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India's evergreen revolution in cereals

O. P. Yadav, D. V. Singh, B. S. Dhillon and T. Mohapatra*

The term 'Green Revolution' (GR) is used to highlight an unprecedented increase in wheat production in India during 1968–72. The critics of GR allege that there is technology fatigue, especially after 1980s. The present study was undertaken to analyse the trends in productivity of major cereals and compare yield gains during the GR era and post-GR era. The period of 68 years since 1950 was divided in four phases: pre-GR era (1950–66) referred to as phase I, GR era (1967–83) as phase II, post-GR era of 1984–2000 as phase III and post-GR era of 2001–17 as phase IV. The annual rate of gain in productivity (kg/ha/yr) in each phase was estimated by linear regression. The annual gain in wheat productivity in phase III (53.1 kg/ha) was 30% higher than that in the GR era (41.0 kg/ha). In rice, the productivity gains increased consistently: annual gain in phase III (32.3 kg/ha) and phase IV (41.6 kg/ha) was 68% to 117% respectively, higher than that in the GR era (19.2 kg/ha). The rate of gain in productivity of maize and pearl millet in phases III and IV was 188–530% higher in comparison to the GR phase. The progress can largely be attributed to development and adoption of improved cultivars with higher yield potential and crop management technologies. The analysis provided conclusive evidence of India experiencing evergreen revolution in major cereals.

Keywords: Cereals, crop productivity, green revolution, improved cultivars.

WITH bitter memories of the Bengal famine of 1943 still fresh, India was facing a stiff challenge in early 1960s, of feeding its fast growing population of 459 million as the country was experiencing deficit of food grains production by 10 million tonnes (mt). Fortunately, 1960s also witnessed development of dwarf wheat cultivars, the cultivation of which in a large area resulted in 88% increase in wheat production during 1968–72 compared to 1963–67. Such an unprecedented increase in production was termed as 'green revolution' (GR) in India. During the same period, 17–22% increase was recorded in rice, maize and pearl millet production. Since then, the country has made consistent progress in foodgrains production, primarily through increase in productivity (Figure 1) and has achieved a record production of 284.9 mt in 2017–18.

Critics of GR often allege that its achievements were short-lived, remained restricted to a certain geographical area and that there has not been any impressive progress after mid-1970s (refs 1–3). Some also consider that technology fatigue has set in[4]. In the present study, an analysis of the trends in productivity over 68 years since 1950 is presented and the annual productivity gains in the GR era (1967–83) are compared with two post-GR eras (1984–2017) in wheat, rice, maize, pearl millet and sorghum.

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Data source and analysis

The study is based on data on the productivity of crops (www.agricoop.nic.in) for 68 years (1950–2017). This period was partitioned in four phases of 17 years each. Pre-GR era (1950–66) is referred to as phase I, GR era (1967–83) as phase II, post-GR era of 1984–2000 as phase III and post-GR era of 2001–17 as phase IV. The

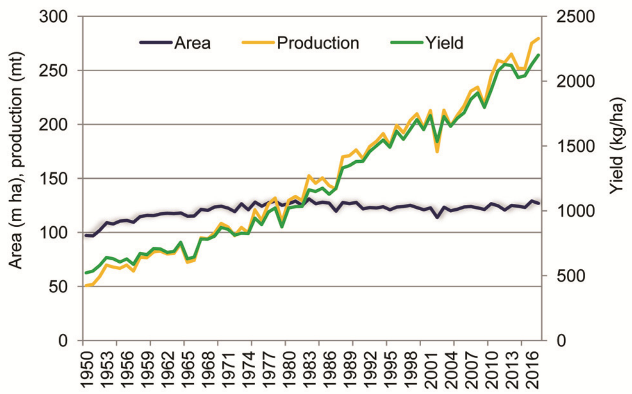

Figure 1. Area (m ha), production (mt) and productivity (kg/ha) of food grains in India since 1950.

gain in productivity (kg/ha/yr) was estimated using linear regression in different phases. Productivity increase is considered as the combined outcome of enhanced genetic potential of cultivars and improved crop management practices.

Trends in productivity

Wheat

During phase I, tall varieties were cultivated which were not responsive to external inputs. The annual increment in productivity was 11.6 kg/ha (Figure 2). In phase II, productivity gain increased to 41.0 kg/ha/yr as dwarf breeding materials were successfully used to develop locally adapted cultivars, which made a huge impact. This phase also included 5 years of the GR period. Improved agronomic management, including appropriate depth of sowing and irrigation at crown root initiation played a catalytic role in the exploitation of genetic potential of dwarf cultivars.

In phase III, emphasis was given to the development of cultivars with high yield potential and built-in resistance to rusts by deploying genes imparting resistance. This phase registered an annual productivity gain of 53.1 kg/ha, which was 29% higher than that in the GR phase.

