

Enhanced Species Diversity Unlocked by Habitat Conservation in Agricultural Landscapes: New Perspectives on Ecological Weed Management and Sustainable Intensification

—Species Diversity and Habitat Conservation

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Abstract

The impulse to remain profitable by increasing agricultural production levels in view of the greater demand for food, provided impetus to production intensification. The aim of this review is to summarise current literature, reporting specifically on the impact of production intensification on habitats and yield constraints caused by weeds. Secondly, in alleviating these effects over the short term, ecological measures that enhance species diversity in conserved habitats and promote semi-natural habitats in the agricultural landscape, are discussed. In large-scale intensive agriculture, weed control is predominantly rooted in agrochemical applications in the form of herbicides. Long lasting intensive agricultural practices show discord both with the promotion of the biodiversity of microbes belowground and aboveground and with organisms involved in the breaking down of plant material. The presence of native species in the surroundings, in combination with hedgerows and field margins, with a comparatively intricate and balanced variety of plants in a sheltered environment, are essential for settlement of benign insects, particularly in the face of intensive agricultural production. The promising tactic of advantageous seed predators enables decreased herbicide applications. Crop mosaics arranged to advance compatibility at the landscape scale are important to bolster pollination services and insect management, while ecological variety in the surroundings acts as a safety net for habitat diversity. Weed control in combination with different tactics of vegetation use, comprising cover cropping, hedgerows and field margins, sets up safe havens

in the landscape, and improves the diffusion of complementary life forms. Field margins perform a meaningful natural function as point of provision for forage, safe havens and distribution passageways for pollinators and insect predators. Production practices that promote more heterogeneity and combine high density semi-natural safe havens and habitat conservation in agro ecosystems are beneficial to species diversity across trophic levels and contribute to agricultural production stability and food safety.

Keywords

Crop mosaics, Field Margins, Hedgerows, Microbial Nitrogen Immobilization, Semi-Natural Habitats, Soil Microbes, Weed Cross-Resistance, Weed Seed Predation

1. Introduction

The impulse to remain profitable by increasing agricultural production levels in view of the greater demand for food, not only preceded, but also provided impetus to production intensification. Simultaneously, the feasibility of agricultural production processes required a mandatory shift to lower input costs [1]. Intensely cultivated agricultural production is an operation of numerous components, emanating from a range of divergent dimensions [2]. The extent of intense farmland practices includes the greater application of agricultural chemicals (synthetic fertilizers, herbicides, fungicides and pesticides), increased crop seeding density and periodic mechanical cultivation.

The greater demand for agricultural products emanates from alterations in consumer demand and the rapid escalation in human population size. Coupled with climate change, the aforementioned factors also drove the enlargement of terrestrial surface areas required for agricultural activities, causing the destruction and discontinuity of ecosystems and a concomitant deterioration in biological diversity [3].

The limitations of intensification are evident in the priority given to the enlargement and clearing of surface areas and improving production systems, while moulding agrarian areas into various fragmented zones of respective secluded and confined indigenous terrains [4]. Agricultural regimens such as monoculture, that is repeatedly practiced over a number of years, also weaken the assortment of life forms in the environment, adding to a contraction in the collection of living organisms settled at the regional scope [5]. The conversion of biological safe havens to cultivated land is a major hazard to earthbound biological diversity and can influence the performance of the ecological environment and lead to modifications of its intended role that affects all living organisms [6].

Moreover, production intensification intruded on the native havens of a range of life forms and altered multi trophic abundance in the surroundings and thereby causing its degradation [7]. These include semi-natural habitats being

field margins and hedgerows, and consequently, the biological diversity native to these zones [8]. This is a big concern, since the assortment of biological life preserve the bedrock of all life on earth [9]. Research data have indicated that production intensification in agriculture gravitates towards a diminished assortment of biological organisms and a conformed form of crop production practices that expedite the dispersion of plant diseases, pests [10] and weeds.

