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Robust seed systems, emerging technologies, and hybrid crops for Africa

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ABSTRACT

Hybrid crops are underutilized in many developing countries. Subsistence farmers in sub-Saharan Africa (SSA) rely predominantly on outdated hybrids and open-pollinated varieties, which has limited the region's ability to achieve food security and agricultural sustainability goals. Key challenges in SSA include lack of access to improved hybrid seed, insufficient infrastructure to support a formal seed system, and limited smallholder farmer access to input and output markets. Implementing improved seed systems and creating greater market access will require engagement from the public and private sector and the governments within Africa. This paper reviews the importance of hybrids in agriculture, the challenges associated with creating new hybrids, and the technological advancements that will enable more efficient production of quality hybrids in Africa.

1. Introduction

Over the past several decades, the adoption of improved land management practices, synthetic fertilizers and pesticides, and high-yielding hybrid seeds have supported significant improvements in agricultural productivity, food quality, efficiency (Spielman and Pandya-Lorch, 2009), and sustainability (Ciampitti and Vyn, 2014; Grassini and Cassman, 2012; Tian et al., 2016). However, the advancements made possible through the "green revolution" have not benefited all world regions equally. Yield gains have plateaued at very low levels in areas where there is limited agricultural infrastructure, knowledge, and inputs (Grassini et al., 2013). Agricultural productivity in developing countries is much less than in developed countries (FAO et al., 2015), and inefficient use of inputs in these regions contributes to disproportionate environmental degradation (West et al., 2014) and greenhouse gas emissions (Tian et al., 2016). As a result, progress towards food security remains challenging in many developing countries (Economist Intelligence Unit, 2015). Based on the challenges of stagnating yields in major food crops, climate change, and growing demand for food and feed, a greater emphasis should be placed on developing seed systems and hybrid crops in developing regions.

The population of Africa is projected to double by the year 2050 (DESA UN, 2015), and Africa's ability to support over two billion people without significant changes to their current agricultural paradigm is unsustainable. Sub-Saharan Africa (SSA) represents one of the most undernourished regions of the world, with almost a quarter of the population being malnourished with micronutrient and vitamin deficiencies (Bain et al., 2014; FAO et al., 2015). Agricultural productivity in SSA is disproportionately low and yield improvements have lagged behind most other regions (FAO et al., 2014). Maintaining pace with a changing climate is yet another challenge for crop production systems in SSA which have traditionally relied upon older, open-pollinated varieties and limited agronomic inputs. Maize, sorghum, and millet are among the most important cereal crops grown in SSA, as they are especially suited to productivity under diverse growing conditions (Chauvin et al., 2012). However, the productivity and economic value of these crops in SSA remain low. For example, Africa accounts for 15% of the total maize area cultivated globally but contributes less

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than 5% to the global maize harvest (Grassini et al., 2013). This is largely a result of low yield, which remains stubbornly static at approximately 2 metric tons per hectare (MT/ha) (FAOSTAT, 2015). Sorghum yield has remained at approximately 1 MT/ha for over 30 years and remains low relative to other regions, and the yield potential and yield trend of millet is even less encouraging (FAOSTAT, 2015). Although political commitment to improving food security exists, access to improved technologies remains out of reach for many smallholder farmers. Key challenges in Africa include continual cultivation of old hybrids and older open-pollinated varieties and limited access to improved hybrids. The goal of this paper is to discuss the importance of hybrids in agriculture, the challenges associated with developing a hybrid breeding program from a practical, policy, and technical perspective, and to review opportunities and technological advancements that will enable more efficient production of quality hybrids for Africa.

2. Importance of hybrids in agriculture

Most of the genetic gains in major crops from the early 20th century have harnessed heterosis for increased performance, and the agronomic improvements and productivity gains from hybridization under both stressed and optimal growing conditions have been unmatched by other agricultural advancements (Cooper et al., 2014; Tollenaar and Lee, 2002; Tollenaar and Wu, 1999). The value of hybridization in the plant kingdom has been recognized for over 200 years (Box 1), and represents one important tool for long-term, sustainable solutions to food insecurity. Heterosis and hybrid vigor are often used interchangeably and refer to the increased size or rate of growth of offspring over parents when two unrelated parents are crossed (Duvick, 1999). In a hybrid breeding program with a long-term focus, breeders produce new inbreds with good combining ability (the basis of heterotic pools), develop hybrids from these inbreds, and evaluate inbred and hybrid performance in targeted environment, multi-location trials (Troyer and Wellin, 2009). After each growing season, only the best-performing inbreds and hybrids are retained for further evaluation. Based on thorough assessment of field performance, new and improved hybrids that are best suited for high productivity under relevant environmental conditions (e.g., climate, abiotic and biotic stress factors) are commercialized.

