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Potential of Perennial Crop on Environmental Sustainability of Agriculture

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Abstract

Since the advent of agriculture, more than one-fourth of Earth's land surface has been converted for agricultural purposes, which conversion from natural to agricultural landscapes dramatically changes the plant communities that are integral to ecosystem processes. By developing perennial crops through breeding would help deal with the multiple issues involving environmental conservation and food security in a world of shrinking resources. It can provide multiple ecosystem services essential for sustainable production more effectively than production systems based on annual crops, such as protecting against soil erosion, conserving water and nutrients, storing more carbon below ground, and building better pest tolerance. This paper presents advantages of perennial crop system in ecological benefits, introduces the important role of perennial crop at the development of sustainable agriculture, and prospects the significant utilization and potential of perennial crop on sustainability of agriculture and environment.

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Keywords: *perennial crop ;soil erosion control; sustainable agriculture; environmental sustainability*

1. Introduction

The most important humanity's top ten problems for next 50 years are energy, water, food, environment, poverty, terrorism & war, disease, education, democracy and population [29]. The global

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population will continue to grow, yet it is likely to plateau at some 9 billion people by roughly the middle of this century [19]. And as the population grows, so too does demand for land and energy which, together with climate change, will further hinder agriculture's ability to produce enough food to sustain society. Therefore, many researchers agree that agriculture is the "largest threat to biodiversity and ecosystem functions of any single human activity" [7].To quote from the 2005 synthesis report of the United Nations' Millennium Ecosystem Assessment program, "Cultivation often has a negative impact on provision of [ecosystem] services. For example, cultivated systems tend to use more water, increase water pollution and soil erosion, store less carbon, emit more greenhouse gases, and support significantly less habitat and biodiversity than the ecosystems they replace" [5].

At present, more than two-thirds of global cropland is sown to monocultures of annual crops, much land most suitable for annual crops is already in use; and production of nonfood goods (e.g., biofuels) increasingly competes with food production for land [19]. The best lands have soils at low or moderate risk of degradation under annual grain production but make up only 12.6% of global land area (16.5 million km^2) [20]. Supporting more than 50% of world population is another 43.7 million km^2 of marginal lands (33.5% of global land area), at high risk of degradation under annual grain production but otherwise capable of producing crops [20]. With more land worldwide having been converted from perennial to annual cover since 1950 than in the previous 150 years [6], the area occupied by annual species continues to expand, the threat of soil degradation looms larger. This recent expansion of cropland has made it more and more necessary to apply chemical fertilizers and pesticides, which disrupt natural nutrient cycles and erode biodiversity [22, 31, 5].

Perennial crops would address many agricultural problems as well as substantial ecological and economic benefits, relative to annual crop species, they can produce more ground cover, and perform longer growing seasons and more extensive root systems, which make them more competitive against weeds and more effective at capturing nutrients and water. Thereby, perennial crops can be used in reducing soil erosion [25]; minimize nutrient leaching [12]; sequester more C in soils [15]; and provide continuous habitat for wildlife [13]. In addition, mixtures of species in intercrops or polycultures have the potential to improve the performance of a cropping system in terms of yield, nutrient cycling efficiency, and other pests control [21, 33]. In a field experiment encompassing 100 years of data collection, annual crops were 50 times more susceptible to soil erosion than were perennial pasture crops [16], and annual grain crops can lose five times as much water and 35 times as much nitrate as perennial crops [28].This paper reviews some of advantages of perennial crop in ecological benefits, introduces the important role of perennial crop at the development of sustainable agriculture system as well as prospects the significant utilization and potential of perennial crop on sustainability of agriculture and environment.

2. Advantages of perennial crop

Before the introduction of agriculture, almost all of the world's landscapes were covered primarily by perennial plants growing in mixed stands [6]; However, through 10 000 years of plant domestication, not one perennial species was domesticated for grain production. The prevalence of annuals among domesticated, grain-bearing species is often thought to warrant little discussion. For instance, Blumler and Byrne [3] wrote simply that perennial grains were not domesticated because they 'are less subject to selection pressures since stands are not replaced each year. In addition, perennials usually outcross.' But a more detailed look at the differences in susceptibility to domestication of perennial and annual species 10 millennia ago can provide additional insights into that process while at the same time informing present-day attempts to domesticate perennial herbaceous species for grain production and sustainable agriculture.