The abovementioned limitations of production intensification changed the arrangement and sources of distinct environmental services, initiating an extended dependence on non-sustainable means in the form of agro-chemicals [11]. The side effects of intensive agricultural systems, evident in the elevated application of agrochemicals that primarily consist of herbicides, degraded the agricultural landscape and decreased the patchwork of crops, causing a drastic shrinkage in the biological diversity of the agricultural landscape [11] and interfere with the environment [12]. While herbicides are very potent in managing weeds and unwanted plants, it has antagonistic ecosystem and human health consequences [12]. According to reference [13], constant disturbances which also consist of herbicide applications, are characteristic of intensely cultivated agricultural areas. These side effects caused the formation of a rule of constant disruption that normally gravitates towards the invasion of pioneering alien species of pests, diseases and weeds that are opportunist in their nutritional and environmental choices [13]. Finally, results by reference [14] confirm the premise that intensive production practices have afflicted the community architecture of microbes, as well as their heterogeneity, active status and therefore natural impact in the crop rhizosphere.

One of the most prominent ramifications of intensification, evident in weed cross-resistance against herbicides, requires the rearrangement of agricultural production practices that rationally, should include high-density ecological habitats [15]. Reference [16] argued for the synchronized design of sustainable agricultural production systems that reinforce biological diversity for generations to come.

Often, persistent weed control options turn out to be unfeasible and lead to even more substantial applications of herbicides. This has exerted strong selection pressures for weed cross-resistance against herbicides [17]. In addition, the side effects of the use of herbicides are not only evident in the evolvement of weed resistance to agricultural chemicals, but also in environmental pollution of air and water due to spray drift [18] and indicate a compelling call for diversified management strategies.

Literature searches for the current paper, included the keywords “agricultural intensification”, “habitat conservation”, “semi-natural habitat” and “crop mosaics”. To this end, the most recent literature in scientific journals as well as all available and relevant publications, totalling 105 from around the globe, were utilised. The overarching evidence in these publications, emphasise that enhanced species’ diversity is unlocked by habitat conservation in agricultural

landscapes. Therefore, the aim of this review is to summarise current literature, reporting specifically on the impact of production intensification on habitats and yield constraints caused by weeds. Secondly, in alleviating these effects, ecological corrective measures that enhance species diversity of semi-natural habitats in agricultural landscapes, are discussed.

2. Effects of Intensification

2.1. Weeds

Pioneering weeds prevail in many environments and induce substantial damage to agricultural operations and all indigenous life forms [19]. Usually, invasive weeds display improved fecundity and endurance when compared to indigenous plants [20]. Generally, their strong invading abilities and ensuing expansion, relate to a slump in the plethora of endemic species [21]. In addition to competing with crops for light, water, nutrients and growing space, weeds may also affect crop growth and yield through allelopathic processes [18]. In accordance with the viability of agricultural production systems and crop yields, effective weed control is essential to limit weed-crop competitive and allelopathic effects.

In large-scale intensive agriculture, weed control is predominantly rooted in agrochemical applications in the form of herbicides [22]. This is mainly due to their very quick responses, great potency, and relatively nominal expenses [22]. Globally, herbicides have performed a pivotal function in intensive production and that assured the incremental upturn in agricultural yields [23]. For instance, weed interference in safflower can reduce grain yields substantially, but data by reference [24] revealed that the herbicides sulfentrazone and pyroxasulfone or dimethenamid-P in combination with pendimethalin applied pre-emergence of weed seed germination, are efficient treatments for significant control of kochia [*Bassia scoparia* (L.) A. J. Scott] and Russian-thistle (*Salsola tragus* L.).

However, the application of herbicides to eradicate unwanted plants in order to improve the efficiency of crop production practices, caused unwanted side effects in the environment. Herbicides are constituted of minuscule molecules whose main aim is to disrupt the physiological course of action in plants [25]. The function of this herbicidal mechanism of action is to interfere with the plant's metabolic processes that eventually lead to its senescence [12].

Additionally, there is the aggregation of herbicide transmittal, traversing species over the food chain, that in the course of time, extent to humans [12]. The adverse secondary effects in humans mainly involve cell impedance, carcinogenic consequences, declining fertility influences and neurological implications [12]. Finally, reference [12] reported that there is a compelling association between the exposure of humans to agrochemicals and their ailments, especially cancer.