Because hybrid plants are bred and selected to contain the most desirable traits from the parents, hybrid varieties can offer several agronomic, phenotypic, and nutritional improvements. Not only can hybrids offer improved ability to set more ears and kernels under stress (Campos et al., 2006; Cooper et al., 2014), they may also offer tolerance to adverse environmental conditions (Cooper et al., 2014; Tollenaar and Lee, 2002; Tollenaar and Wu, 1999). Performance under sub-optimal conditions will be important as the environmental stresses associated with climate change become more pronounced. Similarly, hybrids may offer a faster route to improved disease resistance, nitrogen use efficiency, resistance to lodging, and grain quality improvements (Duvick, 2005). In the early 1900s, maize production in the United States averaged less than 2 MT/ha with open-pollinated varieties (USDA NASS, 2015). The adoption of maize hybrids (in addition to improved agronomic practices, fertilizers, management practices) resulted in a steep rise in maize yield to average 10 MT/ha in the United States [Fig. 1; (Holland, 2009; USDA NASS, 2015)]. Since this early period of hybrid maize adoption, maize breeders and agronomists have contributed to a steady and consistent improvement in maize yields under both favorable and water-limiting conditions (Cooper et al., 2014; Duvick, 1977; Gaffney et al., 2015) and new hybrids are continuously being developed for improved agronomic characteristics. The resulting maize crop in the United States is resilient to stress and performs well even in sub-optimal growing conditions. Maize yield under drought stress has improved significantly over the past 50 years with no additional water extraction from the soil profile (Reyes et al., 2015). For example, the average maize yield in the United States in 2012 outperformed

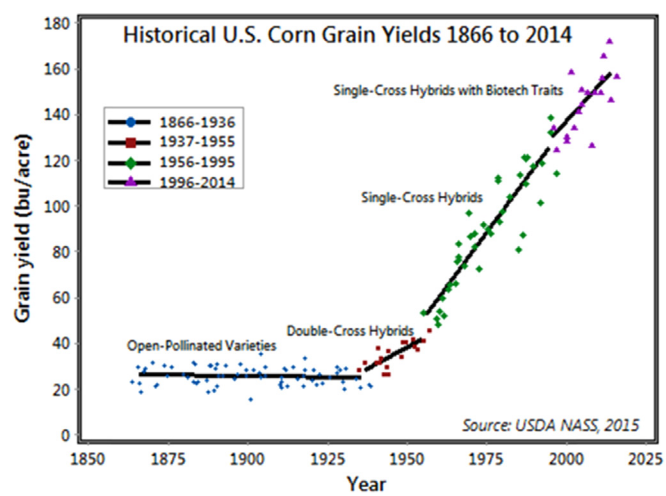

Fig. 1. Average historical maize yields in the United States from 1866 to 2014. Yield data from the United States Department of Agriculture – National Agricultural Statistics Service (USDA NASS, 2015). Shifts in yield trends that correspond to major changes in plant breeding are denoted.

Box 1–History of hybrid development

- 1776 - Kölreuter was among the first to publish on plant hybridization, specifically related to *Nicotiana* hybrids (Kölreuter, 1776).
- 1865 - Mendel researched genetic inheritance in peas and observed hybrid vigor (Mendel, 1865).
- 1877 - Darwin's book entitled, "The Effects of Cross and Self Fertilization in the Vegetable Kingdom," discusses hybrid vigor and notes the benefits of cross-fertilization for plant qualities (Darwin, 1876).
- 1909 - Dr. G.H. Shull, a scientist at the Carnegie Institute in Washington, D. C. begins breeding maize hybrids.
- 1914 - Dr. G.H. Shull defines "heterosis" as "the increased vigor, size, fruitfulness, speed of development, resistance to disease and to insect pests, or to climatic rigors of any kind, manifested by crossbred organisms as compared with corresponding inbreds, as the specific results of unlikeness in the constitutions of the uniting parental gametes" (Shull, 1952).
- 1926 - Henry A. Wallace conducts maize breeding experiments, which led to the birth of the Hi-Bred Corn Company, the first company to develop, produce and market hybrid maize. The company, now called DuPont Pioneer, is a leading developer and supplier of advanced plant genetics to farmers worldwide.
- 1950 - Maize hybrid adoption passed 95% of maize acres planted in the United States (Duvick, 1999).
- 1952 - first hybrid maize produced in Zimbabwe (Rusike and Eicher, 1997)
- By 1965, almost all sorghum acreage in the United States was of hybrid origin (Basra, 1999).