Geoforum xxx (2013) xxx–xxx

Contents lists available at SciVerse ScienceDirect

Geoforum

journal homepage: www.elsevier.com/locate/geoforum

Of yield gaps and yield ceilings: Making plants grow in particular places

Dominic Glover

Knowledge, Technology and Innovation Group (formerly the Technology and Agrarian Development Group), Wageningen University, PO Box 8130, 6700 EW Wageningen, The Netherlands

ARTICLE INFO

Article history:
Available online xxxx

Keywords:
System of Rice Intensification
C4 rice
Genetic engineering
Low external input technology
Crop improvement
Agronomy

ABSTRACT

The System of Rice Intensification (SRI) and rice genetic improvement are proposed as two approaches to improving and increasing rice production. In recent exchanges, they have been represented by their respective supporters as starkly contrasting, almost mutually incompatible alternatives. However, advocates on both sides of this argument have tended to stress the genetic and physiological characteristics of rice plants and place less emphasis on the spatially and temporally situated knowledge and management skills of farmers, which are the means by which any agricultural technology is locally adapted and integrated into livelihood strategies, and technological potential is translated into real outcomes in specific settings. Taking this proposition seriously would entail a substantial reorganisation of agricultural research and extension, bridging the historical divide between these two wings of professional agronomy. It would require agronomists of both types to work more collaboratively with farmers. It would also require scientists to produce new kinds of outputs, such as analytical frameworks, heuristics and decision-making tools to help farmers apply scientific insights to their own constrained circumstances. This argument is made with reference to the cases of SRI (a cultivation system that is said to boost farm yields without the need for genetically improved germplasm) and C4 rice (a crop-improvement project intending to 'supercharge' rice photosynthesis to increase rice yields). The paper uses the agronomic concepts of the 'yield gap' and the 'yield ceiling' to offer a perspective on strategic questions about the goals and organisation of agricultural research and extension.

1. Introduction

How should rice production be improved and increased? In this paper, I use the agronomic concepts of the 'yield ceiling' and the 'yield gap' to explore a dispute between two alternative visions. Advocates of a cultivation method known as the System of Rice Intensification (SRI) argue that changing certain crop management practices can dramatically increase rice productivity and close the gap between the yields achieved on research stations and those produced in farmers' fields. Others propose genetic improvement (including genetic engineering) as a more assured method for accomplishing this goal, and even for raising the genetic 'yield ceiling' of rice.

Certain prominent supporters of these competing views have represented them as starkly contrasting paradigms in agriculture and research, yet in certain respects they share a technocratic perspective, in which intrinsic characteristics of rice plants are imagined to be principally responsible for the crop's productivity. This perspective is reflected in a shared preoccupation with maximising grain yield, neglecting alternative goals that rice farmers might reasonably choose to pursue. However, no matter whether genetic improvement, agro-ecological methods or other technologies are deployed, they must be locally adapted if they are to produce their expected benefits in particular settings. In this paper I argue that, by focusing asymmetrically on the genetic or phenotypic characteristics of plants within agricultural systems that are also human, social and situated in specific agro-ecological settings, SRI advocates and champions of genetic improvement are both liable to neglect the crucial contribution of farmers' locally specific knowledge, experience and skills in negotiating a path to a successful harvest.

This article adopts a geographical perspective on the situated, contingent character of agricultural knowledge and innovations, in other words, the degree to which knowledge and technologies are shaped by the specific places and social contexts in which they are produced; the means by which they are made mobile and conveyed to new locations and communities; the particular social and institutional channels through which they are spread; and the adaptations that allow them to be applied in new social and agro-ecological settings. My argument implies that realising the technological promise of both SRI and genetically improved rice will demand substantial reorganisation and reorientation of agricultural research and extension systems. Specifically, my argument culminates in a call for a more horizontal collaboration between farmers and scientists, a closer integration of basic research and extension functions within the agronomy profession, and a

E-mail address: dominic.glover@wur.nl

0016-7185/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.geoforum.2013.06.001

research and extension system re-oriented to produce new kinds of outputs.

This paper draws on ongoing research on the origins, theory, practice and spread of SRI methods. This work includes extensive reviews of scholarly and grey literature; extended field visits to various sites in India, Nepal and Madagascar (Berkhout and Glover, 2011); dozens of unstructured and semi-structured interviews with agricultural officials, NGO representatives and research scientists; numerous formal and informal interactions with farmers, labourers and extension workers; and direct observation of various farming operations, technology demonstrations, farmer meetings and training events.

The argument is organised as follows. In the next section, I introduce the agronomic concepts of the yield gap and the yield ceiling and show how they are connected to a division of labour within the agronomy profession, which itself is a symptom of a top-down, linear system for producing and delivering agricultural technologies to farmers. Next, I summarise the particular dispute which inspired this paper, between supporters of SRI and advocates of rice genetic improvement (specifically a project that aspires to dramatically increase the phostosynthetic efficiency of rice plants). The following section compares and contrasts these two approaches, showing that they have more in common than first appears. The next section refers to examples from India to demonstrate that nothing in the technical principles of SRI prevents the system from being promoted in a doctrinaire manner that negates its theoretical flexibility and compromises local adaptation. The final section of the paper explores how research and extension systems could become more responsive to small and marginal farmers' needs by developing a more diverse range of locally adaptable technologies, encompassing both crop types and cultivation methods.

