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Self-cover cropping systems and the *plusquam*-annual: New tools for cropping system sustainability

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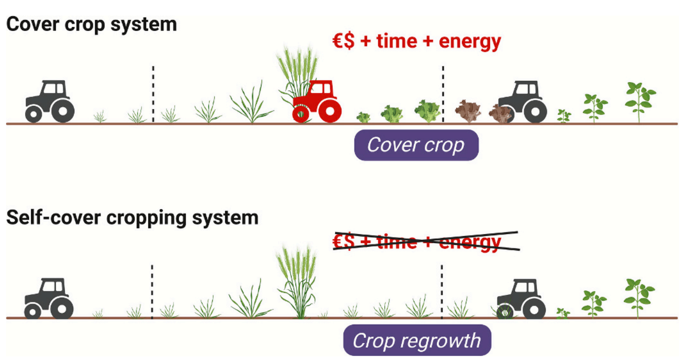
HIGHLIGHTS

- Fallow periods between annual grain crops create environmental issues.
- Cover crops help, but pose financial and managerial burdens to producers.
- We propose self-cover cropping systems via post-harvest crop regrowth.
- We define plusquam-annuals: crops with one grain harvest and regrowth.
- Plusquam-annuals may support more sustainable farming systems.

GRAPHICAL ABSTRACT



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ABSTRACT

Annual grains form the basis of human diets and thus agricultural systems, but the seasonal fallow phases inherent in their production pose environmental challenges. While cover cropping and perennial grains offer potential solutions, both currently carry significant practical hurdles to wide-scale implementation. Here we introduce self-cover cropping systems - achieved through post-harvest crop regrowth - to deliver cover crop-like ecosystem services with fewer challenges. As a corollary, we define *plusquam*-annuals (meaning "more-than annuals") as a distinct, novel crop growth habit characterized by a single grain harvest followed by regrowth with no expectation of a second grain harvest. We suggest viable *plusquam*-annual cereals may already exist and offer a conceptual framework that invites empirical exploration with both applied and theoretical significance for supporting sustainable agricultural systems.

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1. Background

As modern agricultural systems are re-examined through the lens of unprecedented population growth and changing climates, production systems are being reimagined with an explicit intention to consider productivity in tandem with other goals such as minimizing non-renewable resource use and increasing environmental services (Deguine et al., 2023; Nair et al., 2021; Olsson et al., 2024; Swinton et al., 2007). Annual grain production systems, which are scaffolded by annual cereal crops such as wheat (*Triticum aestivum*), rice (*Oryza sativa*), and maize (*Zea mays*), play a crucial role in global food security. While extremely productive, annual cropping poses significant challenges to long-term sustainability in the form of decreased soil productivity (Rubio et al., 2021; Shang et al., 2024), compromised water bodies and drinking water (Hatfield et al., 2009; Michael Beman et al., 2005), greenhouse gas emissions (Shcherbak et al., 2014), and declines in biodiversity (Rigal et al., 2023). Many of these negative outcomes stem from short (<1 year) fallow periods in annual crop rotations between harvest of one crop and sowing of the next (hereafter referred to as seasonal fallow) (Liebman and Helmers, 2024; Kladivko et al., 2014;

