Ecological Intensification Management When Yield Gaps are Wide

By Fernando García, T. Satyanarayana, and Shamie Zingore

Regions with wide yield gaps in maize commonly lack adequate adoption of high-yielding hybrids and crop protection, they are susceptible to water deficits, and have inadequate soil and/or nutrient management practices.

Kenyan research highlights the need to tailor sources of fertilizer in order to account for the multiple nutrient deficiencies associated with low inherent soil fertility.

South Asian and Argentinean studies highlight a need for improved residue management, hybrid selection, planting time, plant population, row spacing, and NPS fertilization management.

Potential yields of maize have increased worldwide as a result of advances in breeding, crop protection, and improved management of soil, water, and nutrients. However, several regions show wide gaps between actual and attainable yields. **Table 1** compares actual yields (Y_A) for maize in several countries to two estimates of yield potential: 1) the yield possible when water availability is limiting (water-limited yield potential, Y_W) and 2) the yield possible with no water limitations (yield potential, Y_P). **Table 1** also provides two estimates of the yield gap calculated by the difference between the ratio of Y_A with either Y_W or Y_P and 80% (the percent of Y_W or Y_P that is realistically attainable). See discussion provided by Grassini et al. in this issue of *Better Crops* for a more detailed explaination on yield gaps.

Table 1. Average actual yield (Y_A), water-limited yield potential (Y_W), yield potential (Y_P), and yield gaps (Y_G) with Y_W and Y_P for maize in different countries.

Country	Average actual yield, Y_A	Water-limited yield potential, Y_W	Yield potential, Y_P	Yield gaps, Yg: $(0.8 - Y_A/Y_W)$ x 100	Yield gaps, Yg: $(0.8 - Y_A/Y_P)$ x 100
	t/ha	t/ha	t/ha	%	%
Argentina	6.8	11.6	13.8	21	31
Brazil	4.7	8.7	12.5	26	42
Bulgaria	5.9	7.3	13.0	-1	35
Burkina Faso	1.5	6.3	10.3	56	65
Ethiopia	2.2	12.5	16.1	62	66
Germany	9.7	11.0	12.8	-8	4
Ghana	1.7	8.6	14.8	60	69
India	1.6	9.3	12.6	63	67
Kenya	1.9	7.1	14.7	53	67
Mali	1.9	9.7	14.6	60	67
Nigeria	1.6	10.8	14.2	65	69
Poland	6.1	10.5	12.5	22	31
Romania	3.4	9.0	12.2	42	52
Tanzania	1.2	5.4	13.8	58	71
Uganda	1.6	6.9	13.7	57	68
Ukraine	4.7	8.2	12.3	23	42
USA	9.7	12.3	14.0	1	11
Zambia	2.3	11.3	16.9	60	66

Source: http://www.yieldgap.org

What are the causes of these wide yield gaps? Studies have shown that the main causes are: lack of adoption of high-yielding hybrids, inadequate crop protection, water deficits, and inadequate soil and nutrient management practices (Dass et al., 2008; Timsina et al., 2010; van Ittersum et al., 2013; Aramburu Merlos et al., 2015). For example, an analysis of simulated, attainable, and actual maize yields in major maize growing ecologies across South Asia revealed wide management yield gaps ranging from 16 to 57% (**Figure 1**; Saharawat et al., 2010). These gaps were ascribed mainly to low yielding genotypes, poor crop establishment due to random broadcasting of the seed, and inadequate and inappropriate fertilizer nutrient applications that leaves 15 to 45% of the maize area unfertilized and the remainder with imbalanced nutrient applications.

The Global Maize Project (GMP) led by IPNI in collaboration with many research institutions in different countries has shown gaps between actual and attainable yields varying from 0 to 30% (at 80% of Y_W). In these experiments, Y_G could not be attributed to a single factor, but rather to the interaction of the several factors related to the management of resource and input technologies.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Mg = magnesium; B = boron; Mo = molybdenum; Zn = zinc. IPNI Projects KEN-GM46, KEN-GM61, IND-GM22, IND-GM-35, ARG-GM-24, ARG-GM-25.

