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Mitigating agricultural intensification in the Western Cape with landscape elements: a synopsis of applicable ecological weed management strategies

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Abstract: **Background:** The agricultural landscape has deteriorated rapidly because of human population growth and the concomitant increased demand for food. Although necessary to feed the global population, production intensification accounts for reduced resilience of cropping systems due to the increased inputs required for greater yields.
Objective: The purpose of this synopsis is to highlight applicable ecological weed management strategies in order to promote weed suppression in intensively managed agricultural production systems of the Western Cape.
Methods: In order to achieve sustainable weed management it is imperative that ecological landscape elements become part of agronomic production processes. These practices and strategies include the adoption of cover crops, living and biomass mulches, hedgerows, increased field margins as well as weed seedbank diversity as non-chemical measures and landscape elements.
Results: Cover crops, living mulches and biomass mulches exert positive impacts on weed suppression, microclimate, soil quality and crop yield.
Conclusions: The outcome of ecological weed management strategies is a reduction and mitigation of the negative effects of intensive cropping regarding soil, water and the agricultural landscape.

Keywords: Biomass mulches; Field margins; Hedgerows; Seedbank; Weed diversity

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1. Introduction

Over the last one hundred years, the pace of landscape deterioration has increased because of increased human population growth and the concomitant increased demand for food (Petellier-Guittier et al., 2020). In the Western Cape Province, where more than 50% of South Africa's agricultural exports originate, this is no different. Struik and Kuyper (2017) contend that food will have to be produced from the current surface area of agricultural land while also ensuring justice in distribution and the equity of resource distribution for food production. To maintain the viability of agricultural systems, greater focus on cost reduction through production intensification is required (Van Eekeren et al., 2022).

Although production intensification is required to provide for increasing human needs (Food and Agricultural Organization of the United Nations, 2017) the downside to this approach is the idea of an accompanying homogenisation of agricultural production areas. Compounding matters in agricultural fields is the increased input of more agricultural chemicals to counter weeds resistant to herbicides (Happe et al., 2018).

In field edges another disadvantage of the simplification of the agricultural landscape and the greater application of agro-chemicals is the ascendency of a small number of competitive, highly competitive and widely dispersed weed species (Storkey, Neve, 2018). Landscape homogenization increases the depletion of ecosystem services in agricultural production systems (Cusser et al., 2016). In addition, this accounts for a decrease in weed variety and the diminished sustainability of cropping systems, including more weed resistance to herbicides (Storkey, Neve, 2018).

Altieri (1995) and Cusser et al. (2016) argued that elements of habitat conservation that include native plants, ease the negative effects of agricultural production intensification. In addition, softening the negative impacts of intensive production on biodiversity demands the application of efficient conservation measures. The planning of counter measures for these negative consequences requires knowledge of the association between production intensification, biodiversity and insect predators that is required for enhancing ecosystem resources in agricultural production areas (Crowder, Jabbour, 2014). Subsequently, Rivera-Pedroza et al. (2019) confirmed that the protection of small strips of native vegetation favours biological diversity.

MacLaren et al. (2020) reported that for reaching the goal of sustainable weed management it is imperative that ecological elements are part of agricultural production processes. It is suggested that an alternative, ecological approach is followed where the aim is not total weed removal, but a comprehension of which characteristics of agroecosystems confer flexibility to noxious weed invasions yet foster a diverse weed population to sustain ecosystem services. Practical management actions that will contribute to sustaining crop production as well as biodiversity and ecosystem function, include an increase in diversity in all its forms, 'little hammers' within and between years and sites, the limitation of resource availability to weeds and taking advantage of the positive effects of weeds (MacLaren et al., 2020).

An example of this strategy is agri-environment schemes (European Commission, 2013) that are being implemented in Europe for this purpose. The introduction of these schemes entail useful steps, like retaining or creating landscape elements that enhance beneficial organisms in agricultural land (Froidevaux et al., 2019; Pita et al., 2020). The variety of species traits and genes found in these populations of living organisms, ensure its survival during future alterations, by providing a safe haven that may become essential to ensure ecosystem services during fluctuating environmental circumstances (Moonen, Bàrberi, 2008).

In agro-ecosystems, biodiversity promotes many ecological contributions to humankind including producing food, increased availability of soil nutrients and the control of pests and diseases (Blaix et al., 2018; Piccini et al., 2019). This approach enhances a diverse set of ecosystem services while diminishing any disadvantage that might occur (Landis et al., 2018). Complimentary methods of restoring some elements of biodiversity is the incorporation of cover crops with living and biomass mulch cropping systems into existing agricultural landscapes. Living and biomass mulch systems enhance agricultural sustainability by lowering the application of agro-chemicals and simultaneously boosting soil health (Bhaskar et al., 2021) as well as weed seed predation that suppresses weed populations (Schumacher, Gerhards, 2022).

Recently, Wietzke et al. (2020) reported that the implementation of a well thought out mixture of native plant strips, field margins and hedgerows provide benefits for all beneficial living organisms. However, such ecological gains come with crop yield penalties and increased inputs that require compensation for farmers who adopt such practices.

Nevertheless, Happe et al. (2018) provided evidence that even minor restoration with hedgerows is advantageous to valuable life forms in closely located fields within intensively managed agricultural landscapes. In addition, natural habitats often include unmanaged field margins since they incur low establishment and maintenance costs, due to their location in unproductive marginal lands and along secondary roads, farm tracks and fences (González et al., 2017).

The negative consequences of agricultural intensification, such as increasing weed resistance and the accompanying weed invasions that are more difficult to manage, necessitates a review of ecological weed management strategies. Petit et al. (2015) emphasised the quest to develop production practices that lessen herbicide use in order to reach the goal of sustainable agriculture. According to MacLaren et al. (2020) alleviating ecological interconnection and functions in order to manage weeds, requires the conservation of both agricultural and pristine natural land, while also diminishing the external inputs required to reduce weed-crop competition. In addition, ecological theory can assist to pinpoint practices that are viewed as valuable at the agroecosystem level and to be viable over the long term.

