

Plant Breeding: It's a Journey, Not a Destination

Food and fiber for an ever-increasing world population

The world's population continues to increase, doubling from 3 to 6 billion between 1960 and 1999. By 2050, the number of humans is expected to exceed 9 billion. Providing food and fiber for this enormous population is an ominous challenge facing humankind, without significant addition of new arable lands, challenges of changing weather patterns, and decreased quantity and quality of fresh water. Genetic selection by plant breeders brought about the 'Green Revolution' of the 1960s and 1970s that increased production of major crops and saved millions in the developing world from starvation. Plant breeders continue this success story by developing superior crops to meet the world needs for food, fiber, and fuel.

Plant Breeding: Continuous investment pays continuous dividends

Plant breeding is never complete. Long-term support of plant breeding is the major reason why the USA still leads the world in agriculture, fueling economic growth, new businesses, and new jobs. Today's high-quality, superior-yielding crops are the foundations of even better plants for tomorrow. However continuous increases in crop productivity and quality are directly tied to sustained investment in plant-breeding personnel and infrastructure, such as research stations, greenhouses, labor and materials for crossing and selection, etc. Examples for which long-term investment in plant breeding have paid off handsomely include:

- Continuous selection of grains and oilseeds has increased productivity without requiring more land for cultivation (Fig. 1);
- Selection over 90 years has transitioned blueberry from a wild plant to today's #2 berry crop in the US (Fig. 2);
- Breeding of loblolly pine over the last 50 years has produced trees that grow straighter and yield 30 to 50% more wood per acre (Fig. 3);
- Increased nutritional quality of vegetables; today carrot is the primary source of vitamin A in the US diet (Fig. 4);
- Improved pest resistance prevents crop losses and limits pesticide use.

Plant breeders rely on sustained funding for long-term selection of crops to address such challenges as:

- Increased global trade introducing exotic pests or pathogens;
- Higher mean temperatures and humidity making endemic diseases and pests more serious;
- Drought and reduced access to fresh water contributing to significant yield reductions;
- Increasing input costs for fuels and fertilizers.

Recommendations:

Sustained funding of plant breeding by commodity groups, private industries, USDA, and other state or federal agencies to:

- Support the infrastructure and long-term commitment required to develop superior crops for US production and global consumption;
- Train the next generation of plant breeders to address the needs of a growing world population with fewer inputs and decreasing arable land.

For more information:

Please visit the website of the National Association of Plant Breeders (NAPB) at <http://www.plantbreeding.org/napb/sustainingplantbreeding.html>

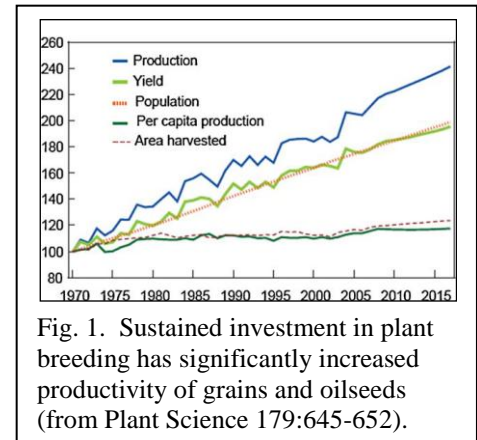


Fig. 1. Sustained investment in plant breeding has significantly increased productivity of grains and oilseeds (from Plant Science 179:645-652).



Fig. 2. Superior blueberry bushes selected from wild progenitors (B. Strik, Oregon State Univ.).



Fig. 3. Controlled crossing of loblolly pine (S. McKeand, North Carolina State Univ.).



Fig. 4. Continual selection of carrot for deeper orange color increases Vitamin A content (<http://www.agripinoy.net/growing-carrot.html>).

Plant Breeding and Rural Development in the United States

Keith E. Woeste,* Sterling B. Blanche, Karen A. Moldenhauer, and C. Dana Nelson

K.E. Woeste, USDA Forest Service Northern Research Station, Hardwood Tree Improvement and Regeneration Center at Purdue University, 715 West State St., Pfendler Hall, West Lafayette, IN, 47907; S.B. Blanche, Rice Research Station, Louisiana State University Agricultural Center, 1373 Caffey Road, Rayne, LA 70578; K.A. Moldenhauer, University of Arkansas Rice Research & Extension Center, 2900 Highway 130 East, Stuttgart, AR 72160; C.D. Nelson, USDA Forest Service Southern Research Station, Southern Institute of Forest Genetics, Harrison Experimental Forest 23332 Old Mississippi 67, Saucier, MS, 39574. Received _____. *Corresponding author (Woeste@purdue.edu).