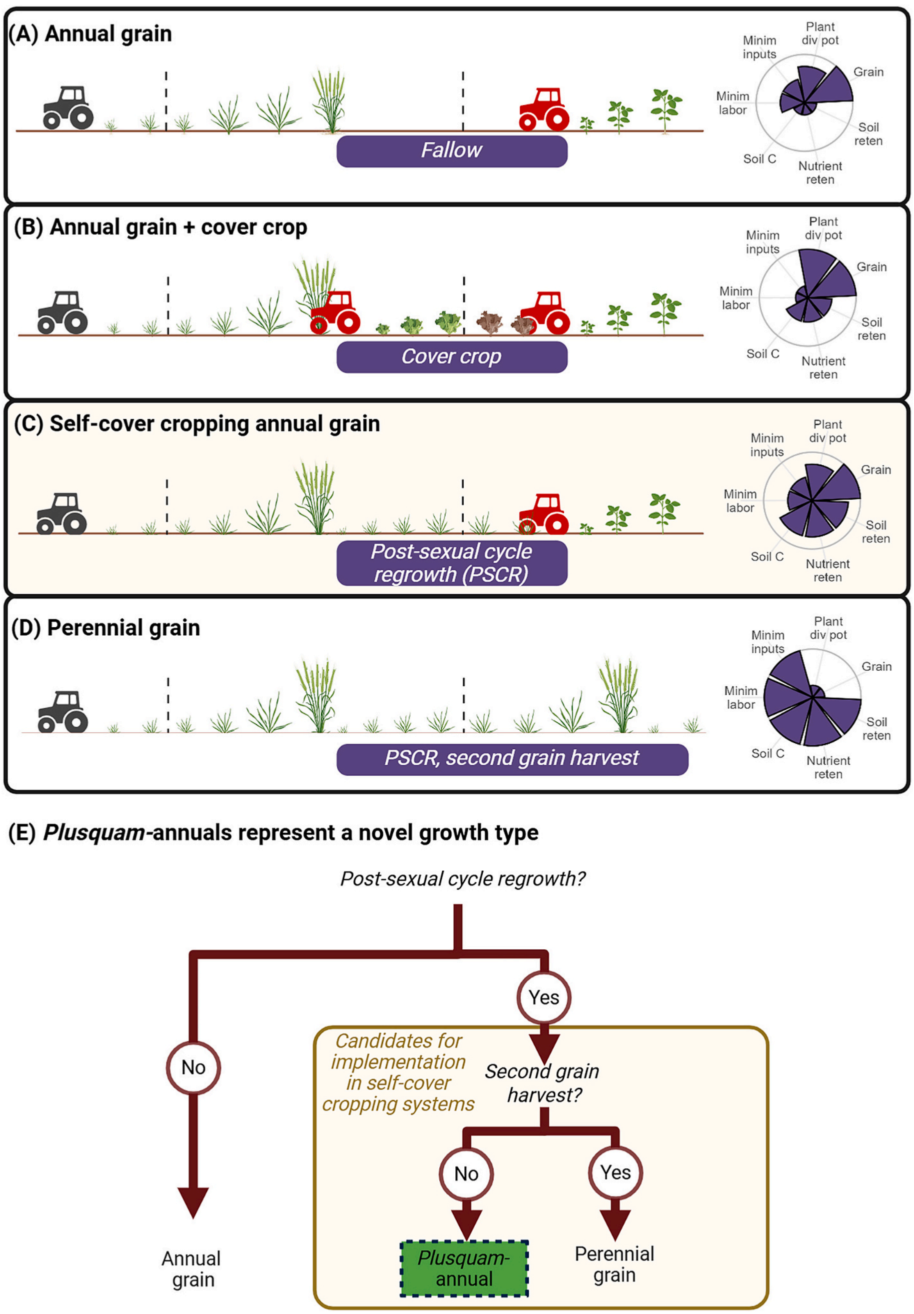

Fig. 1. A conceptual comparison of four cropping systems and their relative performance* in six categories including minimization of labor (e.g., machinery passes) and inputs (e.g., seeds, fuel), potential for incorporating plant diversity, grain production, soil retention, nutrient retention, and soil carbon maintenance and/or accrual. (A) annual grain production system with a winter fallow period between cash crops; (B) annual grain production system with a cover crop planted between cash crops; (C) novel self-cover cropping system exhibiting post-sexual cycle regrowth (PSCR) following grain harvest; (D) a perennial grain system producing multiple grain harvests from one planting; (E) a crop that is capable of PSCR but produces only one grain harvest (monocarpic) occupies a previously unnamed space in crop life histories, which we propose to call a *plusquam*-annual, meaning 'more-than-annual'.
*Performances represent the authors opinions, justifications with citations for these choices is provided in supplemental material.

Dietz et al., 2024; Basevich et al., 2025) (Fig. 1A). As such, several holistic agricultural paradigms (e.g., regenerative, organic) encourage minimizing seasonal fallow through the use of cover crops and/or perennials (Newton et al., 2020; Reilly et al., 2023; Saffeullah et al., 2021; Schreefel et al., 2025).