To mitigate the detrimental side effects, Struik and Kuyper (2017) coined the term "sustainable intensification" since it implies the application of fewer agro-chemicals and other inputs as well as a lower environmental impact. Although conservation agriculture (CA) is one element of sustainable intensification, Gonzales-Sanchez et al. (2015) reported that CA is only possible through the use of pre-emergent, broad spectrum, non-selective herbicides. Clearly, both terms overlap with elements of integrated weed management (IWM) and this forms the foundation of the current summary. The literature above indicates a substantial amount of work in many countries around the globe, but in the Western Cape Province of South Africa, an orchestrated effort covering strategies in ecological weed management is lacking.

In the prevailing Mediterranean climate of the Western Cape Province, these strategies could include living and biomass mulches, cover crops, hedgerows, field margins, seedbank variety and weed diversity as non-chemical measures and landscape elements. Apart from the aforementioned terms used in literature searches for the current paper, additional keywords included "wildflower strips" and "agricultural landscapes". The most recent literature in scientific journals as well as all available and relevant publications, totaling 67 from around the globe, were uitilised.

Although most publications on these topics originate from various climatic zones in North America, Europe and China, many of the principles can be adapted for application locally. Therefore, the purpose of this synopsis is to highlight applicable ecological weed management strategies in order to promote weed suppression in intensively managed agricultural production systems of the Western Cape.

2. Factors complicating weed management

Globally, herbicides are the most widely used agricultural chemical and form an integral part of

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agricultural intensification (Van Eekeren et al., 2022). Urbanisation, enhanced productivity of larger farms and landscape simplification and degradation through agricultural intensification caused larger field sizes, eradication of environmental elements and repetition of monotonous crop rotations (Beckmann et al., 2019). However, in the long-term production intensification clash with the advancement of belowground (microorganisms) and aboveground (decomposers) biological diversity in ecosystems (Van Eekeren et al., 2022).

Schrama et al. (2018) warned that with ongoing land use intensification, these detrimental processes of losses in soil organic content and belowground diversity in micro-organisms are expected to continue and may weaken the resilience of soils against catastrophes, resulting in it being prone to degrading as well as weed, pest and pathogen infestations. Results by Schrama et al. (2018) indicated that lower standards of soil organic carbon might diminish soil fertility, spatial balance in soil properties and ecosystem services. Consequently, it may cause a contraction in agricultural production. In contrast, Gonzales-Sanchez et al. (2015) showed that conservation agriculture, in which the reduction in tillage and maintenance of ground cover is paramount; contribute greatly to reducing losses of soil through erosion.

2.1 Agricultural Intensification

Humans depend on agriculture for food production and a variety of ecosystem resources, but as landscapes are cultivated intensively, its ability to maintain these utilities comes under pressure (Dainese et al., 2019). The emphasis on intensification and optimising productivity may compromise the supply of various ecosystem services, causing an expanded reliance on non-renewable resources like agro-chemicals (Chavarría et al., 2018; Van Eekeren et al., 2022). This is worrying, since biological diversity sustains the foundation of all life on earth (Rivera-Pedroza et al., 2019). One way to balance this is to consider changing the crop rotation to mitigate some of the increase in selection pressure for herbicide resistance that monoculture and monotonous coverage of the landscape with one crop bring. The only solution without consequences for global food production, is to change marginally productive land over to biodiversity and increase production on the best land in areas of high production. Another aspect is to increase agricultural production in areas with low productivity without significantly sacrificing biodiversity.

Higher biodiversity may lead to thorough utilisation of resources and thus optimum performance of the ecosystem (Harrison et al., 2014) and enhance the sustainability of agriculture (Phiffner et al., 2019). Nevertheless, the greatest drawback of intensification in terms of weeds is the evolution of herbicide resistant weeds.

2.2 Weed resistance

Under production intensification, weeds are subjected to the persistent exposure of similar ecological and agronomic circumstances. The extensive use of herbicides in weed control programmes without diversity and usually without tillage in monoculture, has caused the rise of herbicide-resistant weeds and aided the unintended evolution of weed resistance (Weisberger et al., 2019) and this exacerbates weed infestations since chemically, it becomes uncontrollable.

The first proven incident of herbicide resistance in a weed in South Africa was by Cairns and Laubscher (1986) who showed wild oats (*Avena fatua*) resistance to diclofop-methyl in the Western Cape Province (Figure 1). Subsequently, numerous confirmed cases of weed resistance in this agricultural production area were reported (Pieterse, 2010) and due to the nature of the evolution of weed resistance, it continues unabated. The advantageous Mediterranean environmental conditions of this region prompted the sectors of horticulture, viticulture, pastures and rotational grain cropping production systems to be located in close proximity to one another. The year round application of different herbicide groups in the various adjacent production systems of these intensively cropped areas, as well as the compounding factors of spray drift in the prevailing windy conditions, poor calibration of application equipment and poor water quality in spraying mixtures, probably exacerbates selection pressure and the evolution of cross resistant weeds.

Widespread cross resistance of weeds to multiple herbicide groups in the Western Cape Province pose significant economic threats to especially agronomical production. A change in herbicides may be a solution, but if the farmer continues with the same behavior with a new herbicide and lack of diversity, it is only a temporary solution and the appearance of resistance to the new herbicide becomes a pre-ordained conclusion. This demands the pre-emptive design and application of an ecological

Figure 1 - Location of the Western Cape Province at the southern tip of the African continent
Source: bbc.com

approach that will enhance sustainable production (Burns et al., 2018). Bunchek et al. (2020) suggested the application IWM principles that include complementary herbicidal and non-chemical weed management decisions based on an ecological foundation. This is essential for sustainable weed management as well as the perpetuation of herbicides with presently proven efficacy. Diversity in tactics and strategy are based on both IWM and sustainable agro-ecosystems. Furthermore, practices that decrease seed production coupled with those that increase greater weed mortality are deemed as alternatives to herbicide applications, since they reduce the risk of selection pressure (Burns et al., 2018).