Continued improvement in productivity (36.3 kg/ha/yr) was witnessed in phase IV. However, the rate of improvement was slightly lower than that obtained in phase III but close to that achieved during the GR phase. A critical look at the yield data in this phase indicated that productivity during 2014–15 was clearly an outlier (Figure 2). Hailstorms, unseasonal rainfall and high-speed winds during February–March caused lodging and damaged the crop in about 6 m ha area in major wheat-growing states, namely Uttar Pradesh, Punjab, Haryana, Rajasthan, Madhya Pradesh and Maharashtra[5]. If data of 2014–15 are considered as an outlier, increase in wheat productivity during this phase is 40.8 kg/ha/yr that is equal to that of the GR era (41.0 kg/ha/yr).

Rice

During the pre-GR era, rice improvement emphasized selection in traditional varieties to develop new, locally adapted cultivars. Hybridization between indica and japonica types was also attempted[6]. The annual yield improvement during this phase was 15.7 kg/ha (Figure 2). During the GR era, the dwarf and semi-dwarf rice varieties made a significant impact and productivity further increased @ 19.2 kg/ha/yr.

In phase III, greater emphasis was given to the development of cultivars with adaptation to specific niche environments with the result that the rate of productivity increased further to 32.3 kg/ha/yr, which is 68% higher than the gain achieved during the GR era. In phase IV, rice improvement programme emphasized on the incorporation of multiple genes for resistance to diseases and tolerance to abiotic stresses like submergence and drought using conventional and molecular techniques, leading to the development of climate-resilient varieties. Hybrid development and amalgamation of high yield, short duration and superior grain quality were given top priority. This phase witnessed productivity increase of 41.6 kg/ha/yr, which was 116% higher than that achieved during the GR era.

Not only has rice productivity witnessed a continuous increase during all four phases, what is more striking is that the productivity gain has been improving further in each phase. This is a significant achievement since rice is cultivated in the rainy season in northern and eastern India, and thus is always vulnerable to variation in both amount and distribution of rainfall.

Maize

Up to mid-1950s, maize research largely concentrated on the improvement of local landraces and traditional open-pollinated varieties (OPVs). In addition, efforts were also made, though not successful, to introduce hybrids from USA. Because of their temperate background and, therefore, poor adaptation to Indian agro-ecologies, these hybrids did not express their yield potential. The inbred parents had poor vigour, which rendered hybrid seed production extremely difficult. Starting in 1961, a large number of indigenously developed multi-parent hybrids were released. The productivity increase during 1950–66 was 25.1 kg/ha/yr (Figure 2). Under the impression that the major reason for poor impact of hybrids was the difficulty in production and supply of quality hybrid seed to farmers, the emphasis by the end of phase I shifted to composite breeding. There was a modest improvement (9.8 kg/ha/yr) in growth rate of maize productivity during phase II.

Maize improvement strategy was, therefore, given a relook during phase III and a mixed approach of composite breeding, multi-parent and single cross (SC) hybrid breeding was adopted to meet the requirements of different production environments[7]. The improvement in maize yield during phase III occurred at 37.9 kg/ha/yr which was 287% higher than that achieved during the GR era.

Since 2001, the major emphasis has been on breeding of SC hybrids that have the highest yield potential among various types of cultivars. The area under such hybrids is continuously expanding under good agronomic conditions[8]. Maize productivity gain increased to 61.7 kg/ha/yr during phase IV, which was 530% higher than that achieved during the GR era (Figure 2).