The development of perennial crops through breeding would help address the multiple issues involving environmental conservation and food security; they offer a new solution to the long-standing problems of soil erosion and degradation associated with conventional annual small-grain cropping systems. Perennial crops tend to have longer growing seasons and deeper rooting depths, and they intercept, retain, and utilize more precipitation [31]. Longer photosynthetic seasons resulting from earlier canopy development and longer green leaf duration increase seasonal light interception efficiencies, an important factor in plant productivity [14]. Greater root mass reduces erosion risks and maintains more soil carbon compared with annual crops [18]. In addition, perennial crops require fewer passes of farm equipment and less fertilizer and herbicide [17], important attributes in regions most needing agricultural advancement.

"No-till" cropping that annual crops are farmed without tillage, reduces soil loss but requires heavy chemical inputs for control of weeds and other pests. When it improves the soil permeability of previously tilled land, no-till cropping of annual species decreases nutrient runoff, but it does not address the increasingly serious problem of nutrients and water leaching from annual crop fields into groundwater and eventually into rivers and seas [27,32]. Nitrogen losses from annual crops may be 30 to 50 times higher than those from perennial crops [27]. Organic farming of annual crops addresses the problem of pesticide contamination but not the physical erosion of soil. And organic systems do not compensate for the relative inefficiency of annual species in capturing water and nutrients. For example, with no fertilizer inputs and without the benefits of centuries of domestication, the perennial grass *Miscanthus* has 61% greater annual solar radiation interception efficiency by the plant canopy and can produce 59% more above ground biomass than heavily fertilized, highly domesticated annual maize [14]. Regrowth of perennial crop stems and leaves after seed harvest may allow for additional harvests of biomass for livestock feed or biofuels [2].

In parts of Australia, one of the globe's most striking results of annual cropping has been the emergence of soil salinisation. Citing a survey of Lucerne research by Ward [34], they projected that escape of rainwater below the root zone (which can lead to rising water tables and salinisation) could be reduced 90 percent by replacing annual wheat with perennial wheat. Perennial wheat might be used in rotation in drier areas or in long-term stands in higher-rainfall zones. In addition, Bell et al. [2] concluded that "perennial wheat used for the dual purposes of grain and forage production could be developed as a profitable option for mixed crop/livestock producers." In the central plains of the U.S., the ultimate goal of perennial crop is a system that serves the ecological functions that the original prairie did. In Asia, systems involving perennial upland rice and food-producing trees could prevent erosion on lands that are highly susceptible.

In traditional sustainable agriculture, researchers are making the most of currently available perennial plants, by attempting to increase coverage of landscapes with perennial hay and pasture crops; grow perennial biofuel crops; plant more trees and grass along rivers and streams to take up nutrients and other contaminants that escape cropland; and take more erodible lands out of grain production altogether. [24].

3. Approaches to breeding perennial crops

Before perennial grain-cropping systems can be deployed and tested, new, perennial cereal, grain legume, and/or oilseed crops must be developed through breeding [8,10]. Two traditional approaches to developing these crops are direct domestication and wide hybridization, which have led to the wide variety of crops on which humans now rely. The first approach begins with identification of perennial species that have high and consistent seed production relative to other wild species and perhaps other beneficial traits, but it needs more time for cyclic selection within those species to increase the frequency of genes for traits of domestication such as synchronous flowering and maturity, large seeds, and so on. With the advantages of genetic knowledge and technology, however, today's perennial grain breeders can expect to make more rapid progress than did ancient domesticators of annual plants. The second approach to perennial grain breeding is a way of shortening the domestication process by taking advantage of useful genetic variation already fixed in high-yielding crop cultivars. In nature, perennial species are secondary or tertiary gene pools for many annual grains, Wide hybridization can bring together genes for domestication traits and the perennial life history. Currently, such interspecific and intergeneric hybrids are being used by a part of breeding programs as a base from which to develop perennial grain-producing crops. [8,10]. For instance, of the world's 13 most widely grown grain or oilseed crops, 10 are capable of being hybridized with perennial relatives (table 1), including rice, wheat, rye, sorghum and sunflowers [8].