1.1. *The trouble with cover crops*

Cover cropping is an umbrella term that refers generally to the practice of growing a crop for its ability to provide multifunctional services, often to replace seasonal fallow periods (Lamichhane et al., 2025). Cover crops proffer numerous documented benefits, and their use is a well-established conservation practice in agriculture (Schipanski et al., 2014; Daryanto et al., 2018; Snapp et al., 2005). However, implementation of cover crops can be challenging. Establishment of cover crops entails direct costs to the producer in the form of seeds, fuel, and time, and indirect costs through potential risks to cash crop performance (Deines et al., 2023; Garba et al., 2022; Almeida et al., 2024; Nichols and MacKenzie, 2023). In the short term, producer benefits from cover crop use can be tenuous and difficult to quantify (Bergtold et al., 2019; Nichols et al., 2020). While long-term use may offer agronomic benefits which can help offset the costs of implementation, the benefits are not easily priced (Vendig et al., 2023; Wade et al., 2020; Plastina et al., 2020; Zhang et al., 2024; DeVincentis et al., 2020). Voluntary adoption of cover cropping therefore remains low (Fendrich et al., 2023; Platina et al., 2024), and usage depends heavily on policy approaches. Furthermore, even when implemented, weather and management choices (particularly during cover crop establishment (Thapa et al., 2018; Teixeira et al., 2016; Wayman et al., 2017)) render outcomes from cover cropping highly variable (Nouri et al., 2022; Chen et al., 2022).

1.2. *The need for long-term solutions*

Currently, adoption of cover crops relies heavily on policy support (Platina et al., 2024; Kathage et al., 2022; Zhou et al., 2022). In many contexts, the variable outcomes from cover cropping render the cost of supporting cover crop adoption less efficient when compared to other conservation practices (Dalgaard et al., 2014; Christianson et al., 2013; Wauters and Mathijs, 2014). Cover crop policies also may not always translate into measurable outcomes without a holistic approach (Smith et al., 2007; Fleming, 2017), or in systems with large amounts of interannual and landscape variability (Danalatos et al., 2022; Lee et al., 2016; Speir et al., 2022). In some instances policy that constrains management options such as sowing date (Bowman and Lynch, 2019) to ensure more reliable outcomes can result in unintended sustainability tradeoffs due to reduced flexibility in farmer decision-making (Stone et al., 2024; Iversen et al., 2024). Due to the limits to policy interventions, technical long-term solutions are clearly needed to make cover crops more effective and feasible to grow. Genetic improvement of cover crop varieties can undoubtedly contribute (Wilke and Snapp, 2008), however cover crop sowing often conflicts with cash crop activities, an issue that cannot be addressed through breeding alone (Clay et al., 2020; Roesch-McNally et al., 2018). There have been notable and creative attempts provide long-term solutions to the challenges of traditional cover crop systems, including drone-planted cover crops (Stockel et al., 2025) weedy fallow (Wortman, 2016), self-seeding cover crops (Singer et al., 2007), perennial groundcovers (Schlautman et al., 2021) and perennial grain crops (DeHaan et al., 2023). While these all offer potential, each poses substantial limitations that necessitate significantly more research.

2. Self-cover cropping systems through post-harvest regrowth

In this Perspective we propose a novel alternative to conventional cover cropping, herein termed *self-cover cropping systems* (Fig. 1C). In this approach, the cash crop exhibits regrowth following grain harvest, or *post-sexual cycle regrowth* (PSCR), defined in the perennial wheat literature as the retention of viable axillary meristems beyond grain ripening, enabling a subsequent phase of tiller outgrowth (Lammer et al., 2004; Murphy et al., 2010). In annual cropping systems, PSCR could potentially provide environmental benefits comparable to those of cover crops while eliminating the need for cover crop establishment, and therefore also eliminate the attendant uncertainties, variability, costs and risks (Platina et al., 2024; Clay et al., 2020; Yousefi et al., 2024).