3. Suggested practices for implementation in the Western Cape

3.1 Cover crops, living and biomass mulches

One of the major objective of the cultivation of living mulches and cover crops is to suppress weeds (Table 1). In comparison to terminated cover crops, living mulches shows improved weed suppression, decreased soil erosion and nutrient leaching, improved soil health, increased resource-use proficiency (Bhaskar et al., 2021) and slower development of herbicide resistant weeds (Basinger, Hill, 2021). It also increases soil microbial activity, enables biological nitrogen fixation, conserves soil nutrients (Gerhards, 2018) and facilitates weed seed predation (Schumacher, Gerhards, 2022). An increase in seed predator activity and weed seed predation rate (Petit et al., 2018) showed a strong correlation to plant mulches (Meiss et al., 2010).

Living mulches and cover crops promote agroecosystem biological diversity and often this correlates with the presence of a lower incidence of diseases, pests and weeds (Petit et al., 2018) in grain cropping systems (Basinger, Hill, 2021), orchards and vineyards. Weed biocontrol can be based upon interference that sown plants can deliver to weeds by competition for resources, such as light, water, and nutrients as well as by allelopathy. Sown plants would include cover crops as well as the main crop leading to decreased seed germination and decreased weed biomass attributed directly to cover crops (Petit et al., 2018). In addition, living and biomass mulches promote soil health, soil stabilisation, water infiltration and soil water content. They also increase organic matter and nitrogen content by legumes and enhances a variety of soil microorganisms (Basinger, Hill, 2021). Furthermore, they also suppress weed emergence and development and thereby provide an added advantage for weed control and inhibiting the evolution of herbicide resistance (Bunchek et al., 2020).

Either terminated by mechanical crimper rolling, flail mowing or by means of herbicide application, living mulches forms a biomass mulch. Biomass mulches suppress weeds by obstructing seed germination and inhibiting seedling growth (Farooq et al., 2011). These mulches may change the germination flushes of weeds by adjusting the conditions of the seed germination layer and modifying the light waves that penetrate to weed seeds (Moore et al., 1994).

Perennial row crops lends themselves to intra-row application of biomass mulches in the form of wood chips or straw bales with modified manure spreaders. In

Table 1 - Summary of the benefits of suggested practices, for implementation in the Western Cape, that improve ecological weed management

	Suggested practices			
	Cover crops, living and biomass mulches	**Hedgerows**	**Field margins**	**Seedbank diversity**
Factors showing an improvement	Weed suppression; soil microbial activity, health, organic carbon, enzyme activity, water infiltration, water content; biological nitrogen fixing; weed seed predation	Biodiversity and ecological equilibrium; abundance and richness of pest predators; safe haven of heterogeneous soil microorganisms, carbon, water infiltration; movement corridor of mobile organisms	Ecosystem services; safe haven for taxa, foraging opportunities, pollen & nectar; pest control; arthropod biodiversity	Biodiversity & regulating benefits; soil enrichment; soil nutrient leaching, physical properties; crop pollination; sustainability of agro-ecosystem
Factors showing a decrease	Soil erosion & nutrient leaching; evolution of herbicide resistance	Soil erosion	Soil erosion, spray drift	Weed-crop competition; invasive weeds; soil mechanical compaction, nitrate leaching
References	Basinger, Hill (2021); Bhaskar et al. (2021); Bunchek et al. (2020); Gerhards (2018); Schumacher and Gerhards (2022); Qu and Feng (2022)	Holden et al. (2019); Petellier-Guittier et al. (2020); Stašiov et al. (2020); Zhang et al. (2021)	Blary et al. (2021); González et al. (2017); Hackett and Lawrence (2014), Landis et al. (2018); Penn (2018)	Blaix et al. (2018); Colbach et al. (2021); Juarez-Escario et al. (2017); Liebman et al. (2021); Moreau et al. (2020); Poudel et al. (2018); Storkey & Neve (2018)

the Western Cape Province, this is a common practice in citrus orchards to promote weed suppression, conservation of soil water, improving water infiltration, regulating soil temperature and nutrient levels (Farooq et al., 2011). In addition, biomass mulches improves crop stand establishment, early plant development, greater growth rates and shorter growing periods until harvest of perennial crops (Dong et al., 2009). Furthermore, the application of biomass mulches is a proven practice of enhancing the plant growth environment to facilitate greater crop yields. Mulching practices exert positive impacts on weed suppression, micro-climate, soil quality and crop yield (Li et al., 2018). Qu and Feng (2022) showed that it also increases soil organic carbon with an associated improvement of soil enzyme activity. Organic matter attaches soil particles together to form aggregates. Once broken down by soil microbes, plant residues produces sticky substances that form larger aggregates as granules or peds. These peds facilitate improved soil permeability and aeration that enables crop emergence and stimulates root growth (Qu, Feng, 2022).

3.2 Hedgerows

Findings by both Happe et al. (2018) and Morandin et al. (2016) indicated that the cultivation of hedgerows in field edges is beneficial to organisms taking refuge in intensively managed agricultural areas. Indeed, hedgerows that enclose crops, vineyards and orchards are advantageous to all living organisms in intensively cultivated landscapes (Graham et al., 2018) since it provides significant above-ground biodiversity benefits (Holden et al., 2019) (Table 1).

Petellier-Guittier et al. (2020) provided further proof of the benefits of hedgerows as well as its use as movement corridors in intensively used agricultural landscapes. Blary et al. (2021) reported that concatenated hedgerows are essential as forage and for unhindered movement corridors of mobile organisms.

A critical advantage of hedgerows in intensively used production systems is that it can provide essential resources for the survival of living organisms. Hedgerows provide suitable living space for species and may significantly limit soil erosion, promote biological diversity and ecological equilibrium in landscapes (Stašiov et al., 2020). Generally, these habitats correlates to an increase in abundance and richness of pest predators (Zhang et al., 2021).

