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AGRICULTURE REDESIGN THROUGH PERENNIAL GRAINS: CASE STUDIES

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ABSTRACT

Multiple purpose perennial crops are potentially the most adoptable by farmers and of most value to society, as means to provide grain, forage for livestock systems, recycling of nutrients to protect water quality, and build soils. This paper examines the services provided by two perennial grain crops as case studies: perennial wheat and semi-perennial pigeon pea. In Michigan, intermediate wheatgrass provided significant benefit to environmental services when investigated in field experimentation, especially through reducing leaching of nitrogen to almost nil. The results were consistent with perennial wheat as providing valuable environmental services, particularly in places with steep, marginal lands, such as Nepal. In Africa, diversification with legumes has a long history, and is the basis of the natural regeneration of fertility in extended bush fallows which dominated agricultural production until recent decades. A new type of perenniation is urgently needed, one where semi-perennial legume food crops are integrated with cereals and tuber crops. Improved varieties of legumes have tended to emphasize short-duration growth types with large grain to shoot ratios (high harvest index); this has come at the cost of extended vegetative cover which can double or triple photosynthesis and nitrogen fixation potential. Judicious combinations of short-duration food legumes (soybean, cowpea, groundnut and bean) and shrubby or viney grain legumes (pigeon pea, mucuna and climbing bean) with cereal crops is a promising way forward, to sustainably intensify production while gaining desirable perennial traits. A 'doubled up legume' system of pigeon pea grown in mixtures with short-statured food legumes, where pigeon pea is ratooned to grow a second year as an intercrop with maize has doubled fertilizer efficiency compared to sole maize, based on hundreds of participatory research actions on-farm in Malawi. Over 10 000 farmers are now pursuing innovations with various combinations of improved pigeon pea germplasm and integrated crop, soil and residue management. Participating villages have demonstrated, measurable improvements in yield stability and child nutrition. This is some of the emerging evidence that perennial grains can help communities overcome degraded soils and build family health for a resilient future.

Keywords: participatory research, agricultural systems, pigeon pea, perennial wheat, doubled up legumes

INTRODUCTION

The purpose of this paper is to illustrate the potential of two perennial grain crops — (i) perennial wheat (*Triticum aestivum x Thinopyrum elongatum*) and (ii) a semi-perennial legume crop, pigeon pea (*Cajanus cajan*) — to address critical production issues. The contribution of perennial wheat is explored using intermediate wheatgrass in Michigan. A doubled up legume system with pigeon pea is explored in Malawi. The results are used to illustrate how perennial grains can improve ecosystem sustainability and family health.

PERENNIAL WHEAT

A comprehensive, 4-year field study conducted in southwest Michigan is quantifying environmental services associated with perennial cereals, including high nitrogen retention, pure water quality, and soil building (Culman *et al.* 2013). Perennial wheat is a novel cereal crop under development through two different pathways. One pathway is the domestication of a perennial relative of annual wheat (*Triticum aestivum*), a forage grass called intermediate wheatgrass (*Thinopyrum intermedium)*. Another pathway that plant breeders are pursuing is to cross perennial grasses with annual wheat to develop a perennial form of wheat. Both pathways have the potential to produce multi-purpose crops; that is, crops that can be grown for grain or fodder and provide environmental benefits (Glover *et al.* 2010).

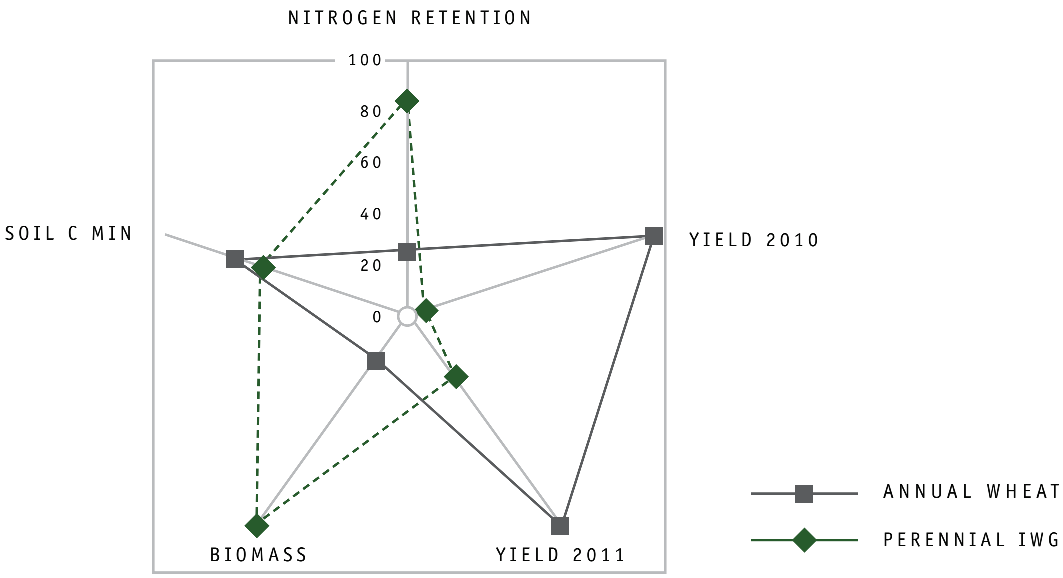
Dozens of lines of perennial wheat have been developed by plant breeders through repeated crossing of annual wheat with perennial grasses including intermediate wheatgrass and *Thinopyrum elongatum*. The new crop is under selection, as breeders choose lines that have a perennial growth habit (with post-sexual reproduction regrowth), while exhibiting grain characteristics similar to that of the annual wheat parent. The majority of the genetic makeup of this new crop is that of annual wheat, at least among the lines being developed at Washington State University by Drs. Stephen Jones and Kevin Murphy (Murphy *et al.* 2009).

