Title

Agronomical and ecophysiological approach exploring seeding density and architecture of Kernza perennial grain (*Thinopyrum intermedium*) to optimize its multifunctional outputs

Abstract

Crop diversification is one of the pillar of agroecological transition. However, alternatives to dominant annual cereals, which represent the core of current intensive agricultural systems, and generate negative environmental impacts, are lacking. This has triggered a renewed interest in developing perennial crops that could produce grain while providing valuable ecosystem services, notably in terms of soil protection, carbon sequestration and nutrient cycling. Currently, Kernza is the most advanced perennial grain crop prototype for temperate regions, and the first commercially available to farmers (in the USA). However, many important hurdles still prevent a more widespread use of this new crop. Notably, grain yields in the field are relatively low, and tend to significantly decline over the years under current practices. In addition to breeding progresses, the development of adapted management strategies is thus urgently needed to optimize Kernza production potential over multiple seasons. In that regard, the increase in sward density as stand ages has been identified as an important component of the observed yield decline after the first cropping year, although the underlying evolution of yield components in relation to plant and tiller density remains unclear. Besides, a better characterization of the services Kernza can provide beyond production is needed to clarify potential interests and appropriate farming contexts based on multi-criteria assessments.
In that context, This PhD project aims at (i) investigating the effect of plant density, seeding architecture, and legume intercropping on tillering dynamics, grain yield components and biomass production over 3 growing seasons; (ii) evaluating the resilience of Kernza performances to spring and/or summer drought episodes and iii) evaluating the build-up of ecosystem services over the growing seasons. The obtained results will help design management practices optimizing the desired production or services outputs, which are being identified and discussed with farmers in a broad diversity of contexts through the Kernza observation network coordinated by ISARA across France.

Disciplines and key words

Anglais Agronomy, Ecophysiology, Ecology, Perennial grain, Soil protection, Yield, Ecosystem services

Français Agronomie, écophysiologie, écologie, céréales pérennes, protection du sol, rendement, services écosystémiques

Introduction

The agrifood system is confronted with the enormous challenge of evolving into a more sustainable model to drastically reduce its environmental footprint (Pimentel et al., 2012;Davies and Shen, 2020; Pengue et al., 2018), while providing a sufficient supply of food and fibres for a growing global population. Although highly productive, intensive farming practices entail several negative impacts, such as soil erosion, water pollution, loss of biodiversity and poor carbon budget. Notably, grain production (including cereals, oilseeds and legumes), which accounts for a large majority of cultivated lands globally, relies on annual crops (wheat, barley, maize, etc...), requiring frequent tillage, high input levels (fertilizer and pesticides), while providing limited soil cover over time. Important efforts are thus underway to develop alternative systems that can minimize these environmental impacts (Pimentel et al., 2012) while maintaining sufficient production levels.

Among explored avenues, the introduction of perennial grain crop, which do not require yearly sowing, has gain considerable attention in recent years. Such crop may contribute to producing grain and forage, while providing extensive ecosystem services, including soil erosion and N-runoff mitigation, reduced use of chemical inputs, or carbon storage (Crews et al., 2018; Soto-Gómez and Pérez-Rodríguez, 2022). Regarding cereals, the perennial wheat-relative *Thinopyrum intermedium* (Intermediate Wheatgrass) has emerged as a promising candidate, due to its favorable agronomical and nutritional grain characteristics (Wagoner and Schaeffer, 1990). Ongoing breeding efforts at the land Institute (Kansas, USA), aimed at grain production, have led, for US farmers, to the marketed variety Kernza™ (DeHaan and Ismail, 2017), which is thus currently the most advanced prototype for the development of perennial cereals in temperate regions. A research program, started in 2016 and coordinated by ISARA, aims to evaluate the behavior and production performances of this new crop in Western Europe, and assess the potential for its implementation in farming systems (Duchene et al., 2019). Additionally in France, an on-farm Kernza observation network has been recently set up, involving 25 volunteer farmers across the country, testing the crop in real (and diverse) production conditions (organic and conventional, grain growers and mixed livestock systems).
Intermediate Wheatgrass is a deep-rooted perennial grass that can grow substantial amount of biomass, and demonstrates good regrowth capacities over multiple growing seasons, providing year round soil

cover (de Oliveira et al., 2020; Duchene et al., 2020). Accordingly, it is expected to provide most of the above-cited environmental benefits, besides grain production, as supported by several recent studies (e.g. Culman et al., 2013; Jungers et al., 2017; Kim et al., 2021). However, despite the growing interest that such feature has attracted among practitioners, significant obstacles remain for Kernza to become a widely cultivated cereal. Most importantly, grain yield potential of most recent germplasms reach at best 10 to 20 % of what modern wheat varieties can produce. Besides, grain yield tends to strongly decline over time, so that the number of productive consecutive harvests can hardly exceed 2 to 3 under current management practices. Recent agronomical studies support the view that the build-up of excessive density, and the induced intraspecific competition, over successive growing seasons underlies yield decline (Cassman and Connor, 2022; Hunter et al., 2020; Law et al., 2020). However, the understanding of yield components in relation to plant development patterns over time for a perennial grass such as IWG remains limited. Therefore, while further breeding progress to increase grain yield potential are needed, there is an equal and urgent need to strengthen the understanding of the agronomical drivers underlying grain yield in IWG over multiple growing seasons, in order to develop adapted management practices for farmers to optimize the desired output (i.e. grain, forage, services).