Furthermore, it has an important role in modifying soils in agricultural production systems and ecosystem benefits (Holden et al., 2019) since it serves as a safe haven of specific and heterogeneous soil microorganisms. Additionally, Holden et al. (2019) reported deteriorating soil quality due to production intensification that correlates to losses of soil carbon and hampers soil water infiltration and holding capacity which in unison cause declining crop yields. Hedgerow soils provide essential ecological services in agricultural landscapes, *inter alia* increased soil carbon, improving water infiltration, greater incidence of earthworm variety and acting as a refuge for specific arbuscular mycorrhizal communities (Holden et al., 2019). Holden et al. (2019) hypothesised that those larger areas containing hedgerows and field margins globally could be an essential strategy for capturing carbon and increasing soil quality.

3.3 Field margins

Field margins forms a transitional zone between the arable crop and boundary arrangement, including adjacent crops, hedgerows, farm roads and fences (Hackett, Lawrence, 2014) (Table 1). Landis et al. (2018) reported that the establishment of perennial semi-natural habitats along field edges and margins show the greatest possibility to promote several ecosystem services. Similarly, some approaches aim to reduce agronomic disturbances and to protect natural vegetation and habitat in agricultural landscapes (Geldenhuys et al., 2021).

Field margins enclosing crops serve as a safe haven for large numbers of taxa and provide refuge from adjacent field disturbances. Due to its hosting of sufficient biodiversity, field margins contain adequate foraging opportunities for higher fauna and flora in the food chain (Blary et al., 2021). Apart from affording refuge from intensive production practices, field margins also provide alternative non-pest prey items as well as both pollen and nectar (Penn, 2018).

Field margins also functions as a habitat and a corridor for some organisms such as insect predators that provide natural pest control (Blary et al., 2021). Field margins influences insect movements into cropped fields after disturbances such as agro-chemical application. By employing margins as refuge for insect communities, pest control in agricultural fields can be influenced by changing its species' mixtures (González et al., 2017). Consequently, as part of wider ecosystem services, field margins provide pollination and pest control as supplementary agronomic advantages for the crops it encloses (Blary et al., 2021). In addition, it enhances the heterogeneity and spill-over of beneficial organisms into crop fields (González et al., 2017). They concluded that forest amount at the landscape scale in Argentina, is more influential for arthropod biodiversity and biological control in soybean than forest proximity. Furthermore, results by (González et al., 2017) suggest that maintaining remnants of forest in agricultural landscapes can be effective for conservation of arthropod biodiversity while contributing to biological control of stinkbugs in soybean fields. Similarly, in the Western Cape, the native vegetation of the Cape Floral Kingdom might play a similar role regarding insects.

Hackett and Lawrence (2014) reported that by establishing grasses, field margins act as a physical barrier to weed invasions by occupying growing space and also through strong plant competition and interference (Marshall, 2004) by way of growing space, water, nutrients and allelopathy. Results by Hackett and Lawrence (2014) showed that the successful growing of competitive grasses with a great plant height, significantly prevented the growth of noxious weed species. Field margins can also serve to limit and diminish the side effects of intensive cropping by restraining the presence of pesticides and fertilisers via water leaching, spray drift and inhibiting soil erosion (Hackett, Lawrence, 2014).

Since the Cape Floral Kingdom forms part of the Western Cape, a wide variety of native trees, shrubs, and grasses are well adapted to its Mediterranean climate and soil types. However, due to the great variety in climatic zones and soil types of this region, the choice of plants for uitilisation in field margins will have to be site-specific. Grass species occurring in the Western Cape for this purpose include *Hyparrhenia hirta* (L.) Stapf., *Eragrostis capensis* (Thunb.) Trin. and *Themeda triandra* Forskk. In terms of shrubs, the genera Protea, Leucospermum and Leucadendron contain relevant species for inclusion while tree species falling in this category are *Searsia pyroides* (Burch.) Moffet. and *Olea europaea* L. subsp. *cuspidata* (Wall. & G.Don) Cif.

Management of field margins promotes both crops and beneficial organisms. Its proper configuration enhances the presence of predators by contributing considerable numbers of ecological niches (Penn, 2018). In this regard, mowing is favoured in most situations to adjust or sustain the configuration and formation of field margins (Hackett, Lawrence, 2014). Kirmer et al. (2018) showed that a proper, site-specific regular mowing regime maintains plant diversity in field margins. Furthermore, field margins in intensively cropped landscapes mown in spring to early summer sustain long-term biodiversity (Kirmer et al., 2018). By contrast, in some instances in the Western Cape, farm tracks and fences are viewed as sources of weed seeds that might invade crop fields. This prompts annual applications of non-selective herbicides in road reserves and along fences that otherwise could have served as field margins. Already, unconfirmed reports suggest the possibility of the evolution of herbicide-resistant weeds occurring along these farm tracks and fences. This poses serious threats to herbicide efficacy and weed management in grain cropping systems.

According to Hackett and Lawrence (2014), the location of field margin establishment, with a width of 2 m - 15 m, is important since this optimises its advantages. This can improve habitat links as well as its multiplicity in an agricultural landscape. Overall, longer term and less disturbed field margins seem to contribute dependable environmental benefits (Hackett, Lawrence, 2014).

3.4 Seedbank diversity

Weed diversity is becoming increasingly relevant in view of the occurrence of the ryegrass hybrid (*Lolium multiflorum* x *L. perenne*) (Ferreira et al., 2015) populations in mono-stands of more than 6,000 plants m^{-2} in some localities of the Western Cape Province. Storkey and Neve (2018) suggested that the goals of stable arable biological heterogeneity by reducing the risk from an invasion of severely competitive, weeds resistant to herbicides in cropping systems, are based on both ecological and production strategies with focal points of weed species richness and evenness. Furthermore, depending on the mixture of species, more diversity in weed populations translate into lower crop competition and less risk of dominance by invading herbicide-resistant species (Table 1). Yvoz et al. (2021) expressed the opinion that due to changing perceptions, weeds are essential organisms that maintain vitally important natural resources in agroecosystems. Furthermore, due to its great species variety, field margins will support the stability of weed functional diversity in arable landscapes. Storkey and Neve (2018) hypothesized that weed variety point to the sustainability of the entire agricultural production system.

