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Improving the phenotypic expression of rice genotypes: Rethinking "intensification" for production systems and selection practices for rice breeding

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ARTICLE INFO

Article history:
Received 21 December 2014
Received in revised form
13 April 2015
Accepted 4 May 2015
Available online 12 May 2015

Keywords:
Expression of genetic potential
Rice phenotypes
Selection criteria for plant breeding
Selection efficiency
System of Rice Intensification

ABSTRACT

Intensification in rice crop production is generally understood as requiring increased use of material inputs: water, inorganic fertilizers, and agrochemicals. However, this is not the only kind of intensification available. More productive crop phenotypes, with traits such as more resistance to biotic and abiotic stresses and shorter crop cycles, are possible through modifications in the management of rice plants, soil, water, and nutrients, reducing rather than increasing material inputs. Greater factor productivity can be achieved through the application of new knowledge and more skill, and (initially) more labor, as seen from the System of Rice Intensification (SRI), whose practices are used in various combinations by as many as 10 million farmers on about 4 million hectares in over 50 countries. The highest yields achieved with these management methods have come from hybrids and improved rice varieties, confirming the importance of making genetic improvements. However, unimproved varieties are also responsive to these changes, which induce better growth and functioning of rice root systems and more abundance, diversity, and activity of beneficial soil organisms. Some of these organisms as symbiotic endophytes can affect and enhance the expression of rice plants' genetic potential as well as their phenotypic resilience to multiple stresses, including those of climate change. SRI experience and data suggest that decades of plant breeding have been selecting for the best crop genetic endowments under suboptimal growing conditions, with crowding of plants that impedes their photosynthesis and growth, flooding of rice paddies that causes roots to degenerate and forgoes benefits derived from aerobic soil organisms, and overuse of agrochemicals that adversely affect these organisms as well as soil and human health. This review paper reports evidence from research in India and Indonesia that changes in crop and water management can improve the expression of rice plants' genetic potential, thereby creating more productive and robust

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Peer review under responsibility of Crop Science Society of China and Institute of Crop Science, CAAS.

http://dx.doi.org/10.1016/j.cj.2015.04.001

phenotypes from given rice genotypes. Data indicate that increased plant density does not necessarily enhance crop yield potential, as classical breeding methods suggest. Developing cultivars that can achieve their higher productivity under a wide range of plant densities—breeding for density-neutral cultivars using alternative selection strategies—will enable more effective exploitation of available crop growth resources. Density-neutral cultivars that achieve high productivity under ample environmental growth resources can also achieve optimal productivity under limited resources, where lower densities can avert crop failure due to overcrowding. This will become more important to the extent that climatic and other factors become more adverse to crop production. Focusing more on which management practices can evoke the most productive and robust phenotypes from given genotypes is important for rice breeding and improvement programs since it is phenotypes that feed our human populations.

1. Introduction

There is certainly need for continued improvement in the genetic potentials of rice varieties, as such potentials can yield greater returns on the land, labor, capital, seeds, water, and other inputs that farmers invest in their rice production. Also, plant breeding can increase the range of options available to farmers. However, we suggest here that more attention be given to ways in which rice varieties (genotypes) can be managed more beneficially, to induce the fuller phenotypic expression of their genetic potentials and obtain more robust and more productive plants.

This suggestion reframes somewhat the tasks of plant breeding for proved rice performance, given that observed phenotypes do not map directly to genotypes, reflecting environmental influences as much as genetic endowments. When breeders use phenotypic expression and yield performance under test-site conditions for their screening and selection, their efforts will be more efficient and successful to the extent that these decisions are informed by a fuller understanding of environmental influences on phenotypic expression and of the associated mechanisms of such influences. We need to double the world's rice production by 2050 [1]. Achieving this ambitious goal will require realizing more effective agronomic expression of the genetic potentials that exist in rice cultivars, beyond the gains that can still be made in raising rice potentials through various methods of plant breeding.

Data presented in Table 1 show the increases in rice yields at the national level that have been achieved over the past five decades in 10 countries that produce over 85% of the world's rice: Bangladesh, Brazil, China, India, Indonesia, Myanmar, Pakistan, Philippines, Vietnam and Thailand, calculated from FAO and USDA sources available on IRRI's website [2].

Between 1960 and 2010, these countries achieved, on average, a 150% increase in paddy rice yields, an impressive accomplishment. These gains were based in large part on the breeding of new, improved varieties and on national programs to exploit these greater genetic potentials, although credit must go also to rice farmers for their efforts and adaptations to raise their respective levels of productivity. More was required than just better, more productive genes for higher yield.

It is evident from inter-decade comparisons of crop performance that there has been a *deceleration* in the improvement of yields since the 1980s. Rice yields in these 10 countries increased, on average, by 23.2% during the decade of the 1980s; however, this rate of increase declined to 19.3% for the 1990s, and then to 16.5% for the 2000s (Table 1).

Table 1 – Country paddy yields (t ha^{-1}), 1959–2011, three-year averages from FAO and USDA statistics. [a]

Country	1959–1961	1969–1971	1979–1981	1989–1991	1999–2000	2009–2011	5-decade increase (%)
Bangladesh	1.67	1.70	1.89	2.59	3.77	4.20	151
Brazil	1.69	1.34	1.46	2.14	3.25	4.53	176
China	2.03	3.30	4.28	5.62	6.32	6.60	225
India	1.53	1.67	1.86	2.62	3.01	3.30	116
Indonesia	1.93	2.38	3.53	4.33	4.38	4.36	126
Myanmar	1.65	1.71	2.45	2.85	3.14	3.29	100
Pakistan	1.36	2.24	2.41	2.32	2.95	3.28	141
Philippines	1.21	1.65	2.23	2.79	3.10	3.64	200
Thailand	1.65	1.93	1.85	2.10	2.60	2.83	71
Vietnam	1.94	2.07	2.15	3.18	4.25	5.44	180
Average yield	1.67	2.01	2.41	2.99	3.57	4.15	149
Increase during the decade (%)	–	20.4	19.4	23.2	19.3	16.2	–

[a] For a review of increases in rice productivity over the past five decades, we analyzed yield statistics (t ha^{-1}) for the past ten decades from the ten countries that have the highest production of rice (86% of the world's total), found in IRRI's online rice statistics data base [2]. Three-year averages were calculated for the start and the end of each decade to smooth out year-to-year variations, and data from FAO and USDA were averaged to account for the differences in annual average yield reported from these two sources. The decadal averages are unweighted to reflect the variations in country experience, because otherwise the trends in India and China would dominate the statistics.