2. Yield gaps, yield ceilings and professional agronomy

Plant breeders and agronomists are accustomed to thinking about crop yields in terms of several types of deficit, relative to a theoretical maximum yield. The deficits are usually termed 'yield gaps', while the theoretical maximum yield for a given crop or variety is known as the 'yield ceiling', 'yield potential' or 'yield barrier'.

Conceptually, yield gaps can be defined at different scales or levels. A common example is the gap that exists between the yields produced on typical farms and those achieved on agricultural research stations. To take account of differences in farmer skill or resources, one can also identify a gap between the yields achieved on average farms and those achieved by the most productive farmers in the same agro-ecological region. Similarly, a yield gap may exist between the best yields achieved on a regional research station and the record yields achieved anywhere in the world for the same crop or variety. Record yields may approximate the best possible yield for the crop concerned, yet scientific modelling may still point towards a theoretical maximum yield even higher than anything seen in reality (Lobell et al., 2009; Plucknett, 1995).

The yield ceiling or yield potential is a concept that expresses the theoretical maximum yield that could be produced by a given crop variety in a given context or, in its most absolute sense, under perfect conditions (i.e. with an optimal supply of nutrients, sunlight and water, at ideal temperatures, and unconstrained by diseases, pests or weeds). The yield ceiling of a given crop variety is thus a contingent property, governed by genetics but also conditioned by local agro-ecological factors, such as soil fertility, as well as the crop management practices to which it is exposed.

The yields achieved on agricultural research stations may approach the yield ceiling, but the yields produced on small farms in developing countries rarely come close to those achieved on research stations, let alone the theoretical maximum potential yield. This yield gap exists because the circumstances under which poor and marginal farmers produce their crops are even further from theoretically optimal conditions than those which can be created – at considerable effort and expense – on research stations (Lobell et al., 2009; Plucknett, 1995).

As an example, yield gaps and yield ceilings for rainfed rice in India have been estimated. Using average farm yields as a reference, the gaps were as large as 973 kg per hectare relative to the best farm yields, almost 1.5 tons per hectare ($t\ ha^{-1}$) compared to experimental yields, and more than 2.5 $t\ ha^{-1}$ compared to model-based estimates of yield potential (Lobell et al., 2009, p. 186).[1] The magnitude of these deficits evokes the size of the opportunity, as well as the challenge, of raising average rice yields on ordinary farms (see Laborte et al., 2012).

It is appropriate to note that resource-poor farmers may not actually aspire to achieve the maximum possible yield for a given crop. Economists recognise a concept known as the 'economic yield', which expresses the yield level that is economically rational to achieve, given specific resource constraints. The most sophisticated calculations of economic yield also take into account the opportunity costs attached to any investment in crop productivity, which is a way to recognise that poor and marginal farmers may have reasons to invest in alternative livelihood activities besides farming, or to display different kinds and degrees of interest in different crops.

Professional agronomy is concerned with both closing yield gaps and raising yield ceilings. However, this truism glosses over the conceptual and practical difference between these two goals and the challenge of prioritising between them. The agronomy profession encompasses two wings, distinguishable by the nature and proximity of their relationship to farmers' fields and crops. As professional agronomy emerged and grew, it bifurcated into what we now call extension, whose members became preoccupied with communicating science-based practices in ways that made sense to particular farmers in specific places, and their research-station colleagues, including plant breeders and microbiologists, who saw agronomy's role as generating robust, generalisable new knowledge through rigorously controlled experimentation. We see the legacy of this disciplinary specialisation today in the liminal, commutable character of 'field trials' and 'demonstration plots' (Maat, 2011; Maat and Glover, 2012).

Conceptually, closing yield gaps is the business of extension workers and agricultural engineers, who try to devise and promote practical solutions for particular situations. Meanwhile, raising yield ceilings is the mission of plant breeders and genetic engineers, who try to develop germplasm with the potential to produce higher yields under a range of conditions. The two tasks are understood to be connected but distinct. Indeed, raising crop yield potential is thought of by some plant breeders as a key step to *maintain* an 'exploitable yield gap', which leaves room for average farm yields to be improved (Cassman, 2001).

The disciplinary and organisational division of labour within professional agronomy reached its apotheosis during the Green Revolution. In that period, international and national agricultural research systems became increasingly focused on crop genetic improvement, with the aim of generating a steady flow of new crop varieties that were supposed to perform very well across a range of settings when used alongside adequate quantities of inputs, especially fertilisers and irrigation. In this limited task they were remarkably successful. Meanwhile, the communicative role of extension agencies – to close yield gaps by transferring modern

[1] These calculations were based on the yield potential of rainfed rice, whereas the average farm yields included those from irrigated areas, so they may underestimate the true yield gaps (Lobell et al., 2009).