Available online at www.sciencedirect.com

ScienceDirect

Field Crops Research 106 (2008) 53–59

Field Crops Research

www.elsevier.com/locate/fcr

Soybean yield trends from 1972 to 2003 in mid-western USA

D.B. Egli *

Department of Plant and Soil Sciences, University of Kentucky, 427 Plant Science Building, 1405 Veterans Drive, Lexington, KY 40546-0312, USA

Received 12 April 2007; received in revised form 14 October 2007; accepted 18 October 2007

Abstract

The increases in crop yield that played an important role in maintaining adequate food supplies in the past may not continue in the future. Soybean (*Glycine max* L. Merrill) county yield trends (1972–2003) were examined for evidence of plateaus using data (National Agricultural Statistics Service) for 162 counties (215 data sets) in six production systems [Iowa, Nebraska (irrigated and non-irrigated), Kentucky and Arkansas (irrigated and non-irrigated)] representing a range in yield potential. Average yield (1999–2003) was highest in irrigated production in Nebraska (3403 kg ha^{-1}) and lowest in non-irrigated areas in Arkansas (1482 kg ha^{-1}). Average yield in the highest yielding county in each system was 31–88% higher than the lowest. Linear regression of yield versus time was significant ($P = 0.05$) in 169 data sets and a linear-plateau model reached convergence (with the intersection point in the mid-1990s) in 35 of these data sets, but it was significantly ($P = 0.10$) better in only three data sets (<2% of the total). Absolute (kg ha^{-1} year^{-1}) growth rates were associated with productivity, but relative rates were not with the mean relative rates ranging from 1.0 to 1.3% over the six systems. There was, however, a two- to threefold range in relative rate among counties within systems in Nebraska, Iowa, Kentucky and Arkansas (irrigated). Yield did not change (linear regression not significant, $P = 0.05$) between 1972 and 2003 in 41 counties in non-irrigated areas of Arkansas and Nebraska and in six Kentucky counties of which four had high levels of double-cropping soybean after wheat (*Triticum aestivum* L.). I found no convincing evidence that soybean yields are reaching plateaus but the technology responsible for this yield growth was apparently completely ineffective in low-yield, high-stress environments.

Keywords: *Glycine max* (L.) Merrill; Crop productivity; Yield growth rate; Yield plateaus

1. Introduction

Higher yield played a major role in the increase in the total production of most agronomic crops in the last half-century (Evans, 1998; Cassman, 1999). Recent evidence, however, suggests that yield growth of some crops may be slowing or may have stopped in some environments. Yield of rice (*Oryza sativa* L.) and wheat (*Triticum* spp.) seem to have reached plateaus in some countries (Pingali et al., 1997; Calderini and Slafer, 1998; Cassman et al., 2003), while in other countries the increases continue unabated, albeit at slower rates in some situations (Rosegrant and Ringler, 1997). Soybean yield in the US shows steady increases through 1998 (Specht et al., 1999), but Nafziger (2004), extending the analysis through 2003, suggested that average soybean yield in the US and in six corn belt states may have reached a plateau near the turn of the century.

The appearance of yield plateaus may jeopardize the ability of agricultural production systems to expand the food supply enough to accommodate the nearly 1.5 billion people (an increase of 23% over 2005) expected to be added to the world population by 2025 [based on the medium variant from the 2004 UN population division estimates (available on line at esa.un.org/unpp/, verified 12 October 2007)]. The importance of continually increasing yields is enhanced by the need to limit expansion of crop production onto poorer quality soils whose use may damage the environment and endanger long term sustainability (Lal, 2003), by possible reductions in the contribution of irrigated agriculture to world food production (Postel, 1999), and by potential diversion of crop land from food to fuel production (Baker and Zahniser, 2006).

Cassman et al. (2003) suggested that increasing yield depends, in part, on the gap between yield in farmer's fields and yield potential [yield of an adapted cultivar when nutrients and water are not limiting and pest, diseases, weeds, lodging and other stresses are effectively controlled (Evans, 1993)]. It will become progressively more difficult for farmers to increase their yield as the exploitable yield gap decreases, and

* Tel.: +1 859 257 5020x80753; fax: +1 859 257 7874.
E-mail address: degli@uky.edu.

0378-4290/$ – see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.fcr.2007.10.014

eventually plateaus will develop as farmer yields approach the potential yield. If yield potential is increasing, the exploitable yield gap will be maintained and farmer yields will continue to increase, but if it is not, as suggested for maize (*Zea mays* L.) (Duvick and Cassman, 1999) or rice (Cassman et al., 2003), yield plateaus will develop, and they will occur first in high-yield environments where the difference between yield potential and farmer yield is smaller.