Furthermore, the excessive dependency on herbicides, which evidently is a side effect of intensification, did not contemplate the repercussions of its repeated and unchecked use, namely the proficiency of all life forms to readjust to unfavourable environmental surroundings [26]. Coupled to the simultaneous

lack of any precautions or alternative management strategies, these repercussions exacerbated the evolution and dissemination of weeds cross-resistant to different herbicide groups [22]. Addressing this constraint, requires the preventative drafting and utilization of a wider farmland concept that will improve the sustainability of intensive cropping systems [27]. In terms of ecological aspects, this concept includes habitat conservation and the introduction of ecological high density semi-natural habitats.

Generally, the first tactic to deal with the production constraint of cross-resistant weeds in cropping systems, is the application of increased herbicide rates [28] as well as the utilization of active ingredients that linger for an extended period in the surrounding farmland [29]. Currently, cross-resistant weeds occur in 100 crops across 72 countries [30]. Globally the evolution of this phenomenon is manifested in large-scale agricultural production systems [31]. Extensive cross-resistance to diversified active chemical ingredients suggest serious environmental and commercial hazards, particularly to food production and safety [32].

2.2. Microorganisms and Insects

Long lasting intensive agricultural practices show discord both with the promotion of the biodiversity of microbes belowground and aboveground involved in the breaking down of plant material [1]. Reference [33], showed the unintended ramifications of herbicides on benign insects. This happens when the collateral consequences of herbicide applications influence the plant heterogeneity and the assortment of higher plants that is naturally beneficial to insect variety in agricultural landscapes [33].

After the use of herbicides, reference [34] observed a significant reduction in populations of a myriad of living organisms that are active in nutritive processes in the environment, including carnivore, vegetarian and decomposer groups. Similarly, reference [35] reported extreme alteration in the structure of macroarthropod community associations following the application of herbicides. Specifically, a drastic distortion in the interplay and structure of associations among these organisms may change its active status and cohesion [36]. Subsequent to a reduction in the application of herbicides, studies by reference [36] also suggest a higher fraction of beneficial indigenous species retracing. Notwithstanding, reference [37] concluded that the intended and unintended side effects on benign insect mobility cannot be overlooked.

3. Ecological Countermeasures to Side Effects of Agricultural Intensification

In the quest for sustainable agricultural production that will benefit humanity, all side effects of agricultural production processes need to remain enclosed by a functionally protected zone [38]. Reference [39] mooted transforming agricultural production practices, since it is favourable to the ecology, habitat hetero-

geneity and ultimately sustainable agriculture [40]. Earlier, reference [41] reported that landscapes with preserved safe havens in the environment at its foundation, diminish the adverse effects of intensive agricultural activities. Concurring, reference [9] provided evidence that the preservation of small sections of indigenous plants promote ecological variety. This encompasses the preservation or establishment of native vegetation strips, essential in the promotion of favourable indigenous species in the landscape [42].

Biological variety is a priceless facet of life on earth and includes a plentiful amount of species, varieties and genes that ensure abundance in ecosystems [43]. Reference [44] mentioned that appeals worldwide necessitate a decline in applications and reliance on herbicides, while reference [45] emphasized that new prospects for planned strategies regarding weed resistance ought to maintain expedient crop yields along with a reduction in the demand for herbicides. Furthermore, the efficient control of nearly all weed resistant populations is by way of an integrated control program that combines different plans of action with an assortment of techniques and methods [46]. Accordingly, the design and applicability of alternative production practices and weed management strategies is critical.

In agroecosystems, biological diversity contributes a number of ecosystem services coupled to a deluge of definite positive influences on crop yield [47]. A study by reference [16] showed that combinations of essential elements, for instance inter cropping, hedgerows and field margins show the best results from a range of options, providing proof of viability and advancement in 75% of instances regarding both habitat heterogeneity and output of crop produce. Similarly, definite symbiosis is the most probable outcome of diversity in agricultural landscapes of Mediterranean and temperate biomes [16]. The sum of plant species per unit area signify the existence of more small areas of biological activity, contributing environmental balance and cohesion that provide numerous safety nets to the surrounding habitats [43]. Accordingly, the presence of native species in the surroundings, in combination with hedgerows and field margins, with a comparatively intricate and balanced variety of plants in a sheltered environment, are essential for settlement of benign insects, particularly in the face of intensive agricultural production [37].