Abbreviations: RD, rural development.

ABSTRACT

Plant breeders contributed enormously to the agricultural and economic development of the United States. By improving the profitability of farming, plant breeders improved the economic condition of farmers and contributed to the growth and structure of rural communities. In the years since WWII, agriculture and the quality of rural life have been driven by policies that encouraged and subsidized an agro-industrial production model. Plant breeders responded by developing methods and deploying products attuned to agro-industrial clients. Major achievements by plant breeders of the era include the development of higher yielding crops suitable to new environments and mechanized harvesting and shipping. As social, technological and economic changes reinforced the expansion and dominance of the agro-industrial model, rural communities sustained high levels of out-migration. At the same time, a variety of societal and economic forces have encouraged new food system models, including the locavores and community supported agriculture. Sustainability indices reflect the desire of mega-retailers to make the relationship between consumers and the production of their food more transparent. These forces, along with an increased focus on the quality of rural life in America, represent opportunities for plant breeders to address the needs of new clients, to develop methods appropriate to their client's values, and to serve traditional clients in new ways.

KEYWORDS Rural life, agriculture and food policy, community development, food systems, agricultural sustainability

Introduction

Plant breeders have made considerable, even extraordinary contributions to the economic expansion of the U.S. (Olmstead and Rhode, 2008); at the same time, plant breeders also

enabled and benefited from the rise of public policies and private interests that dramatically changed the rural environment and landscape (Woeste, 2008). Rural U.S. society—its demographics, livelihood, and way of life—was profoundly altered by these developments (Lobao and Stofferahn, 2008). For example, in the mid-20th C., African Americans were almost entirely uprooted from farming (Lobao and Meyer, 2001). In the following sections, we hope to illuminate how plant breeding served agricultural development in the past, and make the case that rural development, the increased well-being of the land and those who live on it, is important to the future of plant breeding.

Plant Breeding and U.S. Economic Development

Plant breeding was integral to the dynamic process of biological innovation that enabled the rapid demographic, cultural and economic expansion of the North American colonies and, later, the United States (Olmstead and Rhode, 2008). The Native people of North America selected, domesticated and cultivated a number of plant species (Smith, 2006; Smith and Yarnell, 2009). The timely adoption of native crops and their conversion to international commodities was critical to the success of many colonies. Continuous experimentation with new varieties (often derived from imported germplasm) enabled farmers on a frontier that moved ever-westward to produce crops that met their needs in their changed economic and environmental situation (Olmstead and Rhode, 2008). In their assessment of this early period, historians often overlooked the significance of the contribution of plant breeders because they focused on technological change or were misled by a reliance on yield as the sole or best measure of the importance of biological innovation (Olmstead and Rhode, 2008). For example, the mixing of gene pools that led to the development of corn-belt dents in the 19th C. marked a turning point in world agricultural history. While the biological changes resulting from plant breeding enriched farmers individually, they also contributed to broader economic development. Through the modification of plant phenology and the incorporation of genes for resistance to pests and disease, plant breeding made life in remote areas less risky. The macro-economic consequences to rural economies of increased profitability and decreased risk were profound. Increasing land and property values, the development of local economic infrastructure, and the prospect of a (more) stable and (slowly) improving economic condition contributed to long-term social structure in small towns and rural communities. These communities, in turn, nurtured their members; there are as many striking examples of farmers acting in concert to overcome common problems (Olmstead and Rhode, 2008), as there are tragic examples of the consequences when they were unable to do so, for example, the failures of the agricultural marketing cooperatives in tobacco and cotton in the 1920's (Woeste, 1998).

Plant Breeding, Agribusiness, and Rural Life

In modern times, plant breeders are recognized for their role in the development of highly productive, industrial agriculture (Trewavas, 2002; Edgerton, 2009). Yet their contribution to rural development is more controversial. The distinction between farm policy and rural development is at the crux of the controversy. The dominant food system in the U.S., often termed agro-industrial, grew out of the New Deal and developed