By contrast, homogenous weed control systems with a strong dependence on herbicides enforce selection pressure for weedy attributes (Neve et al., 2018). According to Colbach et al. (2021), weeds are a very destructive production constraint in arable crops, but it is indispensable for biological diversity. However, the application of diversified selection pressures in agricultural fields will prevent the ascendancy by some noxious weed species (Neve et al., 2018). Logically, this will requires diverse weed management strategies that encourage and sustain high levels of diverse weed populations (Neve et al., 2018).

Positive aspects of weed communities are the promotion of soil enrichment, prevention of mechanical compaction (Juarez-Escario et al., 2017) and to act as natural adversaries of harmful entomological and pathological infestations (Cicuzza et al., 2012). Winter et al. (2018) elaborated on the positive role of weeds by emphasising the delivery of multitudinous ecosystem services, but with confined competitive effects on crops. These reports prompted Storkey and Neve (2018) to suggest that increasing infield weed heterogeneity could be advantageous, both for agronomical purposes as well as environmentally. Furthermore, a more diverse weed community is an indicator of agronomic and environmental sustainability. The ecosystem functions afforded by weeds include supporting the reduced occurrence of pests, reduction in nitrate leaching, contributing to soil nutrient cycling, improving soil physical properties, enhancing crop pollination and providing regulating benefits (Blaix et al., 2018; Moreau et al., 2020).

Diversifying tactics by numerous crops and its planting dates, crop rotation, cropping mixtures and production practices noticeably increases area-wide weed diversity. This also promotes species richness and encourages variety and interspecies competition in populations of weed communities (Fried et al., 2012). Melander et al. (2020) surmised that generally, weed constraints are disrupted by implementing complex cropping mixtures and systems. By increasing agro-ecosystem arrangements by vegetation, implies that weed management used simultaneously with other strategies of vegetation utilisation, cover cropping as well as the establishment of semi-natural habitats, including hedgerows and field margins, optimises the allocation of the required resources (Blaix et al., 2018). The incidence of a low but uniform distribution of weeds in an agricultural field might ensure the equal provision of ecosystem services. This would augment the resources afforded by the prevailing vegetation in adjacent hedgerows and field margins (Blaix et al., 2018).

Lastly, Storkey and Neve (2018) suggest that an assortment of seeds in the weed seedbank is pointing to the overarching sustainability of the cropping system. Liebman et al. (2021) tested this hypothesis and concluded that weed seedbank variety may undoubtedly be a worthwhile agro-ecosystem sustainability yardstick. However, weed seedbank density will affect crop yields and should be taken into consideration. Nevertheless, promoting the ecological soil seedbank might increase the presence and density of native plants and thereby reduce the negative effects of weeds (Poudel et al., 2018). In an agricultural landscape, growing non-invasive beneficial plants in hedgerows and field margins may achieve this. In conclusion, plants growing in the field margins will improve seedbank composition once it sheds seeds and its offspring will act as a buffer against weeds by filling competitive growth niches. In this regard, Poudel et al. (2018) reported that perennial native grasses have shown potential to competitively suppress noxious invasive weeds, indicating a high possibility of single species replacement control by competitive grasses in field margins that might have the potential to suppress an invasion of a noxious and herbicide-resistant weed.

4. Conclusions

4.1 Future research needs

Initially, a thorough assessment of the feasibility of creating field margins and hedgerows applicable to the Western Cape and incorporated into current farming practices without significant financial impact, would be valuable. Once this is concluded and some practices show positive results, then studying the beneficial ecological effects, could be considered. Although these measures might seem a burden in terms of the production area needed and perceived lower yields, the emphasis on sustainability coupled with the results of beneficial ecological principles should convince farmers that the implementation thereof on an area-wide scale, is imperative.

In that regard, Agri-environment schemes (European Commission, 2013) applied in Europe may be an effective strategy to promote habitat quality for beneficial organisms and counter the loss of biological diversity in intensively managed agricultural landscapes. Since these schemes endeavour to incorporate conservation into cultivated fields and semi-natural habitats bordering crop fields (Happe et al., 2018), it might serve as a blue print for local application in the Western Cape Province.

In future, studies focused on the non-chemical curbing of weed communities as opposed to total control in agricultural production systems will be needed. Realistically, this might lead to weed populations that do not compete detrimentally with the crop and simultaneously contributing favourable ecological services (Petit et al., 2015). These propositions can be coordinated to cover studies on production strategies that include mowing regimes, brush cutting or flail mowing of living mulches and hedgerows. In field margins, studies on the timing of mowing and brush cutting as well as whether biomass is removed or not, will add valuable data to the knowledge base.

Studies on the ecology and management of agro-biodiversity enclosing agricultural land can support the provisioning of modulating ecosystem services (Blaix et al., 2018). In this regard, soil micro-arthropods can be important indicator species for regeneration since it functions in nutrient recycling and the decomposition of organic matter, which eventually increases soil carbon and health (Van Eekeren et al., 2022). It can also be utilised to study contrasting counter measures of intensification.

Furthermore, the clarification and pinpointing of weed species with beneficial and practical characteristics for ecosystem service arrangements is required. It would be preferable to select attributes from species that have minimal interference potential with crops, low seed production capacity and longevity. The objective of these measures would be to avoid weed invasions in production systems (Blaix et al., 2018). Although this is a very tall order in the context of weeds occurring in the Western Cape, Wietzke et al. (2020) concluded that soil type and nutrient status, field and production system history and seedbank structure are factors determining the efficiency of agri-environment actions. To this end, Bhaskar et al. (2021) propagated the development of system-specific recommendations in horticulture, viticulture and grain crop systems.

Given the urgency to diversify control programmes to combat herbicide-resistant weeds and the land degradation issues associated with simplified landscapes, the ecological weed management concepts of cover crops, living and biomass mulches, hedgerows, field margins as well as seedbank and weed diversity, merits more research in future.

