to be addressed. First, fine-scale variation in social, economic and ecological context and how this creates a need for local adaptation. Second, the importance of developing appropriate service delivery mechanisms, markets, and institutional contexts, as well as technologies. Third, appropriate research design, within the scaling process, that enables co-learning amongst research, development and private sector actors. This requires a new paradigm that builds on previous integrated systems approaches, but goes further, by embedding research centrally within development praxis.

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The call to scale-up agroforestry
Agroforestry practices are increasingly promoted as options that can contribute to food security, biodiversity conservation and the provision of a range of other ecosystem services [1,2**]. This has led to demands for effective ways to scale-up agroforestry so that large numbers of people benefit. The term ‘scaling-up’ comes from a research and development (R and D) model that envisages research being done to identify possible improvements to agricultural practice, testing and refining these interventions in pilot locations, and then widely disseminating the refined interventions [3]. Each of these stages may be more or less participatory. There has been extensive work on principles and methods for scaling-up agricultural changes in general [3] with an emerging focus on social processes in agricultural innovation systems [4**]. In this paper, we consider what the concept of scaling-up means for agroforestry and the approaches that are most likely to be effective.

Broadly, agroforestry has been defined as systems where trees interact with agriculture. This can be applied at a range of scales to focus on trees in agricultural landscapes [5], or on a set of agricultural practices comprised of tree species, their management and interaction with other components of the farm or forest systems within which they are embedded [6]. Within agroforestry science and praxis at the present time, there are innovations relating to two different concepts of scale: the operational scale at which work is done (field, farm, landscape, region, nation or planet) and the extent to which agroforestry options deriving from any of these scales of operation is adopted (scaling-up). There are interactions amongst these concepts because the challenges of scaling-up vary with the scale of operation. Recent, high-profile, policy papers that specifically call for scaling up agroforestry [7–9] imply a focus on spreading improved field-scale technology, that is, promoting agroforestry practices on farms. This is echoed in papers that review and promote sustainable, agro-ecologically based or ‘perennalised’ agriculture [7,10–13]. Here, we review the evidence on how effective efforts to spread technology options have been, and then explore how a broader conception of scaling-up, that embeds research within development praxis, can address the limitations that emerge.

Lessons from successes and their limitations
There are numerous accounts of scaling up particular agroforestry technologies or ideas and some syntheses of these [14–16] but no systematic review of the effectiveness of scaling up agroforestry from which the essential ingredients for success can be identified. The examples in the literature are most often examinations of success stories, generally written from the perspective of people closely involved in the scaling-up efforts. While these cases may be illustrative and inspirational, they introduce confirmation bias if used in quantitative studies.
without reference to controls [17]. The temporal scale of evaluation is important in scaling-up agroforestry, where trees may be long-lived system components. Pseudo-adoption has been identified in some cases, where farmers use a technology only while a project actively promotes them [18]. Sustained adoption may require broader changes in service delivery, market function and the enabling policy and institutional environment, over and above dissemination of technology options [19]. Longer term and larger scale evaluations of case studies have identified policy factors that were important for wide scale adoption of agroforestry [20]. The problem with drawing firm conclusions from analyses of case studies is that factors identified as leading to success need to be systematically tested through comparison of cases with and without them [21], and this sort of analysis has not been applied to agroforestry. The potential benefits of more fully incorporating local knowledge in developing improved agroforestry options, and the way in which they are communicated to farmers, have also been identified [22,23].

Silver bullets verses locally adapted options
A series of seminal lessons, very relevant for scaling-up agroforestry today, can be derived from the well-documented case of alley cropping over two decades ago, echoed in very recent developments to combine conservation agriculture (CA) with trees. CA involves three key agronomic principles of providing continuous ground cover, reducing soil disturbance and diversifying crop rotations. Integrating trees in crop fields can contribute to implementing these principles [10].

Plot-scale research trials measuring agronomic aspects of alley cropping with a few fast-growing shrub species were interpreted as the technology having widespread potential to improve soil fertility and increase crop yield. On-farm trials rapidly led to attempts to scale-up, with, for example, the formation of an Alley Farming Network for Africa and large projects promoting the technology [24]. It quickly became apparent that, rather than having general applicability, the technology was relevant to specific circumstances relating to climate, initial soil conditions and where land was scarce and labour abundant [25]. With hindsight, the initial over generalisation has been attributed to [25,26]:

- Problems with agronomic experimentation, principally interference amongst plots resulting in over estimation of yield benefits.
- On-farm research that focussed on the plot and did not consider broader interactions within the livelihood system, such as alternative uses for biomass, or constraints such as labour and land tenure.
- Inadequate understanding of the interactions between technology performance and the environment, with development of a narrowly defined technology package assumed to be broadly applicable.

CA has similarly been promoted as a widely-applicable approach to improved management of cropland [27]. Its general applicability has, however, been challenged, generating a vigorous debate [28,29,30]. More extensive commentary presents evidence that the principles of CA are by no means universally appropriate [31], showing that careful targeting and local adaptation are needed [32] and these should be underpinned by an appropriate research agenda [33].