in the years after WWII. Since the emergence of the agro-industrial food system, “rural America has been adjusting itself . . . in an effort to meet the priorities and expectations of the nation as articulated by metropolitan political and economic elites. Central among these has been the goal of establishing a stable, highly predictable, generally healthful, and cheap food-supply system that would meet the needs of a burgeoning urban-industrial and now post-industrial population (Lapping and Pfeffer p. 91).” As described above, one of the most important features of farm policy since WWII has been the push to develop an agricultural sector that resembled manufacturing industries in efficiency and productivity (Hightower 1973; McIntyre et al., 2009); in other words, the rise of modern agribusiness. Plant breeders took an active role in this transformation, their enthusiasm spurred by the dynamic changes in scientific knowledge, as gene discovery occurred, and by the vast changes in computer and communication technologies. During this period there were also many changes in intellectual property protection (IPP) starting with the Plant Patent Act passed in 1930 (Evenson, 1999; Smith, 2008). Many private as well as public institutions looked at IPP as a way to recoup financial investments. Working within the agro-industrial paradigm, plant breeders focused on improving the profitability of agricultural production for increasingly concentrated and globalized agricultural markets. For example, plant breeders improved the suitability of a wide variety of crops for handling by machines in vertically integrated production, processing, distribution and marketing chains that now routinely stretch across national boundaries (Douches et al., 1996; Pike, 1997; Kelly et al., 1998; Finn and Knight, 2002; Bouton, 2007). Plant breeders influenced rural economies by improving the efficiency and profitability of crop production, and by maintaining or extending the environments in which a crop was grown. These efforts often served the farm policy of the period after WWII, which was summarized in the 1950s by Secretary of Agriculture Ezra Taft Benson as “get big or get out”, and by his assistant, Earl Butz, who himself would become Secretary of Agriculture, with the slogan “adapt or die” (cited in Berry, 1999; Hightower, 1973; Congressional Quarterly, 1973).

The benefits and negative externalities associated with the rise of agribusiness were not uniformly distributed. High levels of concentration of agribusiness in the U.S. contributed to massive dislocation, migration, and the eclipse of many small-towns (Lobao and Stofferahn, 2008); the dominance of the agro-industrial model also undermined sustainability, contributed to environmental degradation, and increased inequity in wealth in the food system (McIntyre et al., 2009). In rural areas of the U.S., many smaller landowners remain on their farms, but most no longer make their living as farmers; typically the great majority of their income is derived from non-farm employment (Mishra and Sandretto, 2002). Farm policy is not intended to address the needs of this type of landowner; that is the mission of rural development (RD). Although there is no single vision of what constitutes RD, in general RD programs attempt to address the needs of the rural environment, rural communities and small to mid-sized agricultural producers. Rural development programs within the USDA and agencies such as the Federal Reserve (Federal Reserve Bank of Kansas City, 2000) address the upheaval felt by farmers and those who lived in small rural communities by attempting to reduce the economic and social isolation of rural life and to enhance economic activity in rural areas. These approaches do not directly address the desire felt by many farmers and

small landowners to continue farming and to have a meaningful connection to their nearby communities through their land and what it produces, although there are programs within the USDA that do address these concerns (USDA-NAL, 2009).

Emerging Social Forces and the Future of Plant Breeding

It should be clear from the above that the U.S. agro-industrial food system is a critical driver—both positively and negatively— for the well-being and identity of rural Americans and the condition of rural land. Although the current food system has deep roots and powerful economic and political support, forces are emerging that may, over time, bring about important changes in what Americans eat and how and where it is grown. Although we can't predict the scale or scope of the impact of these forces over the next generation, even small changes in the current food system can have important implications for plant breeders and for rural development.

Agro-industrial markets are changing because concepts of sustainability are becoming mainstream concerns. Mega-retailers are exploring how to respond to consumers' concerns over food quality and the environmental impact of land use decisions (<http://walmartstores.com/Sustainability/9264.aspx?p=232>; http://www.sysco.com/aboutus/aboutus_sustainability.html; Hatanaka et al., 2005). Sustainability standards are expected to become more widespread in the future because they contribute to profits (Székely and Knirsch, 2005). The goal of rating products using a sustainability index will require traceability and transparency at every step of the market chain, and may provide consumers with additional options concerning the types of food (and industrial) systems they wish to support. If sustainability criteria are applied broadly to all agricultural products, the impact would extend beyond food to include the landscape and flower industries, paper and lumber production, and the manufacture of clothing from the tillage of the field to the delivery of the finished product. If consumers respond to a sustainability index, producers large and small will look to plant breeders to help them capture their share of the sustainably-grown market. Whether these changes will benefit non-industrial food producers will depend in large part on how sustainability is defined, and especially how sustainability standards include measures of social impact (Ranganathan, 1998; Vanclay, 2003). Increased awareness of sustainability and market-based mechanisms for translating consumers' concerns will be an opportunity for plant breeders to develop new methods to address the needs of rural clients and urban consumers.