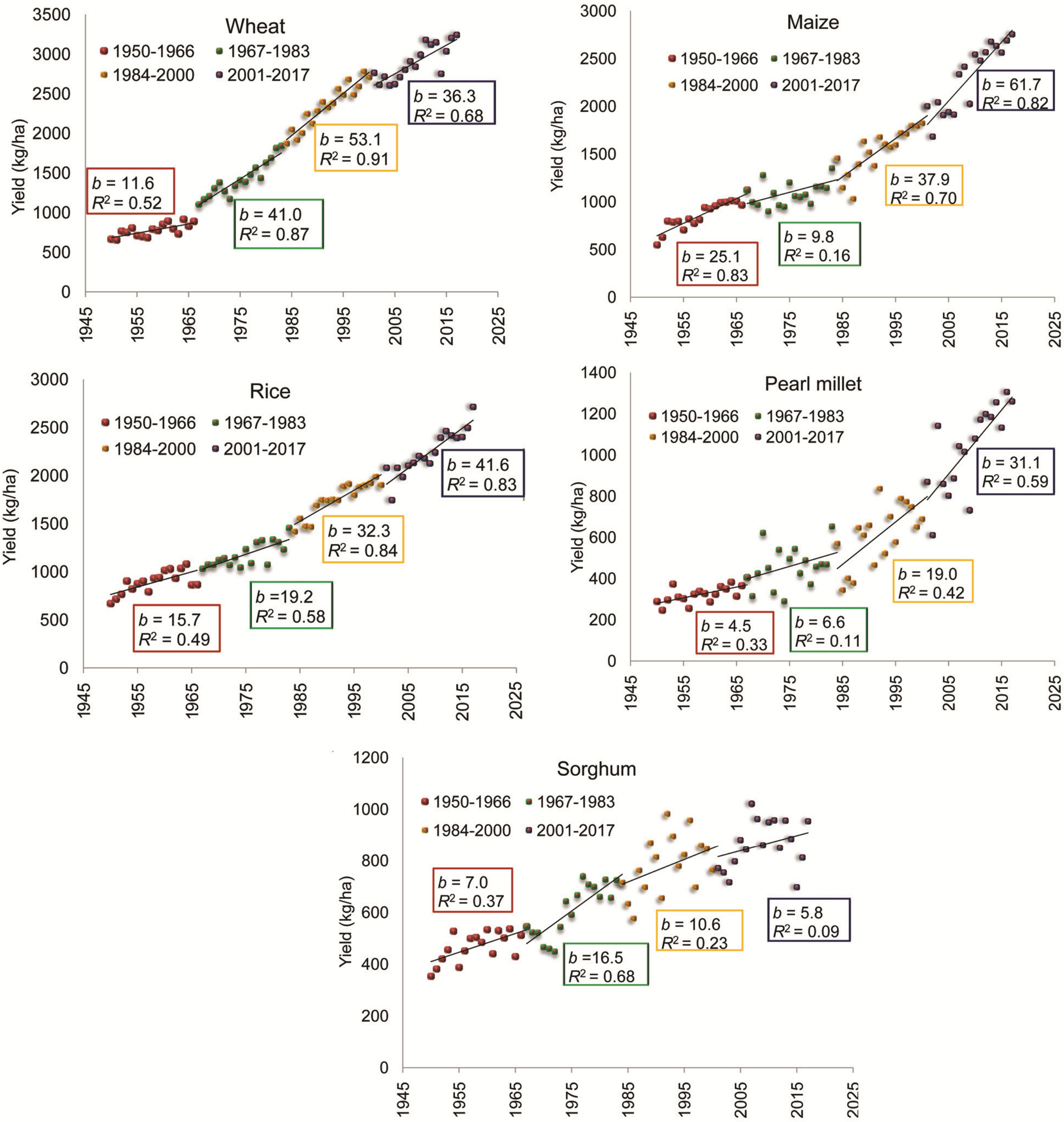

Figure 2. Productivity (kg/ha) trend of cereal crops in four phases since 1950. The coefficient b is rate of increase in yield (kg/ha/yr) in each phase and R^2 is the coefficient of determination.

Pearl millet

During phase I, pearl millet improvement largely concentrated on the enhancement of yield in locally adapted materials and a good number of OPVs were developed. The rate of improvement in productivity during this phase was only 4.5 kg/ha/yr (Figure 2). Utilization of cytoplasmic male sterility (CMS) marked the beginning of hybrid development, though large-scale cultivation of few hybrids with narrow genetic base led to downy mildew (DM) epidemics in mid-1970s, offsetting the impressive achievements made in hybrid development. Thus, there was annual increase of 6.6 kg/ha in productivity during phase II.

A large number of genetically diverse CMS lines were developed and utilized in hybrid breeding during phase III. Consequently, DM was largely contained and productivity increase during this period was 19.0 kg/ha/yr, which was 188% higher than that during the GR era. During phase IV, the improvement programme laid much great emphasis on adaptation to niche area and genetic diversification of both seed and pollinator parents[9]. As a result, rate of improvement in grain productivity further increased to 31.1 kg/ha/yr, which was nearly five times that achieved during the GR era. This rate of improvement assumes greater significance considering that more than 90% of pearl millet is grown on marginal soils under rainfed conditions.

Sorghum

During phase I, sorghum yields went up by 7.0 kg/ha/yr (Figure 2) as traditional OPVs and local cultivars dominated the scene. In phase II, the yields increased by 16.5 kg/ha/yr, largely due to development of high-yielding hybrids based on CMS. The yields in sorghum increased by only 5.8–10.6 kg/ha/year in phases III and IV which was much lower than that obtained in other crops, this rendering sorghum a lesser competitive crop in its cultivation domain.

During 1966–2017, the sorghum area in *kharif* season, in spite of higher productivity drastically decreased from 11 to 2 m ha. During this period, *rabi* area also decreased from 6 to 3 m ha. The sorghum improvement programme continued mainly targeting *kharif* season, in spite of drastic reduction in the area. The serious problem of grain moulds in *kharif* sorghum continued to remain a challenge. On the other hand, research on *rabi* sorghum which is cultivated on residual moisture in Maharashtra, Karnataka and Telangana did not get due attention. As a result, productivity gain declined during phases III and IV, though the productivity per se increased.

Conclusion

The analysis of rate of increase in productivity of major cereal crops since 1950 clearly shows that there is consistent increase in productivity. This is a result of strategic and applied research in crop improvement and management practices. The rate of increase in productivity of pearl millet and maize since 1980s has been several times higher than that realized during the GR era. Rice productivity witnessed a continuous increase during all four phases with the rate of productivity being 68–117% higher in last two phases than that in the GR era. The rate of productivity gains in wheat in the last two phases was either higher or close to that realized in the GR era. The present study convincingly shows that India has been witnessing a silent evergreen revolution in major cereals.

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Received 2 August 2018; revised accepted 27 March 2019

doi: 10.18520/cs/v116/i11/1805-1808