Adaptive multi-paddock grazing of cover crops in integrated crop-livestock systems in Mediterranean regions: a review

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Abstract. Small-grain farming systems in Mediterranean climatic regions are characterized by poor quality soils, high climate variability, and resulting heavy agrochemical reliance. The integration of continuously grazed monocrop pasture phases has improved soil fertility, crop productivity, and mitigated financial risk. However, emerging sustainability issues such as herbicide resistance, inputs costs rising disproportionately to product prices, and increasing climate variability and predictability, drive the need for ongoing innovation in crop-livestock integration. The option of growing multi-species cover crops as a dual-forage and service crop is evaluated within Mediterranean climate contexts. Furthermore, the option of subjecting the cover crops to adaptive multi-paddock (AMP) grazing management as an alternative to the standard set stocking approach is discussed.

Introduction

Crop production in dryland Mediterranean climatic regions is compromised by characteristically low soil organic matter content and poor soil structure, fertility and resilience to environmental stresses. The consequent reliance on intensive fertilizer use, coupled with increasingly variable precipitation regimes, and the threat of herbicide-resistance jeopardizes the sustainability of these small-grain cropping systems (Aguilera *et al.* 2013). In conjunction with conservation agriculture management principles, the integration of livestock in cropping systems, through inclusion of pastures, has helped to combat these challenges through including greater diversification and hence, resilience; and improving income stability, and profitability (MacLaren *et al.* 2019a). Nevertheless, recent advances in grazing management and planted pasture research call for a revisiting of livestock integration tactics in Mediterranean region small-grain systems. As an alternative to monoculture pastures, multi-species cover crops are increasingly promoted in temperate areas of the USA and Europe as not only improved forage sources, but also for a range of soil quality and agroecosystem benefits (Wortman *et al.* 2012). Moreover, as an alternative to standard set stocking, highly intensive grazing approaches such as AMP grazing have received growing interest for their potential to increase productivity and stability in planted pasture and rangeland systems across the globe (Wang *et al.* 2018). The aim of this review is to highlight the benefits and limitations of continuous grazing of monoculture pasture phases in Mediterranean climate crop-livestock systems, which is the standard practice. This will then be contrasted to AMP grazing of multi-species cover crops in terms of the plausible benefits, synergies and tradeoffs for ecosystem service delivery, crop production, and profitability.

Cover crops versus monoculture pastures

In farming regions where double cropping is practiced, cover crops are often planted in the fallow season for a range of services that are advantageous to the production system. However, in Mediterranean regions with a poor rainfall distribution, their cultivation generally implies forfeiting a cash crop or pasture in the single winter growing season, incurring financial losses. Thus, their utilization as fodder is necessary to justify their inclusion in these rotations financially (Smit *et al.* 2021; Sanderson *et al.* 2013).

The integration of monoculture pasture phases into Mediterranean-climate crop rotations and the associated income diversification through supporting a livestock enterprise, has helped in dampening fluctuations in income as a result of both grain price and climate variability (Bell *et al.* 2013). This practice has also further optimized the beneficial characteristics of conservation agriculture, particularly via the capacity of pastures to improve weed control and break pest and disease cycles, sequester soil carbon, increase biodiversity, and improve nutrient cycling (Planisich *et al.* 2021). However, the increased diversity that cover crops offer may provide superior soil quality and crop productivity benefits to monoculture pastures.

Perhaps the most significant advantage of multi-species cover crops compared to monoculture pastures, is that they do not only offer temporal diversity (through a crop rotation sequence), but also offer spatial diversity. Thus, through utilizing a combination of cover crop species that excel at different services, this may sustain a greater number of agroecological functions simultaneously. Importantly, however, it is the selection for *functional* diversity of the cover crop that is of more importance for ecosystem functioning than diversity (species richness) per se (Finney and Kaye 2017). For instance, given the poor organic matter content of soils in Mediterranean-type environments, cover crops are often selected for functionally diverse traits that mediate nitrogen-related services such as sequestering, scavenging, and supplying of nitrogen to the main crop. This could be achieved through combining legumes and cereal species for their respective nitrogen fixing and retention functions, while also providing significant carbon input and conservation benefits (Blanco-Canqui and Jasa 2019). Nevertheless, selecting for cover crop multi-functionality may also cause trade-offs for service provision. For example, selecting for a highly weed-suppressive mix depends on individual species competitiveness rather than functional diversity. By implication, such a mix will typically have a relative abundance of competitive non-legumes, resulting in lower inorganic nitrogen availability and potentially reduced cash crop yields (MacLaren *et al.* 2019b).