A second force likely to alter the current food system is the rapidly increasing cost of health care, and the emergence of diabetes and obesity as drivers of economic, social, and political change. In 2005, the Centers for Disease Control and Prevention estimated that 67% of non-institutionalized adults age 20 years and over in the U.S. were overweight or obese (<http://www.cdc.gov/nchs/fastats/overwt.htm>). The effect of this trend on health is reflected in the number of Americans with diagnosed diabetes, which is projected to increase 165%, from 11 million in 2000 to 29 million in 2050 (prevalence of 7.2%) (Boyle et al., 2001). Although the links between nutrition and health are complex, dietary factors are associated with 4 of the 10 leading causes of death in America (U.S. Department of Health and Human Services and Public Health Service, 2004). Changes in diet can have large impacts on U.S. agriculture (Buzby et al., 2006). As the costs associated with treating nutrition-related diseases increase, it is likely that

providers of health insurance, both public and private, will focus on ways that improved nutrition can save money and lives. The consequent effects on food production and marketing are difficult to anticipate, but they could be profound. Increased awareness of the links between nutrition, health, and health care costs, will be an opportunity for plant breeders to address rural development by engaging new clients in the health-care sector.

The Relationship between Plant Breeding and Emerging Biomass, Bio-fuels, and Carbon Markets

In general, biomass and bio-fuels, as industrial raw-materials, will probably be grown and handled as commodities in much the same ways that commodity crops are currently grown and handled under the agro-industrial model. As these markets emerge, plant breeders will have the opportunity to influence which crops are adopted and the environmental impact of the cropping systems that are used to produce them. Unless plant breeders and policy makers approach new crop development with a considered awareness of sustainability and RD, the benefits of new opportunities in biomass or bio-fuels will likely accrue to landowners in much the same way that the benefits from production of commodity crops do currently. The exception to this rule may be with respect to carbon sequestration markets. Depending on how incentives are written into future legislation, landowners may be able to realize new economic benefits by switching from an annual to a perennial crop, to a perennial form of their current crop, or by converting acreage to uses that favor long-term carbon sequestration, such as forests or grasslands. Plant breeders are actively engaged in the development of perennial crops, seeds, and planting stocks that improve the success of afforestation and ecosystem restoration (Burton and Burton, 2002; McKeand et al., 2003; Hebard, 2005; Jacobs and Davis, 2005; Lesica and Atthowe, 2007).

Clients and Methods Matter: The Relationship between Plant Breeders, Non-industrial Farmers, and Emerging Food-system Models

Historically, most plant breeders in the U.S., both public and private, have served private enterprise and agricultural policy rather than RD. Typically schooled in Colleges of Agriculture of Land Grant Universities, plant breeders are exposed to modern food or commodity production systems, but are less often exposed to the diverse visions of what constitutes RD (see Hightower, 1973; Berry, 1977; Federal Reserve Bank of Kansas City, 2000; www.rurdev.usda.gov) and so may be unaware of the ways in which their efforts on behalf of farm policy, agribusiness, or agricultural development as defined by one constituency may be viewed by other constituents, especially those with an interest in RD (Allen, 2006).

Plant breeding, as a discipline, can benefit from increased awareness of the needs of new constituents, rural and urban, and the development of new methods to address those needs. Over the past 60 years, urban and non-rural food buyers have become alienated from rural life and from the rhythms and demands of food production. Some have begun to take issue with what they see as undesirable consequences of the agro-industrial food production model. They have driven the demand for alternative food systems including

organic food. The organic market sector is still small; about 5 percent of U.S. vegetable acreage and 2.5 percent of fruit and nut acreage was certified organic in 2005 (Greene, 2005), but it is one of the fastest growing new markets. In the U.S., most organic food is produced and sold as part of a food production system that opts out of *some*, but not all, of the perceived disadvantages of the agro-industrial model. Many see organic food and even “big-organic” as an acceptable compromise that better reflects their values related to farming, food, and stewardship of resources. Organic food production is only one of several emerging food systems. The force behind their emergence is

“a vision of a New American agriculture, built on an entrepreneurialism rooted in both community and environmental responsibility that promotes producer-consumer cooperation, a shared commitment to a negotiated landscape combining elements of the city and the country, and community-based food-security systems”(Lapping and Pfeffer, 1997, p. 92).