It is notoriously difficult to identify yield plateaus resulting from the failure of the yield improvement process. Many historical plateaus, such as those predicted by Paddock and Paddock (1967), Jensen (1978) and Wennblom (1978) have proven to be illusions that were simply the result of several years of unfavorable weather conditions. Since true yield plateaus are expected first in high-yield environments (Duvick and Cassman, 1999), finding them only in those environments would suggest that such plateaus represent, in fact, a true cessation of yield growth and are not simply a function of the weather. To evaluate this hypothesis I compared county soybean yield trends from high- and low-yield environments in the US soybean belt. Counties are more likely to provide the high-yield environments needed to test this hypothesis than states where the yield estimates include both high- and low-yield counties. Only data from the USA were used to minimize confounding affects resulting from the availability of technology (including improved cultivars), the application of available technology (influenced by social and/or economic factors), the use of ineffective technology, and variation in environmental conditions. These confounding affects would probably be much greater if comparisons were made among countries, as is often the case (Pingali et al., 1997; Cassman et al., 2003).

2. Materials and methods

County soybean yield estimates from 1972 through 2003 were obtained from the National Agricultural Statistical Service (NASS) website (www.nass.usda.gov/, verified 12 October 2007). Four states – Arkansas, Kentucky, Iowa and Nebraska – were chosen to represent a range in productivity within a relatively close geographic proximity. Irrigated and non-irrigated yields in Arkansas and Nebraska were analyzed separately. Counties with less than 4048 ha (10,000 acres) in 2003 were excluded from the analysis to avoid introducing artifacts resulting from the small area (extreme year-to-year variation, undo influence by a single producer, greater likelihood of inexperienced producers). All 99 counties in Iowa exceeded this minimum, so 48 counties were chosen at random. A total of 215 data sets were analyzed, representing 162 counties (many counties in Arkansas and Nebraska included both irrigated and non-irrigated production) (Table 1).

A linear-plateau model [segmented model in the PROC NLIN procedure in SAS (SAS for Windows, v. 9.1, SAS Institute, Cary, NC)] was used to search for yield plateaus in the 169 data sets (out of 215) that exhibited a significant increase in yield between 1972 and 2003 [i.e., linear regression was significant ($P = 0.05$) and examination of residuals and quadratic models on a subset of counties suggested that the linear model was appropriate]. The linear-plateau model was chosen because the expected response was a relatively short plateau at the end of a long linear phase. The model was fit to each data set with an iterative procedure that produced an estimate of the slope and intercept of the linear portion of the curve and the point at which this regression line intersects the flat (zero slope) line representing the plateau. This intersection point was regarded as the beginning of the plateau. This analysis produced one of three possible results for each data set: (1) the model did not reach convergence; (2) the model reached convergence, but the intersection point was near or beyond the end of the data set, i.e., after 2001 (slope from this model was always equal to the slope from the linear regression model); and (3) the model reached convergence with the intersection point between 1972 and 2001. The linear-plateau model was accepted only for those data sets in category 3 and they were evaluated for significant ($P = 0.10$) improvement over the linear model using the F ratio computed as the difference in the error mean squares of linear and linear-plateau models divided by the error mean squares from the linear-plateau model. Significant improvement over the linear model was taken to signify existence of a yield plateau. The rate of yield gain was estimated by the linear regression of yield versus time in all data sets, except the data sets where the linear-plateau model was significant and then the slope of the linear part of the model provided an estimate of rate. Relative rates were calculated by dividing the absolute rate (kg ha^{-1} year^{-1}) by the mean predicted yield.

3. Results

The counties included in this analysis accounted for >90% of the harvested area (1999–2003) in irrigated and non-irrigated production in Arkansas, Kentucky and Nebraska. Roughly half of the 99 counties in Iowa were analyzed and they accounted for ~45% of the harvested area. County yields at the beginning (1972–1976) and end (1999–2003) of the 32-year period varied substantially among the six production systems with average irrigated yield in Nebraska at the end more than double the yield in Arkansas without irrigation (Table 1). The value of irrigation in Nebraska and Arkansas was obvious, as was the exceptional productivity in Iowa without irrigation.

Harvested area increased during the 32-year period in five of the six systems analyzed with non-irrigated production in Arkansas representing the exception, and here the area declined substantially (Table 1). Expanding production area can reduce the average yield if expansion occurs onto less productive soils (i.e., producers use their most productive soils first) or if it involves less experienced producers; whereas declining areas may have the opposite effect. It is impossible to quantify these effects, but yields were higher at the end of the period in those systems with increases in harvested area.

The year-to-year variability, primarily reflecting direct and indirect effects of the weather, was generally larger at the county level than at the state or country level (Specht et al., 1999; Nafziger, 2004). This difference is not surprising as the yearly variation in weather would probably be greater in the