Sub-Saharan Africa

Maize is the dominant food and cereal crop in sub-Saharan Africa (SSA) and accounts for 28% of the cereal area and 36% of the cereal production (FAO Statistics). Maize production has increased by 500% between 1961 and 2014, mainly due to area expansion, with less than 30% of the increase attributable to productivity, as maize yields have remained less than 2 t/ha on average (**Figure 2**). Despite many areas with high potential for maize production, low yields achieved by smallholder farmers in SSA are associated with complex constraints, including variable and unreliable rainfall, poor soil fertility, low use of fertilizer, limited use of improved seed varieties, and low investments in infrastructure that constrain access to input and output markets. Poor soil fertility conditions and low fertilizer use are recognized as some of the main yield-limiting factors. The use of mineral fertilizers in most countries in SSA has been

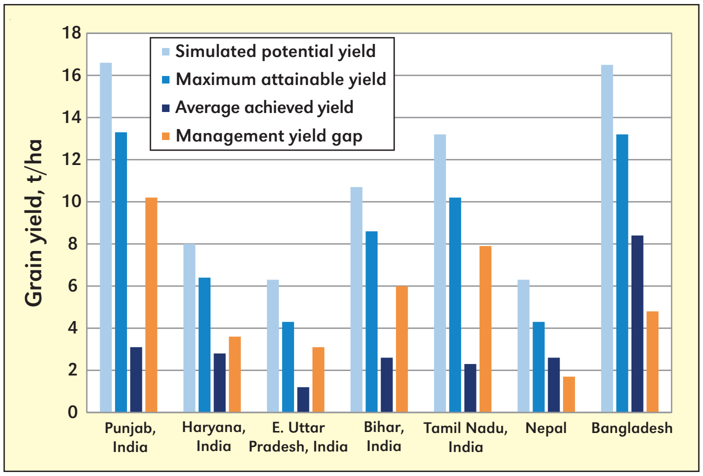


Figure 1. Potential, attainable, and actual yields and management yield gaps under different ecologies across South Asia (Saharawat et al., 2010).

mainly promoted through blanket N+P recommendations that are based on agro-ecological zones.

Increased use and proper management of fertilizer provides the most important step to increased maize productivity in SSA. As investments are being accelerated to help smallholder farmers to increase fertilizer use, parallel efforts are also required to ensure balanced fertilizer use to optimize productivity, fertilizer use efficiency, and minimize nutrient losses.

Maize trials conducted as part of the GMP in Eastern and Central Kenya showed the strong influence of agro-ecological conditions and balanced nutrient application on maize yields (**Figure 2**). Maximum attainable yields achieved with fertilizer over three seasons were higher (8 t/ha) at the Muguga sub-humid site compared with semi-arid Kambiyamwe (5 t/ha). Under farm conditions, yields were very low at both sites (<2.5 t/ha), as a consequence of poor agronomic practices and very low fertilizer application rates. Control yields with no fertilizer applied in on-station trials were higher than on-farm yields, suggesting the capacity to improve yields with improved maize varieties and optimal plant spacing.

In Muguga, yield across all treatments were >5 t/ha. This is more that 500% higher than the current maize yield average in smallholder farming systems in sub-humid zones in central Kenya, indicating a large yield gap between current and attainable yields. Balanced nutrient management (use of N+P+K+S+Zn+B) in the first year resulted in a 2% increase in grain yield over the current N+P recommendation. Second and third years of the balanced treatment increased productivity by 8% and 12% over N+P, respectively. Similar effects of balanced fertilizer application were observed in Kambiyamawe, despite lower yields due to moisture constraints.

The results from the GMP in Kenya highlight the need to change the blanket recommendations and tailor sources of fertilizer to account for the multiple nutrient deficiencies associated with low inherent soil fertility and long-term N+P application. There is growing recognition of the need to address K, secondary, and micronutrients in maize production. Soil mapping programs in Ethiopia and other countries have established high occurrence of S, Zn, and B deficiency, while significant maize responses to S, Zn, B, Mg, and Mo have been observed across the continent. Efforts are also underway in many countries (e.g., Malawi, Kenya, Ethiopia, Rwanda, and Tanzania) to support the development of fertilizer blends containing K, secondary, and micronutrients and make them available at larger scales.