Various safe havens consisting of native species are points of inception and supply the basic needs and refuges for a whole series of ecological life forms in agroecosystems [48]. The existence of area-wide hedgerows and field margins in agroecosystems can thus promote the definite influences of environmentally friendly production systems [49]. Worldwide, entrenched native safe havens adjacent to agricultural fields and in the countryside stratum is acknowledged as valuable for keeping the functioning of all life forms healthy [50].

3.1. Soil Microorganisms

Processes in the soil microbiome have valuable functions in affecting numerous ecological roles in the rhizosphere that comprise carbon and nitrogen cycling

and the decomposition of plant material in ecosystems [51]. Through root exudation, some plants may alter the soil microbial profile and diversity for its own competitive advantage [52], due to influences on the formation, heterogeneity, and dispersal of soil microbial colonies [53]. In addition, data showed that soil type and locality are major determinants in the regulation of interactions among plants and microorganisms [54]. Moreover, a reduction in habitat heterogeneity of vegetation reveals it as the force behind the change in active status of soil microbes [55] and developments in the multiple operations of its microbiome [14].

Over all heterogeneous taxonomic genera, the process of variegation probably causes a win-win scenario when the focus is on soil microbes, including bacteria and fungi. It shows a decreased myriad and variety of pests linked to reduced yields and indicates that diversification could successfully diminish plant pests [16]. Ecological interplay may also accomplish effective functions in modifying weed communities by means of microbial degeneration of viable seeds in the soil seedbank [56].

Reference [57] followed a distinctive approach and after meticulous detection and preference testing of soil microbial communities, disclosed that particular weed-inhibitive bacteria showed selectivity in suppressing annual invasive Poaceae plants. This implies that it may be considered and utilized in the formulation of weed control tactics [57].

Weed-inhibitive bacteria that diminish the seedbank and show inhibitory seedling development [58] are particularly appealing as biocontrol agents for selected problematic weeds. Since it prefers frigid conditions for effective weed suppression, the preferred time of application are under wintery climatic conditions. With proper application, which is in a similar way to that of agrochemicals during commercial production practices, reference [59] reported weed inhibition of more than 90% after 5 years.

Reference [60] presented appreciable data which imply that arbuscular mycorrhizal fungi can influence the dynamics of weed populations in agricultural production systems. By way of a myriad of methods, the interplay between weeds and arbuscular mycorrhizal fungi may diminish production deficits brought about by unwanted plants. Accordingly, the utilisation of arbuscular mycorrhizal fungi opens up novel approaches to weed suppression [60].

3.2. Microbial Nitrogen Immobilization

Reverse fertilisation is a tactic that entail the application of considerable volumes with a great ratio of carbon:nitrogen (C:N) modifications into the soil. According to reference [61] the general effect is that C modifications had a great detrimental influence on the advancement of all invasive plant species tested. The excess carbon encourages development of soil microbes and excite the foraging of nitrogen causing its ensuing incapacitation within microbial cells [61].

Findings by [62] indicate the probability to enhance and broaden the utilisation of reverse fertilisation as a weed control strategy in agricultural production

systems. The application of various types of soil amendments might achieve the required increase in soil C, but only in very high volumes. As in hereof, biochar commonly applied in huge volumes as a soil amendment, elevates soil carbon retention, improves soil health, and boost nutritious proficiency [63]. Additionally, soil treated with biochar, advances the development of microbes by way of the prevalent symbiosis among plants and arbuscular mycorrhizal fungi [64]. A plentiful amount of beneficial traits permit biochar to grow soil C repository, diminish organic contaminants, and ameliorate the rhizosphere for microbes, thereby broadly regulating the soil habitat [65].

This method of weed suppression is attributable to microbial incapacitation of nitrogen (N) in the short-term and leaves N without the basic microbial biomass. To a large extent, weeds showing cross-resistance against herbicides quickly react to N and are classified as nitrophilous plants [66]. If the period of N debilitation take place concurrently with the urgently critical time of weed suppression, the short-lived decline in inorganic N accessibility for root absorption is a profound mechanism in the rhizosphere for weed suppression in agroecosystems [67].