As described by Lapping and Pfeffer (1997), the innovators of the new models are producer-entrepreneurs and consumers that aspire to establish alternative market relationships or to revitalize markets that were foreclosed by economic developments over the past 70 years. These developments included, for example, the concentration of grocery purchasing into large regional retail chains, the emergence of global, vertically integrated value chains, and concentration of ownership in production and processing (McIntyre et al., 2009). The new models, include the slow food movement, metropolitan agriculture, civic agriculture, community supported agriculture, community gardening, farmer’s markets, farm to school/hospital/restaurant programs, slow food, and the locavore movement (Wiggins, 2008). Not necessarily conceived as mechanisms of RD, the new agricultural models have revitalized the urban/rural interface because they permitted farmers and consumers to redefine their relationship to one another in the food system and to the land (see Table 1). The new models have limitations as drivers of food system change (Hinrichs, 2000), but their importance has increased dramatically in the past 20 years. Metropolitan agriculture, for example, “a form of local economic development and landscape preservation” attempts to bridge urban and rural communities, taking advantage of the geographical proximity of many farmers to urban consumers (Stauber, 1997). Statistics provided by the U.S. Census Bureau show that “the number of farmers who sell directly to the public increased 35% from 1992 to 2002, and the total value of direct sales increased 101%” (Lyson, 2007). These statistics show the close relationship between rural opportunity and urban America. Plant breeders can make a considerable contribution to this relationship, although only a portion of the income on farms practicing metropolitan agriculture comes from growing food. New relationships between metropolitan producers and urban consumers have the potential to revitalize awareness of public technology transfer programs and programs to develop new or value-added markets that enhance rural development (e.g., New Ventures in Food and Agriculture for Indiana, <http://in.marketmaker.uiuc.edu>; USDA National Agriculture Library, Alternative Farming Systems Information Center, http://afsic.nal.usda.gov/nal_display/index.php?info_center=2&tax_level=1).

Emerging food systems and changing values with respect to horticultural production and landscape sustainability may require new genotypes and perhaps even new crop

ideotypes. Some crop traits that are desirable for industrial production (e.g., uniform harvest dates) may not be attractive to small producers. Plant breeders have a long history of working with crops that have a restricted consumer base or are grown for only local or regional markets, and this practice continues today (Gray et al., 2009; New York Agricultural Experiment Station, 2004; Janick, 2004). Economic theory suggests, however, that small-scale growers are often highly risk-averse (Feder, 1980), which could partly explain their attraction to heirloom varieties (Merwin, 2008; Rutgers, The State University of New Jersey, 2008). Emerging food-system models have arisen in part out of dissatisfaction with the current relationship between plant breeding and agro-industry, including the methods by which new varieties are developed. Most plant breeders are taught to use methods that, in the eyes of those in the emerging food systems, fail “to contextualize research and to recognize the particularities of production and of place” (DeLind and Binger, 2007, p. 303). Methods of crop improvement developed over the past 70 years to serve agro-industrial clients may be unsuitable for non-industrial producers (Deryckx and Dillon, 2005). Models of participatory plant breeding (PPB) can specifically address the reluctance of farmers to adopt new varieties (Sperling et al., 2001; Witcombe et al., 2005). PPB has been used effectively for well over a decade, especially in developing areas of the world (Almekinders and Elings, 2001;), but new breeding models appropriate to organic production (<http://www.agron.iastate.edu/seedsandbreeds/Dillon.pdf>), to low-input and organic agriculture (Murphy et al., 2005; Dawson et al., 2008), to agriculture at the urban-rural interface or even urban areas, and to production environments such as high tunnels require further refinement.

Proponents of alternative food systems have divergent views, but many are pragmatists. While some may use language ambiguously (Hinrichs, 2003), or in ways unfamiliar to those who breed for conventional systems (Beus and Dunlap, 1990; Kloppenburg et al., 2000), generally they are not anti-science (Goodman and Goodman, 2007). New food systems are sometimes linked to sustainable agriculture (<http://agebb.missouri.edu/sustain/>; www.leopold.iastate.edu/research/marketing.htm; Goodman and Goodman, 2007) a more familiar concept to most breeders. In general, we believe these developments represent a real opportunity for plant breeders because they open doors to new clients, re-affirm the traditional public sector role for plant breeding, and represent an unprecedented opportunity to participate in a new discussion between urban and rural Americans concerning food and fiber production and quality, and the stewardship of natural resources. Plant breeders are in a position to make a difference in shaping this discussion, and their skills are needed. Plant breeders must seek to address these movements intentionally; these developments will not be met as an accidental byproduct of plant breeding (or economic policy) made with other objectives in mind. On the practical level, plant breeders might consider developing and incorporating metrics related to RD as measures of the success of their program (Table 2). Metrics of this type might be particularly valuable for new breeding programs, especially when breeders are engaged with clients who are unfamiliar with the Land Grant system. New clients and breeders may need to develop mutually beneficial methods of communication and feedback (Middendorf and Busch, 1997) so that breeders can grow their programs responsibly and justify them to administrative hierarchies.