South Asia

A study comparing attainable (Y_W) and actual (Y_A) yields across the major maize growing ecologies reported that the present average Y_A at farmers' fields is only about 50% of the Y_W, which could be increased through adoption of improved technology (Dass et al., 2008). Maize and maize-based systems, extract large amounts of mineral nutrients from the soil due to large grain and stover yields. Proper nutrient management of exhaustive maize-based systems should aim to supply fertilizers adequate to meet the demand of the component crops and applied in ways that minimize loss and maximize the efficiency of use (Jat et al., 2013). Productivity of maize in India has not increased significantly in the recent past. In a situation of plateauing yield levels and growing environmental concerns, practicing Ecological Intensification (EI) could help achieve greater production with minimal environmental impacts of agricultural production systems.

The GMP in India compared EI with farmers' fertilizer practice (FP) at two locations, one at the University of Agri-

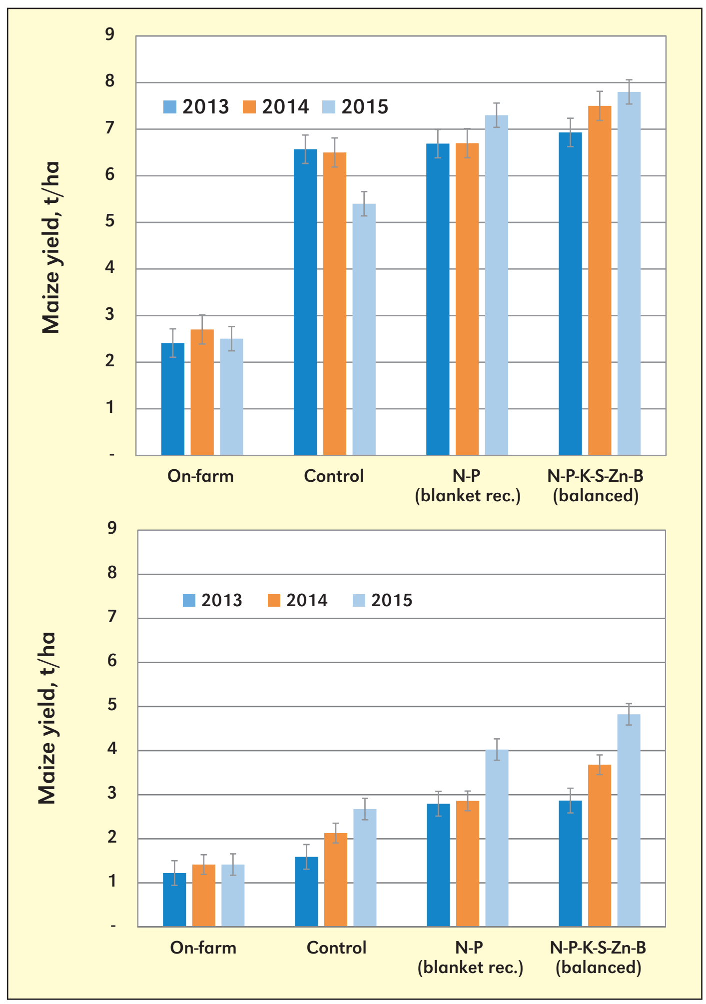
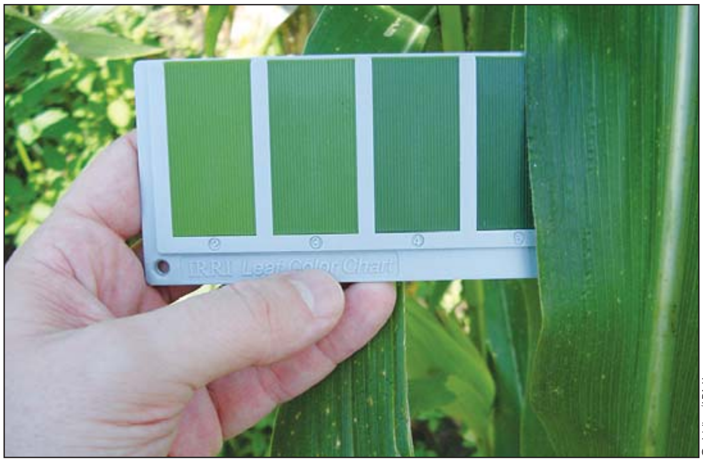


Figure 2. Maize grain yields over three cropping seasons of the Global Maize Project at Muguga in central Kenya (top) and Kambiyamwe in eastern Kenya (bottom). Bars indicate standard errors of the mean.