This PhD project, which is part of the European Project NAPERDIV (https://naperdiv.uni-hohenheim.de/en/startpage) and the CERPET project granted by Agriculture and Food French Ministry, is co-supervised by ISARA and INRAe Clermond-Ferrand. It aims at characterizing the best-suited developmental field conditions in order for Kernza to optimize its production potential, especially in terms of grain yield, over three growing seasons. To this end, the cross effects of density and spatial sowing design (intra and inter row spacing) on tillering dynamics at both plant and population levels, and their impact on yield components will be investigated under non limiting water and N conditions (with a special emphasis on fall regrowth, which has been identified as a critical period for perenniality and grain production). The impact of legume intercropping on these processes and Kernza performances will also be addressed. Additionally, in a context where spring and/or summer drought events are becoming more frequent in the South East of France due to climate change, the resilience of the crop under drought stress will be evaluated in non-irrigated plots. Altogether, these results will be used to define adapted and economically viable agronomical strategies and yield targets for Kernza growers and the potential associated trade-offs to consider depending on whether the expected output is mainly grain, forage, or a combination of both. They will also contribute to a better characterization of the services Kernza can provide regarding the agroecological transition of grain production systems, and their adaptation to a changing climate, and how they can be part of a strong grain valorization of this new crop supporting the emergence of a value chain downstream production.

The project will benefit from a stimulating scientific environment provided by the academic partners on the subject of perennial grains in Europe (SLU Sweden, Gembloux Belgium, Louis Bolk The Netherland) and the USA (Land Institute, Kansas). It will also build on the input from other research programs already taking place at ISARA to explore technical and economic conditions for the implementation of Kernza in grain and mixed/livestock farming systems in France, and the various partnerships that have been developed with stakeholders across the whole value chain (producers, cooperatives, processing). Notably, data from the national observation network, giving access to very contrasted pedo-climatic and farming system contexts, will enable a critical cross analysis with the findings from the above described analytical trial, favoring the emergence of field-adapted management strategies.

Methods

Density and spatial sowing architecture influence on Kernza™ performances over time

Based on a comparative literature review of density studies on wheat vs forage grasses (grown for seed production), and the experience accumulated in field trials across the Kernza observation network, a range of plant densities compatible with grain production will be tested over three growing seasons, spanning contrasted levels of intraspecific competition. Each density level will be achieved with different combinations of inter and intra row spacing, as the distance to neighboring plants is known to significantly affect tillering patterns in grasses (Lecarpentier et al., 2019). Finally, intercropping with a slow growing legume species will be implemented for intermediate densities.

For all treatments, a detailed analysis of tillering dynamics will be conducted both on a plant and area basis, along with the evaluation of all grain yield components and biomass production and quality to disentangle Kernza developmental processes driving the evolution of grain yield in the field over successive growing seasons. These observations will be complemented with regular plant phenotyping measures.

Experimental plots at INRAe Crouel (Clermont-Ferrand, France)

Ecosystem services

Phenotyping of the above ground biomass will be complemented with an evaluation of root development based on soil core samplings in the different treatments over time, in order to get an overview of the soil cover, litter input, and soil volume exploration potential of the plant. Besides, the specific question of the hydric behaviour of a perennial grain system will be assessed against an annual wheat system on non-irrigated plots in a separate experiment. The implementation of soil sensors will allow the estimation of soil water availability and fluxes over the growing season, while a regular monitoring of leaf water potential and photosystem yield using dedicated leaf sensors will be performed. Concomitant below and above ground monitoring will help building a comprehensive picture of water dynamics and associated plant response, especially during dry periods, that are frequent in summer and spring in this area.

Results and perspectives

The originality of this PhD program is to combine field oriented agronomical approaches aimed at optimizing management practices of the novel perennial grain crop Kernza, with ecophysiological and developmental analysis of tillering and flowering dynamics, which can provide important knowledge that is currently largely lacking for perennial grasses, as all current cereal crops are annuals.

Expected outcomes form the project are thus twofold: (1) Combined with on-farm testing and dialogue with farmers, this analytical trial is designed to provide **key basic management principles to Kernza growers** regarding the best implementation and management strategies in terms of sowing densities and layout supporting the different potential production outputs from the crop. (2) The **detailed analysis of tillering processes** and how they relate to grain yield sustainability over time in a perennial grain will contribute to filling current knowledge gaps, and therefore offer new perspective to guide future breeding efforts towards designing **perennial grain ideotypes** adapted to the different production context and objectives.

Schedule

Year 1: Exploring relevant literature and Data mining, preparing and setting the experimental trials
Year 1 to 3: Field experiment, follow up and data collection
Year 3: Publication - Objective of 3 scientific papers (1 accepted, 2 submitted) at the end of the PhD
Year 2-3: Dissemination

Complementary program (from CERPET program)

Year 1-3: co-design and testing of Kernza management practices in the French Kernza network
Year 1: Technological tests
Year 1-3: Comparison with others references

Supervision

This Doctorate will be supervised by Drs Camille Bathellier (Dr), Christophe David (Dr, Habilitation) and Olivier Duchene (Dr) from ISARA, Agroecology and Environment Research Unit and Dr Thierry Langin (Dr, Habilitation) from CNRS, GDEC Research Unit. The doctorate will be registered at Doctorate School ABIES (Agro-Paris Tech Saclay).

An external scientific committee will be set up with scientists from the Land Institute and others partners.

Partnership

This project will be developed in close collaboration with INRAE Clermond-Ferrand and The Land Institute.
Experimental trial plots will be implemented at INRAE Clermont-Ferrand, and the *Land Institute* (Kansas, USA) will provide perennial grain germplasms for testing.

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