Since 2007, field studies have been underway in Michigan at the W.K. Kellogg Biological Station, evaluating intermediate wheat grass (IWG) and perennial wheat lines for production potential and other ecosystem services such as soil building properties. Grain yields remain low to moderate, from about 0.3 to 1.8 mg per ha grain yield of perennial cereals relative to 2 to 4 mg per ha from annual wheat (Jaikumar *et al.* 2012). From an initial, 2 year assessment, IWG produces modest to almost zero grain yield and is a vigorous, true perennial grass that can be grown as a forage crop as it is highly productive and of good quality fodder (Figure 1), and it has substantial environmental benefits (such as reducing nitrogen leaching to almost undetectable amounts). (See Culman *et al.* 2013 for the first report on this novel cropping system). The root growth and biomass belowground of IWG is consistently five-fold higher, relative to annual wheat (C. Sprunger, unpublished data).

Perennial wheat has the advantage that it produces a crop that is recognizable as wheat, so the grain can be sold in an already-existing market, and there is the potential for growers to use it as a dual purpose crop whereby farmers who have livestock graze it during the spring, then plants are allowed to grow back and grain harvest occurs later that same year. Farmers reap an immediate return and have the added benefit of gaining from its long-term impact: large root systems that we predict will improve soil-organic matter, carbon sequestration, and water quality. There is considerable evidence that water quality is improved markedly by growing a crop of IWG, with 80 percent or higher retention of nitrogen in the soil-crop system, reducing nitrate leaching to almost zero through water loss pathways, as indicated by field experiments in the Snapp lab at Michigan State University (Figure 1) (Culman *et al.* 2013).

Somewhat surprisingly, there is limited evidence from these field experiments that IWG or perennial wheat lines have been effective at supporting rapid gains in soil carbon. The active soil carbon pool and nitrogen recycling is indeed markedly improved by IWG, but total soil carbon has been slow to respond in the initial years of these long-term perennial grain experiments.

FIGURE 1. BASED ON DATA PRESENTED IN CULMAN *ET AL.* (2013) COMPARING THE ECOSYSTEM SERVICES SUPPORTED BY PERENNIAL GRAIN IWG WITH THOSE PRODUCED BY ANNUAL WHEAT IN A FIELD TRIAL CONDUCTED AT KELLOGG BIOLOGICAL STATION, MSU, IN SOUTHWEST MICHIGAN



Soil C respiration measurements are consistent with active soil C pools being modestly enhanced in the presence of IWG, by about 15 percent relative to annual wheat (Figure 1). But no effect of a perennial grain (relative to annual wheat) has been observed for soil carbon sequestration pathways, as indicated by soil permaginate oxidizable carbon measurements (Culman *et al.* 2013). The almost complete lack of overlap between the prototype perennial grain IWG and annual wheat shows that the benefits of annual wheat are primarily grain yield as yet, whereas IWG has considerable fodder and environmental services and is not yet a significant producer of grain.

Taken together, the results are consistent with IWG as fitting well into a dairy or cattle farm. In contrast, perennial wheat shows potential as a cover crop to grow in marginal areas of the farm to protect fragile areas such as along riverbeds, but the unique property of perennial wheat is that, in addition to soil conservation, these new genotypes can also produce yields of grain and fodder. These results have implications for other regions of the world, such as Western Nepal, where wheat is the dominant crop and where its production as an annual crop requires excessive amounts of labour, provides too few additional benefits (e.g. to livestock), and is highly variable due to variable weather. Perennial wheat offers a range of opportunities for overcoming the challenges of annual wheat production (Figure 2).