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4-Panel Leaf Color Chart for real time crop N status assessment.

cultural Sciences Dharwad, Karnataka, and the other at Birsa Agricultural University, Ranchi, Jharkhand. EI considered application of the right rates of N, P_2O_5, and K_2O for maize production, involving all the limiting secondary and micronutrients. 4R nutrient management was combined with other best management practices such as planting time, planted population, hybrid selection, residue management, etc.

Maize was planted during the sixth consecutive monsoon season in a Vertisol at the experimental station of the University of Agricultural Sciences, Dharwad, Karnataka. EI recorded a significantly higher yield (6.5 t/ha), which was 26% higher than FP and consistent with the results obtained in the last five years (**Table 2**). The higher grain yield under EI may be

Table 2. Effect of Ecological Intensification (EI) versus Farmer Practice (FP) on maize yield at Dharwad (India).

	Grain yield						
	2009	2010	2011	2012	2013	2014	Mean
Treatments	- - - - - - - - - - - - - - - - - - - -			t/ha		- - - - - - - - - - - - - - - - - - - -	
EI	4.5	4.1	3.9	6.4	6.8	6.5	5.4
FP	3.4	3.3	2.9	5.4	5.6	5.5	4.3
EI - FP	1.2	0.8	1.1	1.1	1.2	1.1	1.1*

*Significant at $p<0.05$

attributed to higher crop uptake of N (162 kg/ha), P (72 kg/ha), and K (53 kg/ha), which were 19, 20, and 26% higher than the FP, respectively. A net return of US$1,080/ha was obtained with EI, which was 22% higher than that obtained with FP (US$883/ha). The other metrics considered for evaluating the performance of EI point to enhanced nutrient use efficiency. Partial Factor Productivity for N (PFP_N), was higher in EI (18.7) than FP (17.1). Agronomic efficiency (AE_N) was also higher under EI (35.7) than with FP (9.1).

Long-term evaluation of EI within a maize-wheat rotation in Ranchi, Jharkhand with red and lateritic soil produced a six-year average grain yield of 6.2 t/ha—amounting to 123% more than the FP average (**Figure 3**). This EI research effectively determined the right rates and timings for N application to optimize both yield and profitability of this maize-wheat cropping system. Applying 240 and 150 kg N/ha (in maize and wheat respectively) split between three applications based on Leaf Color Chart-based N assessment proved to be most beneficial (Biradar et al., 2012).

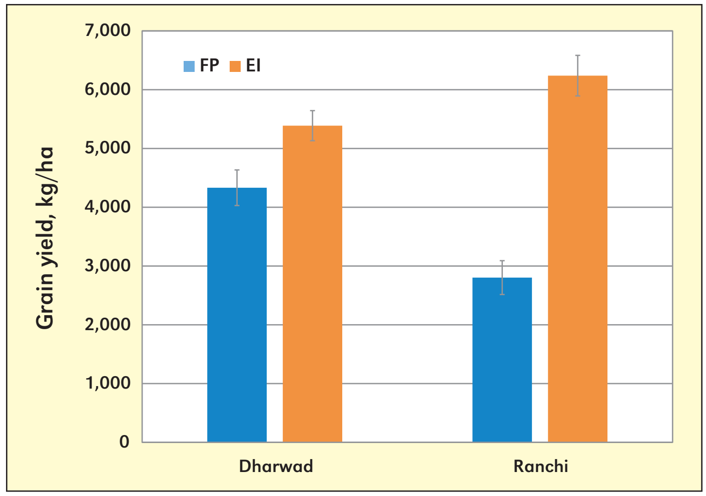

Figure 3. Average grain yields of maize under farmers' practice (FP) and ecological intensification (EI) at the Global Maize Project sites in India. The data represents an average of six years (2009-14). Vertical bars show standard errors of the means.

Argentina

Comprehensive estimations of gaps (at 80% of Y_W) find 20% differences between current and attainable maize yields at the country level, with regional variations between 9% and 49% (Aramburu Merlos et al., 2015). This wide regional variability of Y_G has been attributed to differences in cropping history and technology adoption by farmers (nutrient use, control of insects, pests, and diseases).