Acknowledgements

We thank Phil Simon, Lori Peemoeller, Bill Tracey and David Cleveland, and several anonymous reviewers for their valuable criticisms, comments and suggestions for improving the manuscript. In addition we thank our fellow Plant Breeding Coordinating Committee subcommittee members—D. Cummings, D. West, J. Wolmstead, K. Chenault, C.S. Cramer, X. Sha, L. Wessel-Beaver, D.B. Weaver, C. Griffey, G. Myers, K.R. Lamkey, M. Carena, L. Ferguson and S. St. Martin - for their discussions in the early going and support throughout. The use of trade names is for the information and convenience of the reader and does not imply official endorsement or approval by the United States Department of Agriculture or the Forest Service of any product to the exclusion of others that may be suitable.

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Table 1. Characteristics of Civic Agriculture (from Lyson, 2007)

1. Farm production is local and marketing is local.
2. Farm production is integrated into the community.
3. Farmers compete on the basis of quality and not least cost.
4. Civic agriculture is less capital intensive, less land extensive, more labor intensive.
5. Civic agriculture depends on local, shared knowledge and not uniformity of practice.
6. Civic agriculture is more likely to forge direct markets and less likely to depend on middlemen.

Table 2. Sample metrics for successful plant breeding for rural development.

<u>Metrics for successful plant breeding for rural development</u>		
	<i>Breeding for new and sustainable landscapes, agricultural, and horticultural systems</i>	<i>Agro-industrial breeding and rural development</i>
Processes	<p>1. Plant breeders attend and present at meetings of groups involved in metro-ag, civic ag, and sustainability of landscapes, agricultural, and production systems, and vice versa. 2. Clarification of expectations and roles for public and private sector breeders within the context of emerging food systems. 3. Coordination with seed industry to provide a product that rewards their role fairly while respecting the desire of farmers to save seed. 4. Coordination with existing NIFA (formerly CSREES) and cooperative extension programs, and with non-profit and NGOs who already have experts with established relationships with producers, consumers and agencies with a stake in new food systems and improved nutrition. 5. Incorporation of the goal of sustainability into the long-term objectives of breeding programs. 6. Develop mechanisms by which new clients provide measurable, critical, routine and sustained assessments and advice to breeders, administrators and funders of breeding programs.</p>	<p>1. Plant breeders attending and presenting at meetings of groups involved in rural development, vice versa. These gatherings will need to include many rural citizens who are not farmers. 2. Clarification of metrics for understanding the impact of new varieties on rural development, e.g., what types of crops/improvements/traits make a difference? 3. Development of a shared understanding or at least a mechanism to develop a shared understanding of the values rural citizens wish to see supported. 4. Development of models to integrate these values into the profit-directed goals of corporations that hire plant breeders.</p>

Products	<p>1. Development of curricula to train students in participatory plant breeding. 2. Internships in participatory breeding. 3. Grants focused on participatory breeding approaches for small producers. 4. Publication of peer reviewed articles related to breeding in the context of non-industrial food systems. 5. Development of teams (breeders, soil scientists, pathologists) focused on solving problems faced by non-industrial farmers. 6. Adoption of varieties or cultivars tested or produced through participatory breeding. 7. Development, recruitment or retention of new producers into non-agro-industrial food systems. 8. Development of new markets for existing producers in new food systems (e.g., ability to reach ethnic consumers). 9. Increased awareness of the potential of plant breeding to improve the health of consumers, the environment, and the economic well-being of metropolitan area producers. 10. The introduction of new crops or new varieties that introduce new markets or improve the choice within or extend the season of existing markets.</p>	<p>1. New varieties that significantly expand markets or enable new market development. 2. Investment into rural enterprises by companies directly and indirectly related to agro-industrial production. 3. Increased stability of production, leading to increased land values, reduced insurance costs, increased efficiency of markets, and increased investment in the broader agricultural sector. 4. Continued lowering of the percentage of disposable income spent by rural citizens on food.</p>
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