Author's contributions

The author read and agreed to the published version of the manuscript. MIF: conceptualization of the manuscript and development of the methodology. MIF: data collection

and curation. MIF: data analysis. MIF: data interpretation. MIF: funding acquisition and resources. MIF: project administration. MIF: writing the original draft of the manuscript. MIF: writing, review and editing.

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References

Altieri MA. Agroecology: the science of sustainable agriculture. Boulder: Westview; 1995.

Basinger NT, Hill NS. Establishing white clover (*Trifolium repens*) as a living mulch: weed control and herbicide tolerance. Weed Technol. 2021;35(5):845-55. Available from: https://doi.org/10.1017/wet.2021.45

Bhaskar V, Westbrook AS, Bellinder RR, DiTomasso A. Integrated management of living mulches for weed control: a review. Weed Technol. 2021;35(5):856-68. Available from: https://doi.org/10.1017/wet.2021.52

Beckmann M, Gerstner K, Akin-Fajiye M, Ceaușu S, Kambach S, Kinlock NL et al. Conventional land-use intensification reduces species richness and increases production: a global meta-analysis. Global Change Biol. 2019;25(6):1941-56. Available from: https://doi.org/10.1111/gcb.14606

Blaix C, Mononen AC, Dostatny DF, Izquierdo J, Le Corff J, Morrison J et al. Quantification of regulating ecosystem services provided by weeds in annual cropping systems using a systematic map approach. Weed Res. 2018;58(3):151-64. Available from: https://doi.org/10.1111/wre.12303

Blary C, Kerbiriou C, Le Viol I, Barré K. Assessing the importance of field margins for bat species and communities in intensive agricultural landscapes. Agric Ecosyst Envir. 2021;319. Available from: https://doi.org/10.1016/j.agee.2021.107494

Bunchek JM, Wallace JM, Curran WS, Mortensen DA, Van Gessel MJ, Scott BA. Alternative performance targets or integrating cover crops as a proactive herbicide resistance management tool. Weed Sci. 2020;68(5):534-44. Available from: https://doi.org/10.1017/wsc.2020.49

Burns EE, Lehnhoff EA, McKenzie SC, Maxwell BD, Dyer WE, Menalled FD. You cannot fire with fire: a demographic model suggests alternative approaches to manage multiple herbicide-resistant *Avena fatua*. Weed Res. 2018;58(5):357-68. Available from: https://doi.org/10.1111/wre.12315

Cairns ALP, Laubscher EW. Differential tolerance of Western Cape wild oat to diclofop-methyl and mixtures containing diclofop-methyl. Stellenbosch: Stellenbosch University; 1986.

Chavarría JYD, Baudron F, Sunderland T. Retaining forests within agricultural landscapes as a pathway to sustainable intensification: evidence from southern Ethiopia. Agric Ecosyst Envir. 2018;263:41-52. Available from: https://doi.org/10.1016/j.agee.2018.04.020

Cicuzza D, Clough Y, Tjitrosoedirdjo SS, Kessler M. Responses of terrestrial herb assemblages to weeding and fertilization in cacao agroforests in Indonesia. Agrofor Syst. 2012;85:75-83. Available from: https://doi.org/10.1007/s10457-011-9456-6

Colbach N, Colas F, Cordeau S, Maillot T, Queyrel W, Villerd J et al. The Florsys crop-weed canopy model, a tool to investigate and promote agroecological weed management. Field Crops Res. 2021;261. Available from: https://doi.org/10.1016/j.fcr.2020.108006

Crowder DW, Jabbour R. Relationships between biodiversity and biological control in agroecosystems: current status and future challenges. Biol Cont. 2014;75:8-17. Available from: https://doi.org/10.1016/j.biocontrol.2013.10.010

Cusser S, Neff JL, Jha S. Natural land cover drives pollinator abundance and richness: leading to reductions in pollen limitation in cotton agroecosystems. Agric Ecosyst Envir. 2016;226:33-42. Available from: https://doi.org/10.1016/j.agee.2016.04.020

Dainese M, Martin EA, Aizen MA, Albrecht M, Bartomeus I, Bommarco R et al. A global synthesis reveals biodiversity-mediated benefits for crop production. Sci Adv. 2019;5(10):1-13. Available from: https://doi.org/10.1126/sciadv.aax0121.

Dong H, Li W, Tang W, Zhang D. Early plastic mulching increases stand establishment and lint yield of cotton saline fields. Field Crops Res. 2009;111(3):269-275. Available from: https://doi.org/10.1016/j.fcr.2009.01.001

European Commission – EC. Overview of CAP Reform 2014-2020 highlights improved framework for addressing 21st century challenges. Brussels: European Commission; 2013[access October 9, 2020]. Available from: https://ec.europa.eu/agriculture/sites/agriculture/files/policy-perspectives/policy-briefs/05_en.pdf

Food and Agricultural Organization of the United Nations - FAO. The state of food and agriculture: leveraging food systems for inclusive rural transformation. Rome: Food and Agricultural Organization of the United Nations; 2017.

Farooq M, Jabran K, Cheema ZA, Wahid A, Siddique KHM. The role of allelopathy in agricultural pest management. Pest Sci Manag. 2011;67(5):493-506. Available from: https://doi.org/10.1002/ps.2091

Ferreira MI, Reinhardt CF, Lamprecht SC, Sinclair M, MacKenzie L, Van Coller G. Morphological identification of the ryegrass hybrid *Lolium multiflorum* × *Lolium perenne* and isolation of the pathogen *Fusarium pseudograminearum* in the Western Cape. South Afr J Plant Soil. 2015;32(1):9-15. Available from: https://doi.org/10.1080/02571862.2014.994140

Fried G, Kazakou E, Gaba S. Trajectories of weed communities explained by traits associated with species' response to management practices. Agric Ecosyst Environ. 2012;158:147-155. Available from: https://doi.org/10.1016/j.agee.2012.06.005

Froidevaux JSP, Boughey KL, Hawkins CL, Broyles M, Jones G. Managing hedgerows for nocturnal wildlife: do bats and their insect prey benefit from agri-environment schemes? J App Ecol. 2019;56(7):1610-23. Available from: https://doi.org/10.1111/1365-2664.13412