2.1. *Introducing the plusquam-annual*

While self-cover cropping systems require PSCR (Fig. 1C), unlike perennial grains they are agnostic with respect to the ability of the crop to produce subsequent grain and/or biomass harvests. Previously, the distinction between PSCR and perenniality has not always been clear, with the former being used as a proxy for the latter (Chapman et al., 2022). Conceptually, removing the requirement of multiple grain harvests following PSCR represents a crop growth habit that, to our knowledge, has not been previously articulated. From an evolutionary standpoint, the reproductive fitness of a monocarpic plant exhibiting PSCR is questionable, and therefore may only be possible through anthropogenic intervention (Li et al., 2022). This ‘more than’ annual growth occupies a unique position within the spectrum of plant life histories that is not well-defined (Friedman, 2020). To facilitate consistency in future research we propose the term *plusquam*-annuals - meaning ‘more-than annuals’ – for crops falling into this previously unnamed growth category (Fig. 1E).

The literature suggests *plusquam*-annuals have already arisen from wide-hybrid crosses with perennials, a practice common in the pursuit of perennial grain development and for introgression of agronomic traits of interest (e.g., biotic and abiotic stress tolerance) into elite crop cultivars (Wendler et al., 2015; Prohens et al., 2017). Several studies indicate *plusquam*-annual germplasm already exists, and could be immediately tested for application in self-cover cropping systems (see summary in supplemental material).

2.2. *The role of perennial grains*

Perennial grains (Fig. 1D) could be used in self-cover cropping systems by terminating the perennial grain prematurely to maintain an annual sequencing of crops. Perennial grains have been utilized as multipurpose grain and forage crops (Ryan et al., 2018; Pinto et al., 2024; Hunter et al., 2020), yet to our knowledge they have not been deployed and studied in a self-cover cropping context. While perennial grain crops are generally expected to produce grain for a minimum of three growing seasons (Hayes et al., 2018), current commercially available perennial grains, such as the domesticated intermediate wheatgrass (*Thinopyrum intermedium)* marketed under the trade name Kernza® (Bajgain et al., 2020) and a perennial cereal rye hybrid (*Secale cereale x S. strictum*) (Acharya et al., 2004), often exhibit significant declines in grain yields (>50%) following the first year of production (Daly et al., 2022; Zhen et al., 2024) [but see (Fagnant et al., 2024; Jaikumar et al., 2012)]. While deployment of perennial grains in a self-cover cropping system will not deliver the full benefits expected from a multi-year implementation (Fig. 1D), it offers a practical use case that could garner research support and act as a stepping stone towards wider landscape integration.

2.3. *Breeding and genetics of plusquam-annuals*

Conversion of annual crops into true perennials or *de novo* domestication of perennials both likely require changes in a large number of genes (Chapman et al., 2022). In contrast, although PSCR can result from various physiological traits (e.g., rhizome development, tillering, stay green traits (Fan et al., 2020; Swentowsky et al., 2021; Ma et al., 2019; Westerbergh and Doebley, 2004)), many of them may be simply inherited, and therefore pose lower barriers for transference into elite annual crop cultivars (Zhao and Wang, 2024; Gruner and Miedaner, 2021; Abbasi et al., 2020). Moving forward, relieving the expectation of multiple grain yields may allow perennial grain breeders to produce high-yielding, *plusquam*-annual cereals using traditional phenotypic selection in a medium time frame (Morgounov et al., 2025). Other breeding approaches such as new genomic technologies also offer opportunities; one study found that regular applications of cytokinin throughout the growing season caused significant and meaningful PSCR in spring barley (*Hordeum vulgare*) (Christiansen et al., 1995), demonstrating the presence of biochemical pathways that could be targeted using high throughput mutagenesis screening techniques (Knudsen et al., 2022) or new genomic breeding technologies such as site directed nucleases (e.g., CRISPR-Cas9) or cisgenesis (Holme et al., 2013; Karavolias et al., 2021). Additionally, the conceptual separation of *plusquam*-annual growth habits from perennial growth habits opens the door for interesting genetic studies on perenniality such as presence/absence variant analysis, QTL mapping of segregating populations from interspecific crosses, and differential gene expression analyses (Fan et al., 2020; Fuerst et al., 2023), which would lay the foundation for efficient implementation in breeding pipelines.