Table 1. The world's 13 most commonly grown grain crops and examples of perennial species with which 10 of them have been hybridized[8].

Annual crop		Perennial relatives
Common name	**Species**	
Barley	*Hordeum vulgare*	*Hordeum jubatum*
Chickpea	*Cicer arietinum*	*Cicer anatolicum*
		Cicer songaricum
Common bean	*Phaseolus vulgaris*	—
Maize	*Zea mays*	*Zea mays ssp. diploperennis*
		Tripsacum dactyloides
Oat	*Avena sativa*	*Avena macrostachya*
Peanut	*Arachis hypogea*	—
Pearl millet	*Pennisetum glaucum*	*Pennisetum purpureum*
Rape	*Brassica campestris*	—
Rice	*Oryza sativa*	*Oryza rufipogon*
		Oryza longistaminata
Sorghum	*Sorghum bicolor*	*Sorghum propinquum*
		Sorghum halepense
Soybean	*Glycine max*	*Glycine tomentella*
Sunflower	*Helianthus annuus*	*Helianthus maximiliani*
		Helianthus rigidus
		Helianthus tuberosus
Wheat	*Triticum spp.*	*Thinpoyrum spp.*
		Elymus spp.
		Leymus spp.
		Agropyron spp.

Source: Data on global grain production are adapted from an FAO database [1].

DeHaan et al. [11] predicted that artificial selection in a properly managed agricultural environment could increase seed yield while maintaining perenniality. Applied to agronomic traits and perennial growth habit simultaneously, artificial selection has the potential to generate perennial grain crops with acceptable yields. Four characteristics of perennial plants differentiate them from annual plants and provide them with extra resources that, through selection, can be re-allocated to grain production:

- Better access to resources and a longer growing season [30],
- More conservative use of nutrients [10],
- Generally higher biomass production [26], and
- Sustainable production on marginal lands [4].

Although current breeding efforts focused on developing perennial grain crops have been under way for less than a decade, the idea isn't new. Efforts in the former Soviet Union and the United States to develop perennial wheat in the 1960s were abandoned in part because of plant sterility and undesirable agronomic characteristics [10].Recently ,the Land Institute in the United States, Australia's Future Farm Industries Cooperative Research Centre, the Yunnan Academy of Agricultural Sciences in China, and other research groups are conducting or initiating breeding programs in intermediate wheatgrass [*Thinopyrum intermedium* (Host) Barkworth & D. R. Dewey], perennial wheat (*Triticum* spp. / *Thinopyrum* spp.), perennial sorghum [*Sorghum bicolour* (L.) Moench / *S. halepense* (L.) Pers.], Maximilian sunflower (*Helianthus maximiliani* Schrad.), perennial sunflower (complex hybrids of *Helianthus* spp.), Illinois bundleflower (*Desmanthus illinoensis* (Michaux) MacMillan), and perennial rice (hybrids of *Oryza* spp.) [9]. Meanwhile, recent advances in plant breeding, such as the use of marker assisted selection, genomic in situ hybridization, transgenic technologies, and embryo rescue, coupled with traditional breeding techniques, make the development of perennial grain crops possible in the next 10 to 20 years.

4. Conclusion

Nowadays, researchers make an agreement that perennial crops grown for biomass, forage, or food production, can produce agronomic and environmental benefits derived from perennial cover and species diversity [23]. If efforts, to develop economically competitive perennial crops and post-harvest processing technologies capable of utilizing more perennial crops prove successful, then large areas of land currently being degraded or at high risk of degradation under annual crop production could be farmed more sustainably [17]. Given the time required to make significant changes in agricultural production, the extent to which perennial crops are featured on farms 20 yrs hence largely depends on current decisions made by agricultural scientists and policymakers. Therefore, by improving of plant breeding and fertility management, enhancing the policy and finance support, and closer cooperation between agricultural scientists, perennial cropping systems could greatly outperform annual systems in terms of sustainability of agriculture and environment, which significant agronomic and ecological benefits would be realized in the future.

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