Geldenhuys M, Gaigher R, Pryke JS, Samways MJ. Diverse herbaceous cover crops promote vineyard arthropod diversity across different management regimes. Agric Ecosyst Environ. 2021;307. Available from: https://doi.org/10.1016/j.agee.2020.107222

Gerhards R. Weed suppression ability and yield impact of living mulch in cereal crops. Agriculture. 2018;8(3):1-7. Available from: https://doi.org/10.3390/agriculture8030039

González E, Salvo A, Valladares G. Arthropod communities and biological control in soybean fields: forest cover at landscape scale is more influential than forest proximity. Agric Ecosyst Environ. 2017;239:359-67. Available from: https://doi.org/10.1016/j.agee.2017.02.002

Gonzales-Sanchez EJ, Veroz-Gonzalez O, Blanco-Roldan GL, Marquez-Garcia F, Carbonell-Bojollo R. A renewed view of conservation agriculture and its evolution over the last decade in Spain. Soil Till Res. 2015;146(part.B):204-12. Available from: https://doi.org/10.1016/j.still.2014.10.016

Graham L, Gaulton R, Gerard F, Staley JT. The influence of hedgerow structural condition on wildlife habitat provision in farmed landscapes. Biol Cons. 2018;220:122-31. Available from: https://doi.org/10.1016/j.biocon.2018.02.017

Hackett M, Lawrence A. Multifunctional role of field margins in arable farming. Cambridge: Cambridge Environmental Assessments; 2014.

Happe AK, Riesch F, Rösch V, Gallé R, Tscharntke T, Batárya P. Small-scale agricultural landscapes and organic management support wild bee communities of cereal field boundaries. Agric Ecosyst Envir. 2018;254:92-8. Available from: https://doi.org/10.1016/j.agee.2017.11.019

Harrison PA, Berry PM, Simpson G, Haslett JR, Blicharska M, Bucur M et al. Linkages between biodiversity attributes and ecosystem services: a systematic review. Ecosyst Serv. 2014;9:191-203. Available from: http://doi.org/10.1016/j.ecoser.2014.05.006

Holden J, Grayson RP, Berdeni D, Bird S, Chapman PJ, Edmondson JL et al. The role of hedgerows in soil functioning within agricultural landscapes. Agric Ecosyst Envir. 2019;273:1-12. Available from: https://doi.org/10.1016/j.agee.2018.11.027

Juarez-Escario A, Conesa JA, Solé-Senan XO. Management as a driver of functional patterns and alien species prominence in weed communities of irrigated orchards in Mediterranean areas. Agric Ecosyst Envir. 2017;249:247-55. Available from: https://doi.org/10.1016/j.agee.2017.07.042

Kirmer A, Rydgren K, Tischew S. Smart management is key for successful diversification of field margins in highly productive farmland. Agric Ecosyst Envir. 2018;251:88-98. Available from: https://doi.org/10.1016/j.agee.2017.09.028

Landis DA, Gratton C, Jackson RD, Gross KL, Duncan DS, Liang C et al. Biomass and biofuel crop effects on biodiversity and ecosystem services in the North Central US. Biomass Bioen. 2018;114:18-29. Available from: https://doi.org/10.1016/J.BIOMBIOE.2017.02.003

Li Q, Hongbing L, Li Z, Suiqi Z, Yinglong C. Mulching improves yield and water-use efficiency of potato cropping in China: a meta-analysis. Field Crops Res. 2018;221:50-60. Available from: https://doi.org/10.1016/j.fcr.2018.02.017

Liebman M, Nguyen HTX, Woods MM, Hunt ND, Hill JD. Weed seedbank diversity and sustainability indicators for simple and more diverse cropping systems. Weed Res. 2021;61(3):164-77. Available from: https://doi.org/10.1111/wre.12466

MacLaren C, Storkey J, Menegat A, Metcalfe H, Dehnen-Schmutz K. An ecological future for weed science to sustain crop production and the environment. A review. Agron Sust Dev. 2020;40. Available from: https://doi.org/10.1007/s13593-020-00631-6

Marshall EJP. Agricultural landscapes: field margin habitats and their interactions with crop production. In: Clements D, Shrestra A, editors. New dimensions in agroecology. New York: Food Products; 2004. p. 365-404

Meiss H, Lagadec L, Munier-Jolain N, Waldhardt R, Petit S. Weed seed predation increases with vegetation cover in perennial forage crops. Agric Ecosyst Environ. 2010;38(1-2):10-6. Available from: https://doi.org/10.1016/j.agee.2010.03.009

Melander B, Rasmussen IA, Olesen JE. Legacy effects of leguminous green manure crops on the weed seed bank in organic crop rotations. Agric Ecosyst Envir. 2020;302. Available from: https://doi.org/10.1016/j.agee.2020.107078

Moonen AC, Bàrberi P. Functional biodiversity: an agroecosystem approach. Agric Ecosyst Envir. 2008;127. Available from: https://doi.org/10.1016/j.agee.2008.02.013

Moore MJ, Gillespie TJ, Swanton CJ. Effect of cover crop mulches on weed emergence, weed biomass and soybean (*Glycine max*) development. Weed Technol. 1994;8(3):512-8. https://doi.org/10.1017/S0890037X00039609

Morandin LA, Long RF, Kremen C. Pest control and pollination cost-benefit analysis of hedgerow restoration in a simplified agricultural landscape. J Econ Entom. 2016;109(3):1020-7. Available from: https://doi.org/10.1093/jee/tow086

Moreau D, Pointurier O, Nicolardot B, Villerd J, Colbach N. In which cropping systems can residual weeds reduce nitrate leaching and soil erosion? Euro J Agron. 2020;119. Available from: https://doi.org/10.1016/j.eja.2020.126015

Neve P, Barney JN, Buckley Y, Cousens RD, Graham S, Lawton-Rauh A et al. Reviewing research priorities in weed ecology, eveolution and management: a horizon scan. Weed Res. 2018;58(4):250-8. Available from: https://doi.org/10.1111/wre.12304