Furthermore, this diversity in space may increase resilience of the ecosystem services cover crops provide, as different plant types contribute to particular services in different ways and under different conditions. This enables a higher overall capacity for a cover crop to consistently perform a given function, whether it is providing more consistent, high quality forage material and reducing the risk of feed gaps (Bell *et al.* 2018), or improving resistance against various biotic or abiotic stresses (Isbell *et al.* 2017). Nevertheless, a drawback of this spatial diversity is an increased susceptibility to harbouring insect pests and diseases and forming a ‘green bridge’ between cover crop and cash crop phases, exacerbating pest populations in crops.

Adaptive multi-paddock grazing vs continuous grazing

In the South African Mediterranean climate region, Smit *et al.* (2021) found that continuous grazing of cover crops did not affect subsequent wheat grain yield, however it did improve soil quality, and in particular nitrogen content when compared to a no grazing control. Additionally, MacLaren *et al.* (2019a) found that continuous grazing of cover crops may improve weed management in these crop rotations. These benefits, among others, such as improved pest and disease control, and reduced fertilizer inputs, observed in crop-pasture systems under continuous grazing management have proven to not only provide ecological benefits but also improve economic performance (Strauss 2021). However, the alternative use of AMP grazing management is under scrutiny for potentially superior ecosystem service delivery, crop productivity, and profitability benefits.

Although numerous publications have dealt with the integration of crops and livestock, there is almost no information comparing continuous grazing to AMP grazing in integrated-crop livestock systems, let alone in Mediterranean climatic contexts. Thus, despite substantial anecdotal evidence from producers in support of AMP grazing on multi-species covers versus continuous grazing, there is still a lack of consensus in the scientific literature on the purported advantages. Nevertheless, based on studies from different farming systems and agroclimatic regions, benefits may still be inferred for crop-livestock systems with a Mediterranean climate.

Adaptive multi-paddock grazing is an observant approach, such that animal numbers, grazing intensity and recovery periods are adaptively adjusted to match available forage and ensure sufficient post-grazing plant residual for optimal regrowth. Several studies suggest AMP livestock management not only sustains greater forage production and quality than continuous grazing, but also synergistically enhances cover crop service delivery (Kleppel 2020). This sustaining of the functional value of cover crops may be largely attributed to the adaptive nature of AMP grazing. Other advantages of AMP grazing are linked to the short and intense nature of this high stock-density approach, which ensures even and non-selective utilization of plant material (Teague and Kreuter 2020). This may exert a greater selection pressure on weeds than continuous grazing and also prevent less palatable plant types from dominating as a result of selective grazing. The high utilization of vegetation also implies greater root turnover, thereby stimulating more carbon sequestration and improving soil structure (Kleppel 2020). Furthermore, the high stocking density leads to the formation of a uniform layer of manure and plant litter that is trampled into the soil, enriching it with organic matter and enhancing nutrient cycling and soil fertility (Peel and Stalmans 2018).

There are also potential drawbacks of AMP grazing. Particularly when stocking densities are beyond the optimum and/or grazing duration is too long, this approach may increase the risk of overgrazing and soil compaction (Wang *et al.* 2018). Another limitation of AMP grazing is that its intensive and complex nature implies higher levels of organizational skills, knowledge and commitment are required for it to be effectively executed (Sanderson *et al.* 2013). For instance, the selection of plant species to form a complementary mixture (spatially and temporally) in a specific context and the grazing management thereof, is particularly complex. This is because optimal grazing times for maintaining forage quality and productivity varies for grasses and forage herbs due to their different growth patterns, and therefore trade-offs are inevitable with a mixture (Sanderson *et al.* 2013).

Research agenda

Research is still needed to identify and better quantify the specific services that different cover crop traits provide, as well as determine the species abundances required to achieve them. Knowledge gaps also exist around the interdependence and trade-offs among these services. Addressing these gaps will help farmers to strategically design multifunctional cover crops based on their specific objectives/constraints. Similarly, for producers to consider adopting AMP grazing of their cover crops, it needs to be validated in context-specific grazing studies which investigate its relative contribution to ecosystem service delivery, compared with conventional set-stocking approaches.

A potential limitation of AMP grazing is that it may not ensure sufficient biomass is consistently maintained for cover crops to maintain their functional value to deliver specific ecosystem services to the cropping system (Sanderson *et al.* 2013). Although Kelly *et al.* (2021), suggests judicious cover crop utilization with low intensity rotational grazing may be the best strategy to maintain cover crops' dual-purpose of forage and service provision, this has not been substantiated and remains an area for future research.

Conclusions

The option of integrating cover crops subjected to AMP grazing in crop rotations shows promise as a tool for leveraging natural ecological processes to support soil quality, crop productivity and whole-farm economics. There are also, however, potential drawbacks associated with the intensive and complex nature of this approach. Nevertheless, to accurately evaluate the potential of this practice in Mediterranean crop-livestock systems, more context-specific research is needed.

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