FIGURE 2. DR. DHRUBA THAPA, A WHEAT BREEDER WITH THE NEPAL AGRICULTURAL RESEARCH COUNCIL, HIGHLIGHTS THE STRONG REGROWTH OF SOME OF HIS PERENNIAL WHEAT HYBRIDS

He believes perennial wheat will improve the lives of women farmers, increase wheat yields and quality, and meet multiple farming system needs.

FIGURE 3. TALLER, SLOWER GROWING PIGEON PEAS COMPLEMENT LOWER- AND FASTER-GROWING GROUNDNUTS, WHICH ARE READY FOR HARVEST SEVERAL WEEKS BEFORE PIGEON PEAS MATURE

SEMI-PERENNIAL PIGEON PEA

Another case study, highly relevant to tropical farming systems, is that of the perennial legume species, pigeon pea (*Cajanus Cajan*) (Snapp *et al.* 2003). It is often grown as an annual but traditional cropping systems still involve production of pigeon pea as a short-lived perennial (two to three years). It is a tropical legume that grows as a shrubby semi-perennial crop, and demonstrates a unique set of multi-functional properties, which is being documented in Malawi, southern Africa (Glover *et al.* 2012; Snapp *et al.* 2010). Farmers have long relied on pigeon pea to provide flexible options for livestock feeding and crop production, enhancing flexibility and productivity of the entire farm system. Recent genetic improvements in pigeon pea include new varieties that are broadly adapted to diverse environments. Farmer research groups are testing agronomic innovations through participatory research approaches that promote farmer innovation (Bezner-Kerr *et al.* 2007).

Over 9 000 farm families have newly adopted pigeon pea in the northern Ekwendeni region of Malawi (Snapp *et al.* 2010). Farmer education through participatory action research has promoted experimentation, which includes planting arrangements, crop residue management, and improved fodder for dairy cattle. Because parts of Africa's climate are tropical, farmers can incorporate pigeon pea into cash crops as they can grow for one to three years. After it is harvested, growers can cut it back and use the vegetative material as fodder for livestock or to improve soil fertility, and can sell the peas for profit or use them as a protein-rich food.

Agro-ecology training of farmers has supported local testing of a range of perennial-diversified options, and older, drought tolerant crops such as land races of sorghum are being grown as intercrops with pigeon pea and with other grain legumes (e.g. doubled up legume mixtures of pigeon pea and groundnut or pigeon pea and soybean), and in maize mixed systems (Figures 3 and 4). Growing pigeon pea and doubled up legume systems (with pigeon pea intercropped with soybean or groundnut) has been tested in Kenya and Malawi, with growing evidence that they can substantially enhance production of nutrient-enriched grain compared to sole cropped maize (Snapp and Silim, 2002; Snapp *et al.* 2010; Figure 5). Pigeon pea has a deep root system and leafy residues that enhances soil fertility for consistent yield gains in rotated crops such as maize, as well as supporting production of grain directly.

FIGURE 4. PIGEON PEAS PROVIDE INTERCROPPING OPPORTUNITIES FOR FARMERS

Because of their slow growth rates in the first year, they do not compete aggressively with faster growing legumes such as groundnuts. As they regrow in the second season, they can compete with more aggressive crops such as maize.

