Closing the yield gap under uncertain weather: risk analysis of cropping system intensification in family agriculture of the tropics

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How far do risks related to rainfall inter-annual variability limit the shift from extensive to intensive farming systems in family agriculture of the tropics? We explored this question in the Brazilian *cerrado*, where high average rainfall (up to 1500mm y^{-1}) but large inter-annual variability of weather translates into strongly varying annual crop performance. While many farms maintain extensive farming and cropping systems (CS), many others have shifted to intensive dairy systems within a decade, with associated intensification of maize production as an essential step (Bainville *et al.*, 2005). The study reported here aimed at assessing maize yield inter-annual variability under the range of environments and CS observed in the region to better identify biophysical constraints and management tactics to help close the yield gap. The latter is defined here as the gap between yields obtained by farmers and the potential yield that would be obtained in this region with the same cultivars in the absence of limiting factors other than radiation and temperature.

Materials and Methods

A previously performed regional agronomic diagnosis (RAD, Dore *et al.*, 2008) provided a typology of maize CS across environments (E), corresponding to levels of yield, and with the key interactions between E and CS that explain yield variations. A version of the Stics crop model (Brisson *et al.*, 2003) was elaborated specifically for Family Agriculture in Central Brazil (Stics_facb). It accounted for these key interactions and reproduced the variations of yield and yield gap across CS and E as observed in the network of farmers' fields used for the RAD (Affholder *et al.*, 2003). Such validation based on data collected in farmers' fields showed that the model was able to account for interactions between crop establishment operations, soil N and water status, germination and emergence dynamics, stand density, and weeds competing with maize for light, water and nitrogen.

A simulation experiment was designed in which each class of the CS x E typology was simulated over a series of 21 years of weather data. We present here the most contrasted cases, corresponding to two CS types crossed with two E types consisting in a deep *Latosol* on plateau (DL) and a superficial *Cambisol* on sloping land with stony topsoil (SC). Both soils had high aluminum saturation rates. The CS included an extensive one (Ecs), practiced by subsistence-oriented farms, and an intensive CS (Ics), typical of the new dairy systems. In both CS, soil preparation was performed using tractors owned and managed by associations of 10 to 50 farmers, and weeding was horse drawn. In Ics, liming was practiced to maintain aluminum saturation rate under the threshold of toxicity to root growth. Sowing was horse drawn at 3 plants m^{-2} and tractor drawn with 5 plants m^{-2}, and total N fertilization was 15 and 70kg ha^{-1}, respectively for Ecs and Ics. Two variants of Ics were considered, corresponding to two types of management of tractors under farmers' associations. In IcsR ("responsive"), soil tillage and sowing were performed at dates calculated as a function of soil water status, and with adequate seed depth and density, reflecting the possibility, offered by some associations, for each farmer to adjust the dates of operations and the settings of the machinery specifically for his fields. In IcsI ("imposed"), a random "noise" was used to modify the parameters relative to crop establishment operations, independently for each simulated year, reflecting the rules set by most associations, under which farmers were not permitted to change the settings of the drill or to operate the tractor by themselves, and they had no control over the tractor schedule.

Results and discussions

Simulations showed that yield gains from intensification were highly dependant on soil type and quality of crop establishment operations. The more constraining the soil or lack of flexibility in access to machinery, the smaller the yield response to increasing N fertilizer and sowing density (fig 1). On SC, there was a probability of *circa* 0.2 that yield is not increased when shifting from Ecs to

IcsR. Details (not shown) of the simulation data indicated that this was due to a high frequency of water deficits on these soils with low water storage capacity. This probability increased to 0.5 when considering IcsI, i.e. poorly managed farm machinery due to delayed sowing (relative to last tillage operation) and inadequate seed depth jointly contributed to low stand density and consequently high weed pressure. There was a general awareness in the region that crop establishment was not adequately managed, and the RAD study *per se* had already pointed it out. Our modeling analysis brought the advantage of providing quantitative data on the yield increase that could be expected from improvements of crop management, such as better adapting the sequences of tillage and sowing operation to weather events and to the specific soil characteristics of each field. This advantage was critical to improve awareness of farmers' associations about the value of improving rules for use of collectively-owned machinery.

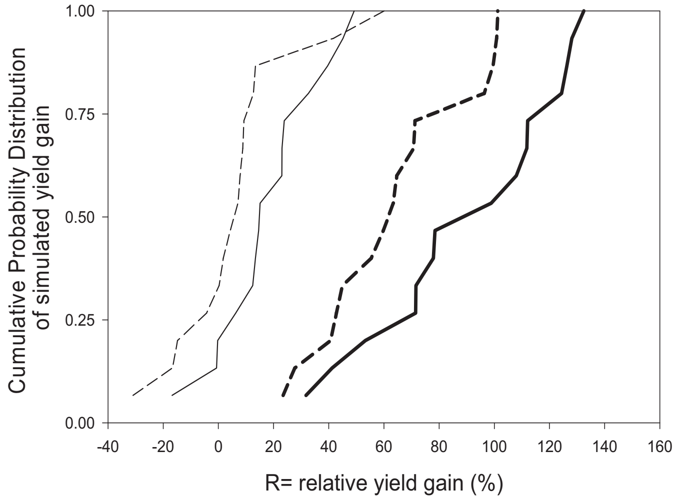

Figure 1: probability that the relative yield gain is lower than a given value R.
Simulation over 21 years of weather data. Thin lines: SC soil, thick line: DL soil.
Continuous line: intensification using "responsive" settings of machinery, R=100.(YIcsR-YEcs)/YEcs
Dashed line: intensification using "imposed" settings of machinery, R=100.(YIcsI-YEcs)/YEcs
Where YEcs, YIcsR and YIcsI are yields simulated for cropping systems Ecs, IcsR and IcsI respectively.

Conclusion

The study confirmed the value of extrapolating to series of climatic data the results of a RAD carried out over a limited number of years, as a way to better identify strategies for yield gap reduction in a small region, and to tailor such strategies to the specific conditions of farmers' fields. The study also suggested that biophysical constraints were severe enough to make maize intensification too risky to be viable at the field level in some cases. This could explain why certain farms did not adopt intensified dairy in the region. Such hypothesis would deserve to be further explored, which would require accounting for the way yield variations translate into variations in farm income.

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