Attainable yields were positively related to the variation in water supply, however yield gaps were larger under conditions of less restricted water availability. In dry years, water is the most limiting factor for crop production, and Y_G is relatively small. In years when water is less limiting, higher Y_G might be related to risk aversion behavior by farmers, which reduces the chances of achieving higher yields in these favorable years by inducing a level of management, and nutrient application, based on yields commonly reached with normal or moderately adverse weather conditions.

Unstable political and economic conditions further reinforce risk aversion by farmers who have been reluctant to adopt proven technologies such as high plant populations, early planting dates, and fertilization, despite the abundant information generated through research. Aramburu Merlos et al. (2015) partially attribute the estimated Y_G for maize to N deficiencies and decreasing soil P availability as a result of long-term negative P balances.

Data from six years of the GMP at Argentina found that improved soil and crop management increased grain yields by 22% at the Balcarce site and by 43% at the Paraná site (**Figure 4**). Differences in management between FP and EI were related to hybrid, plant population, row spacing, and NPS fertilization management (**Table 3**). These improved practices have been adopted from results of previous research (Barbieri et al., 2008; Calviño et al., 2003; Caviglia et al., 2004; Sainz Rozas et al., 1997). The EI treatment has also shown positive impacts in water and N use efficiency (Caviglia et al., 2012; Picone et al., 2013; Cafaro La Menza et al., 2014; Maltese et al., 2015), and in net returns.

Nutrient requirements and response in maize have been

Table 3. Main crop management practices for Farmer Practice and Ecological Intensification at the Global Maize Project sites in Argentina.

Management factor	Farmer Practice	Ecological Intensification
Cultivar	Most common hybrid (RoundReady®)	High yielding and stable (RoundReady® and Bt)
Population, seeds/m^2	6 to 6.5	8 to 8.5
Row spacing, m	0.7	0.525
N fertilization	Fixed rate (regional average); Urea applied at planting	Soil test-based rates; UAN applied at V6
P fertilization	30% less	Buildup to 20 ppm
S fertilization	None	5 kg/ha

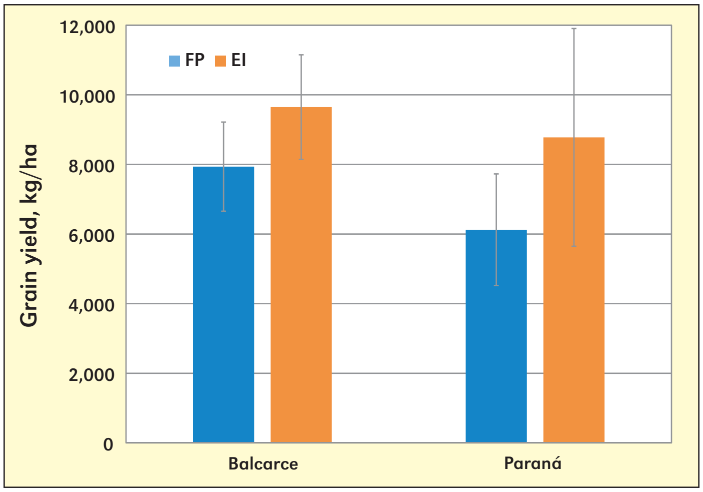

Figure 4. Average grain yields of maize under farmer's practice (FP) and ecological intensification (EI) treatments at the Balcarce and Paraná sites of the IPNI Global Maize project at Argentina. Averages for six growing seasons (2009-14) under a maize-wheat/double cropped soybean rotation. Vertical error bars are standard deviations of the means.