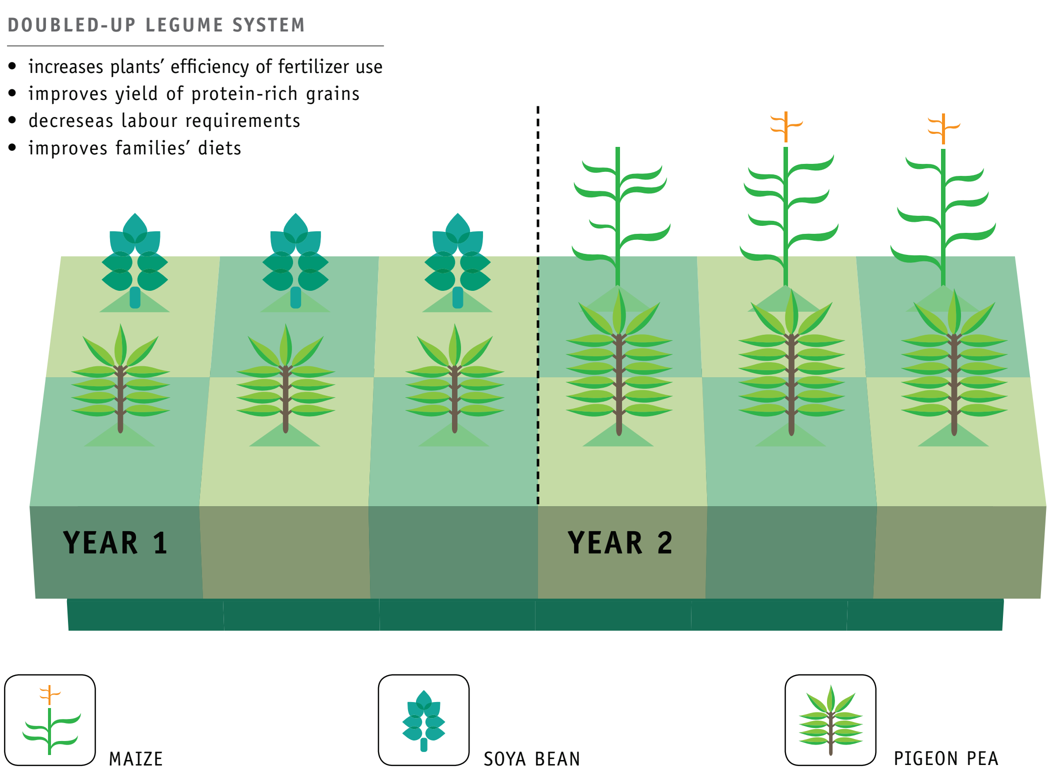
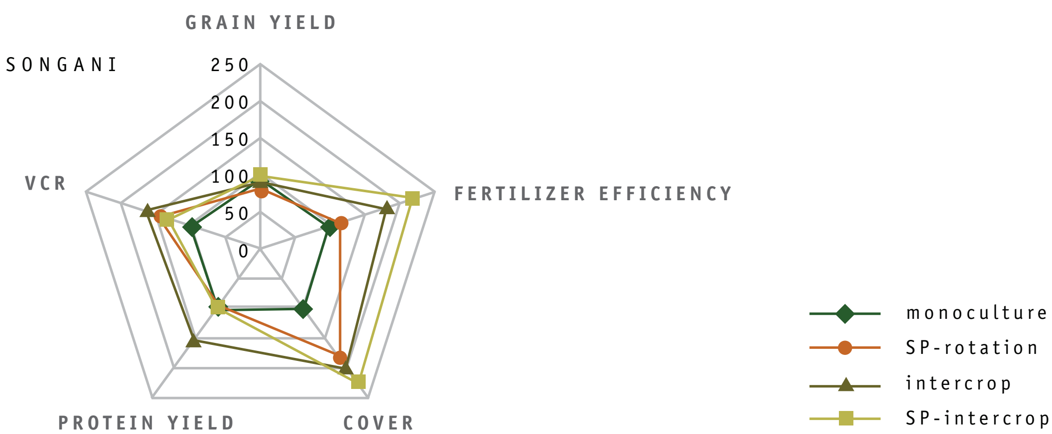


FIGURE 5. SHRUBBY PIGEON PEA INTERCROPS (SP-INTERCROP) AND SHRUBBY PIGEON PEA ROTATIONS (SP-ROTATIONS) DECREASE FERTILIZER REQUIREMENTS; IMPROVE THE VALUE COST RATIO (VCR), FERTILIZER USE EFFICIENCY, AND PROTEIN YIELDS; INCREASE CARBON AND NITROGEN ASSIMILATION AND PHOSPHORUS AVAILABILITY; AND PROVIDE GREATER COVER THAN MONOCULTURE MAIZE



Source: Snapp *et al.* 2010

Long-term field experiments and on-farm monitoring in Malawi have documented the unique ability of these polyculture perennial systems to support gains in soil organic carbon, nitrogen, and water use efficiency and adaptation of crops to climate variability. These are some of the lines of evidence suggesting that perennial crops provide farmers with important new options as a foundation for sustainable intensification of smallholder production in Africa. Further, we predict that the environmental benefits that are associated with perennial grains will prove vital to smallholder farmers' ability to buffer crop production and cope with the on-going variability that is associated with weather patterns in sub-Saharan Africa. Global warming is predicted to induce enhanced variability in the near future, so coping with droughts, rising temperatures, and variable weather will be even more important in the coming decades. The examples presented here illustrate how perennial grains can be used in combination with judicious inputs to provide a sound foundation for wise resource use, to protect the environment, and to support sustainable production in a rapidly changing world.

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