2.4. Tradeoffs

Self-cover cropping systems are not a panacea and entail trade-offs when compared to other system interventions. A simple example using common optimization criteria for agricultural systems (Cinelli et al., 2014; Adeux et al., 2022; Emran et al., 2022; Zhang et al., 2007) can be used to highlight these anticipated tradeoffs (Fig. 1). We anticipate that the strength of self-cover cropping systems lies in balancing productivity, environmental outcomes, and farmer workloads (Fig. 1C). By eliminating the establishment procedures required for cover crops, self-cover cropping systems could contribute to soil carbon accrual through less soil disturbance and a continuous production of root exudates (Poeplau et al., 2021). The established root system could also contribute to improved water quality through better nutrient retention compared to cover crops (Ferchaud and Mary, 2016). Moreover, self-cover cropping systems could positively alleviate the financial, managerial, and labor input demands placed on farmers during and following cash crop harvest. On the other hand, by extending the duration of the cash crop beyond its harvest, self-cover cropping systems could reduce opportunities for short-term infusions of plant biodiversity offered by cover crops. In particular, since *Poaceae* crops presently offer the most likely self-cover cropping candidates (see supplemental material), it is likely that self-cover cropping systems will initially offer less nitrogen fixation opportunities compared to cover cropping systems. However, we foresee ample opportunities to develop hybrid cover crop systems, wherein multiple cover crop species can be layered with PSCR, potentially providing synergistic services and/or allowing for more flexibility in cover crop planting dates.

2.5. Necessity of context

There is wide diversity in cover crop system implementation and goals globally, and self-cover cropping systems will need to reflect this diversity. Agronomic studies that compare self-cover cropping systems to appropriate controls using relevant evaluation metrics will therefore be essential for developing these frameworks while accounting for social, economic, and policy contexts. For example, in Denmark, fall nitrate leaching from arable land is of primary concern, and regulations require cover crop use between winter and spring crops (Dalgaard et al., 2014). In this context lower grain yields from a self-cover cropping cereal may be offset by the monetary savings from not having to establish a cover crop, and winter survival is less important compared to vigorous fall regrowth. Conversely, in the Midwestern and Eastern United States, significant nitrate leaching occurs in the spring and cover crop use is optional – this context would require a self-cover cropping system to produce grain yields equivalent to its annual counterpart and to exhibit significant spring regrowth (Kladivko et al., 2014). In some systems, soil borne pathogens that could use the 'Green Bridge' provided by self-cover cropping systems will need explicit consideration, as will water use in semi-arid environments (Garba et al., 2022; Mahoney et al., 2016). Therefore, involving diverse stakeholders early in the research and breeding processes to collaboratively develop appropriate ideotypes will likely result in more relevant and impactful outcomes (Runck et al., 2014; Nichols et al., 2025).

3. Conclusions

Self-cover cropping represents a novel production system that could provide environmental benefits mirroring those offered by the practice of cover cropping. Additionally, self-cover cropping systems would reduce the producer-level challenges of cover crop implementation and potentially offer more consistent societal benefits. *Plusquam*-annuals were identified as a novel crop growth habit that can be leveraged to develop self-cover cropping systems, while also providing a unique platform for studying important biological processes in crops. The current knowledge base could support the establishment of self-cover cropping systems using several *Poaceae* crops in the short to medium term, while also offering a framework for introducing additional crops in the future. In conclusion, we posit that self-cover cropping systems could offer a unique and effective convergence of productivity and environmental benefits, and merit research investment.

CRediT authorship contribution statement

Virginia Nichols: Writing – review & editing, Writing – original draft, Conceptualization. **Prabin Bajgain:** Writing – review & editing. **Laura Dixon:** Writing – review & editing. **Kim Henrik Hebelstrup:** Writing – review & editing. **Claus Krogh Madsen:** Writing – review & editing. **Robin Morgan:** Writing – review & editing. **Valentin Picasso:** Writing – review & editing.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.agsy.2026.104657.

Data availability

No data was used for the research described in the article.

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