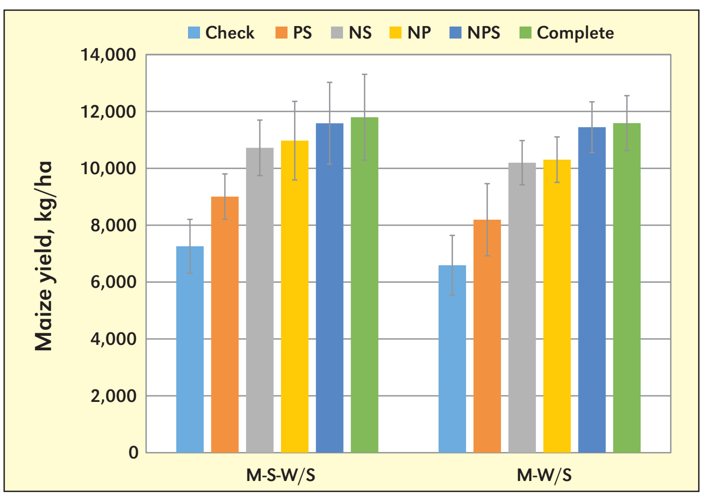

Figure 5. Average maize grain yields under maize-soybean-wheat/double cropped soybean (M-S-W/S) and maize-wheat/double cropped soybean (M-W/S) rotations in long-term fertilization experiments in the central Pampas of Argentina. Averages for five and seven growing seasons (2000 to 2014) for M-S-W/S and M-W/S, respectively. Vertical error bars are standard deviations of the means. Source: CREA Southern Santa Fe-IPNI-ASP.

extensively demonstrated through field experimentation and widely reported in the literature. As an example of the impact on yields, on-farm research in the central Pampas of Argentina has shown that 4R nutrient management could increase maize grain yields by 24 to 76% compared to unfertilized treatments (**Figure 5**).

Summary

Wide yield gaps in maize are still common in several regions of the world. Knowledge and information is available to reduce these wide gaps. 4R nutrient management is a key set of practices among the several management practices involved in getting higher yields. Extension work, public policies, and improved economic and political scenarios could greatly contribute to sustainably narrowing the maize yield gap. BC

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Dr. García is Director, IPNI Latin America-Southern Cone Program, Acassuso, Argentina; E-mail: fgarcia@ipni.net. Dr. Satyanarayana is Director, IPNI India Program, Gurgaon, India, and Dr. Zingore is Director, IPNI Sub-Saharan Africa Program, Nairobi, Kenya.

References

Aramburu Merlos, F., J.P. Monzon, J.L. Mercau, M. Taboada, F.H. Andrade, A.J. Hall, E. Jobbagy, K.G. Cassman, and P. Grassini. 2015. Field Crops Res. 184:145-154.

Barbieri, P., H.E. Echeverría, H.R. Sainz Rozas, and F.H. Andrade. 2008. Agron. J. 100:1094-1100.

Biradar, D.P., Y.R. Aladakatti, D. Shivamurthy, T. Satyanarayana, and K. Majumdar. 2012. Better Crops South Asia, 6:19-21.

Cafaro La Menza, N. et al. 2014. *In* Proc. ASA-CSSA-SSSA Meetings. Long Beach, California, USA.

Calviño, P., F. Andrade, and V. Sadras. 2003. Agron. J. 95:275-281.

Caviglia, O.P., V.O. Sadras, and F.H. Andrade. 2004. Field Crops Res. 87:117-129.

Caviglia, O.P. et al. 2012. Informaciones Agronómicas de Hispanoamérica 7:6-10. IPNI. Acassuso, Buenos Aires, Argentina.

Dass, S. et al. 2008. Indian J. Fert., 4(4):53-62.

FAI, 2015. Fertiliser Statistics, The Fertiliser Association of India, New Delhi.

Jat, M.L., T. Satyanarayana, K. Majumdar, C.M. Parihar, S.L. Jat, J.P. Tetarwal, R.K. Jat, and Y.S. Saharawat. 2013. Indian J. Fert. 9(4):80-94.

Maltese, N. et al. 2015. *In* Proc. Symposium Fertility 2015. IPNI-Fertilizar AC. Rosario, Argentina.

Picone, L., C. Videla, C. Bayer, R. Rizzalli, and F. Garcia. 2013. *In* Proc Symposium Fertility 2013. IPNI-Fertilizar AC. Rosario, Argentina.

Saharawat, Y.S., B. Singh, R.K. Malik, J.K. Ladha, M.K. Gathala, M.L. Jat, and V. Kumar. 2010. Field Crop Res. 116:260-267.

Sainz Rozas, H., H.E. Echeverria, F.H. Andrade, G.A. Studdert. 1997. Rev. Fac. Agron. La Plata. 102:129-136.

Timsina, J., R.J. Buresh, A. Dobermann, J. Dixon, and J. Tabali. 2010. IRRI-CIMMYT Alliance Project on Intensified Production Systems in Asia (IPSA), IRRI-CIMMYT Joint Report, IRRI, Philippines.

van Ittersum, M., K.G. Cassman, P. Grassini, J. Wolf, P. Tittonell, and Z. Hochman. 2013. Field Crops Res. 143:4-17.