Petellier-Guittier C, Théau J, Dupras J. Use of hedgerows by mammals in an intensive agricultural landscape. Agric Ecosyst Environ. 2020;302. Available from: https://doi.org/10.1016/j.agee.2020.107079

Penn HJ. Wooded field margins increase potential for cultural and biological control of soybean pests. Agric Ecosyst Envir. 2018;302:45-51. Available from: https://doi.org/10.1016/j.agee.2017.12.016

Petit S, Cordeau S, Chauvel B, Bohan D, Guillemin JP, Steinberg C. Biodiversity-based options for arable weed management: a review. Agron Sust Dev. 2018;38:1-28. Available from: https://doi.org/10.1007/s13593-018-0525–3

Petit S, Munier-Jolain N, Bretagnolle V, Bockstaller C, Gaba S, Cordeau S et al. Ecological intensification through pesticide reduction: weed control, weed biodiversity and sustainability in arable farming. Environ Manag. 2015;56(5):1078-90. Available from: https://doi.org/10.1007/s00267-015-0554–5

Phiffner L, Cahenzlia F, Steinemann B, Jamar L, Bjørn MC, Porcel M et al. Design, implementation and management of perennial flower strips to promote functional agrobiodiversity in organic apple orchards: a pan-European study. Agric Ecosyst Envir. 2019;278:61-71. Available from: https://doi.org/10.1016/j.agee.2019.03.005

Piccini I, Palestrini C, Rolando A, Roslin T. Local management actions override farming systems in determining dung beetle species richness, abundance and biomass and associated ecosystem services. Basic Appl Eco. 2019;41:13-21. Available from: https://doi.org/10.1016/j.baae.2019.09.001

Pieterse PJ. 2010. Herbicide resistance in weeds: a threat to effective chemical weed control in South Africa. S Afr J Plant Soil. 2010;27(1):66-73. Available from: https://doi.org/10.1080/02571862.2010.10639971.

Pita R, Morgado R, Moreira F, Mira A, Beja P. Roads, forestry plantations and hedgerows affect badger occupancy in intensive Mediterranean farmland. Agric Ecosyst Envir. 2020;289. Available from: https://doi.org/10.1016/j.agee.2019.106721

Poudel AS, Jha PK, Shrestha BB, Muniappan R. Biology and management of the invasive weed *Ageratina adenophora* (Asteraceae): current state of knowledge and future research needs. Weed Res. 2018;59(2):79-92. Available from: https://doi.org/10.1111/wre.12351

Qu Y, Feng BL. Straw mulching improved yield of field buckwheat (*Fagopyrum*) by increasing water-temperature use and soil carbon in rain-fed farmland. Acta Ecol Sin. 2020;42(1):11-6. Available from: https://doi.org/10.1016/j.chnaes.2020.11.008

Rivera-Pedroza LF, Escobar F, Philpott SM, Armbrecht I. The role of natural vegetation strips in sugarcane monocultures: ant and bird functional diversity responses. Agric Ecosyst Environ. 2019;284. Available from: https://doi.org/10.1016/j.agee.2019.106603

Schrama M, De Haan JJ, Kroonen M, Verstegen H, Van der Putten WH. Crop yield gap and stability in organic and conventional farming systems. Agric Ecosyst Environ. 2018;256:123-30. Available from: https://doi.org/10.1016/j.agee.2017.12.023

Schumacher M, Gerhards R. Facilitation of weed seed predation by living mulch and cover crops. Weed Res. 2022;58(4):239-43. Available from: https://doi.org/10.1111/wre.12310

Stašiov S, Diviaková A, Svitok M, Novikmec M, Dovciak M. Hedgerows support rich communities of harvestmen (Opiliones) in upland agricultural landscape. Basic App Ecol. 2020;47:73-82. https://doi.org/10.1016/j.baae.2020.05.001

Storkey J, Neve P. What good is weed diversity? Weed Res. 2018;58(4):239-43. Available from: https://doi.org/10.1111/wre.12310

Struik PC, Kuyper TW. Sustainable intensification in agriculture: the richer shade of green: a review. Agron Sust Dev. 2017;37. Available from: https://doi.org/10.1007/s13593-017-0445-7

Van Eekeren N, Jongejans E, Van Agtmaal M, Guo Y, Van der Velden M, Versteeg C et al. Microarthropod communities and their ecosystem services restore when permanent grassland with mowing or low-intensity grazing is installed. Agric Ecosyst Environ. 2022;323. Available from: https://doi.org/10.1016/j.agee.2021.107682

Weisberger D, Nichols V, Liebman M. Does diversifying crop rotations suppress weeds? A meta-analysis. PLoS ONE. 2019;14:1-12. Available from: https://doi.org/10.1371/journal.pone.0219847

Wietzke A, Albert K, Bergmeier E, Sutcliffe LME, Van Waveren CS, Leuschner C. Flower strips, conservation field margins and fallow promote the arable flora in intensively farmed landscapes: results of a 4-year study. Agric Ecosyst Envir. 2020;304. Available from: https://doi.org/10.1016/j.agee.2020.107142

Winter S, Bauer T, Strauss P, Kratschmer S, Paredes D, Popescu D. Effects of vegetation management intensity on biodiversity and ecosystem services in vineyards: a meta-analysis. J App Ecol. 2018;55(5):2484-95. Available from: https://doi.org/10.1111/1365-2664. 13124

Yvoz S, Petit S, Cadet E, Dessaint F, Cordeau S. Taxonomic and functional characteristics of field edge weed communities along a gradient of crop management intensity. Basic App Ecol. 2021;57:14-27. Available from: https://doi.org/10.1016/j.baae.2021.10.001 14-27

Zhang J, You S, Niu D, Guaman KGG, Wang A, Saqib HAS et al. Landscape composition mediates suppression of major pests by natural enemies in conventional cruciferous vegetables. Agric Ecosyst Envir. 2021;316. Available from: https://doi.org/10.1016/j.agee.2021.107455