In addressing current calls for rapid scaling-up of agroforestry we need to avoid the pitfalls of what might be called bright-side science, where positive evidence is given more weight than negative and data that could contradict prevailing enthusiasms are given limited attention or not collected at all. Common problems include:

-Attributing the key to success to a single intervention without acknowledging the great importance of context for success to materialize.
- Biophysical results based on experimentation in a very narrow range of environments which are then interpreted as broadly applicable.
- Integrated assessments and impact analyses done in a limited range of social, economic and ecological contexts.
- Trying to draw inferences from successful cases only.
- Some basic research design or interpretation errors, such as assuming that correlation in observational studies implies causation or that observations on isolated mature trees can be scaled to predict the effects of planting at higher density.

This points to the need for rigorous research design within the scaling-up process. We next highlight the significance of the variation in response to interventions, which is a major reason for needing to embed research within development.

Heterogeneity of effects
Generally, when the performance of an agroforestry practice is measured over a range of environments or conditions, then large variation is found. This applies at all scales of analysis. Meta-analyses typically show wide ranges of responses from very substantial benefits (of yield, or whatever is assessed) to significant losses [34,35,36]. In 262 cases of planted Sesbania sesban fallows across sub-Saharan Africa, the mean maize yield increase was 2.9 t ha⁻¹, with a range from −0.5 t ha⁻¹ to >6 t ha⁻¹ [36]. These meta-analyses combine data from different environments, cropping systems and management methods but regional trials, in which some of these are controlled, are equally variable. For example, S. sesban fallows at 53 locations across southern Africa, showed a
mean increase in maize yield over an unfertilised control, of 1.7 t ha$^{-1}$, but a range from $-1.6$ t ha$^{-1}$ to 6.3 t ha$^{-1}$, and similar heterogeneity has emerged at local scales (e.g. mean of 0.8 t ha$^{-1}$ with range from $-0.5$ t ha$^{-1}$ to 2.5 t ha$^{-1}$) across 22 farms in two areas of Malawi), and the largest component of variation was within field in a similar trial in Western Kenya (ICRAF, unpublished data).

Such heterogeneity is often hidden in the results of impact assessments, where the principal aim is to estimate the mean effect of an intervention [37], yet such a mean is of little interest to individual farmers taking a decision on whether or not to invest in a practice. Such a farmer requires a prediction of the likely yield in his or her specific circumstances. Another key issue with respect to adoption is the absolute magnitude of yield increases that farmers achieve. This contrasts with the percentage increases that are often quoted and also relates to the land area over which the increase is obtained. A large percentage increase of a small yield is still small, and may not represent a sufficient return on investment for a farmer to adopt, especially if only applied to a small land area [38]. It is absolute production that farmers eat and sell, not percentages.

**A research ‘in’ development paradigm for scaling up agroforestry**

The preceding review highlights three interrelated issues that need to be addressed to develop an effective scaling-up methodology for agroforestry:

- fine scale variation in the context (biophysical, economic, social and institutional) within which agroforestry options need to be adapted to local circumstances;
- the importance of service delivery, market function and the institutional environment to the success of agroforestry adoption over and above the availability of technology options relevant to farmers individual circumstances; and
- the need to continually refine the current knowledge of which ingredients are necessary for effective scaling-up

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**Figure 1**

Representation of the co-learning paradigm that offers communities best-fit technologies now (quite large uncertainty regarding their impact) while capturing experience through research ‘in’ development, to refine matching options to sites and people’s circumstances (progressively reducing uncertainty and risk around adoption decisions).
in any context by embedding research designs with planned comparisons within the scaling process, thus enabling a co-learning amongst research, development and private sector actors.

Addressing these issues requires a new paradigm that builds on integrated natural resource management and farming systems research approaches, but goes further by simultaneously integrating action horizontally, vertically and amongst research, development and private sector actors [19**]. Horizontal integration is across sectors, such as agriculture, forestry, environment, energy and water. Vertical integration relates to national, regional and local scales of governance and field, farm and landscape scales of operation [39]. The first step is to frame scaling-up in broad terms as comprising:

- agroforestry options to improve food security, nutrition, livelihood and environment.
- effective delivery mechanisms for these options including well functioning markets.
- an appropriate enabling policy and institutional environment

and to recognise that innovation is often necessary in all three areas at the same time to achieve scaling-up targets [4**,**19**]. In terms of developing options, a co-learning paradigm (Figure 1) that recognises and addresses fine scale variation in context is required. This uses planned comparisons to systematically test and monitor options across sufficient ranges of context so that qualitative and quantitative performance data can be interpreted to determine which options work in different circumstances and what ingredients it is necessary to combine for successful scaling in different contexts. GIS and remote sensing tools [40] and methods for understanding and operationalizing farmer diversity [41–43] are rapidly developing to make characterisation of fine scale variation in context more tractable.

There is an equally compelling need for research in relation to service delivery and market function [4**]. It is becoming increasingly clear that extension methods vary in effectiveness in relation to what is being disseminated (the message) and the context in which this is being done [44*]. There is also a trend towards effectiveness of policy alternatives being subject to rigorous analysis that allows decisions on policy implementation to be based on evidence rather than conjecture [21].

**Conclusion**

Although there is only a single word difference between research ‘in’ as opposed to ‘for’ development, this represents a huge shift in how both are conducted. In order to scale-up agroforestry, research needs to be able to test options across variation in context over large scaling domains and this is only possible with the magnitude of resources available in development programmes. Conversely, in order to be effective, development programmes need to know what ingredients in terms of options, delivery mechanisms and enabling environment are needed, and this can only be ascertained through the use of planned comparisons and systematic research within development projects. By embedding research in development praxis, both these requirements can be met.

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