3.3. Weed Seed Predation

As a natural weed control mechanism, weed seed predation refers to the consumption of weed seeds by different granivorous animal species and groups. They can consume more than 90% of weed seeds [68] depending on the particular plant species and environmental conditions. Results by reference [69] confirmed the promising aspects of advantageous invertebrates by way of seed predators, enabling decreased herbicide applications without production losses. Typically, this will advance agroecosystem diversity and is worthwhile for habitat persistence [70].

Incidentally, cover crops and living mulches may diminish weed seedling growth by way of microenvironments conducive to granivores of unwanted seeds [71]. Data corroborate that the utilization of cover crops and living mulches can add to the quantity of active carabid beetles [72] and can bring about augmented weed seed predation [73].

3.4. Crop Mosaics

Over millennia, agricultural practices beyond various topographic territories and soil types favoured a mosaic environment within agricultural landscapes [47]. Reference [47] reported that these environments contained extensive biological diversity that underpinned its fecundity through an ecological role, being pollination, pest management and soil health.

Crop mosaics emerge as an integral result of more varied agricultural landscapes, especially when confronted by the onset of pests allied to climate change [74]. Reference [75] confirmed the value of niche compatibility traversing habitats for dissimilar and useful classes of species. Accordingly, crop mosaics ar-

ranged to advance compatibility at the landscape scale is important to bolster pollination services and insect management, while ecological variety in the surroundings act as a safety net for habitat diversity [76].

Furthermore, biodiversity in agroecosystems enhances heterogeneous production practices, a universal description that contains a large assortment of plans of action that increase plant variety in territory and period; from the farmland to the region, with every one accommodating particular advantages of habitat heterogeneity [40]. Increasing ecological variety usually advances the assortment of living organisms and its provision of utilities in the environment [77]. Moreover, native vegetation strips serve as sink habitat for pest species and a shelter of origin for insect predators that overflow into the neighbouring farmland [78].

3.5. Cover Crops, Living and Biomass Mulches

Cover crops and living mulches promote agroecosystem biological diversity and often this correlates with the presence of a lower incidence of diseases, pests and weeds [79] in grain cropping production systems [80]. Data by reference [81] indicate that the practices of cover cropping and living as well as biomass mulches are very important elements of integrated weed management, since it introduces many different suppressive forces on weeds. Living mulches enhances problem plant suppression, diminish soil erosion and nutrient leaching, promote soil quality [81] and moderates the evolution of weed cross resistance to herbicides groups [79]. Mulches can also act as a physical barrier to weed germination and growth [82]. Certain biomass mulch materials, suppresses weeds by root exudation of allelopathic chemicals [18] and facilitate weed seed predation [71].

Reference [83] showed that cover crops and living mulches also increase soil organic carbon with an associated improvement of soil enzymatic activity. Furthermore, apart from promoting beneficial factors, including soil health and soil water content, it also increases organic matter and enhances communities and the variety of soil microorganisms in the rhizosphere [80].

3.6. Hedgerows

According to reference [84], even minor restoration with hedgerows is advantageous to valuable life forms in closely located fields within intensively managed agricultural landscapes. The field boundaries and fences near farm tracks that are arranged and maintained in expanded structures of semi-native havens across agroecosystems [85] may act as refuges for innumerable insects [86].

Enhancing the assortment of life forms in semi-native agricultural surroundings through plants, indicate that weed control in combination with different tactics of vegetation use, comprising cover cropping, hedgerows and field margins, sets up safe havens in the landscape, and improve the diffusion of complementary life forms [87]. Reference [88] presumed that in most cases, the introduction of compounded production programs as well as crop type and rotation schedule arrangements, break the invasiveness of problem plants.

Reference [89] provided further proof of the benefits of hedgerows as well as its utilisation as movement corridors in intensively used agricultural landscapes. Reference [90] elaborated and showed that concatenated hedgerows are essential as forage and for unhindered movement corridors of mobile organisms. Hedgerow soils provide essential ecological services in agricultural landscapes, *inter alia* increased soil carbon storage, greater incidence of earthworm variety and acting as a refuge for specific communities of arbuscular mycorrhizal fungi [91].

3.7. Field Margins

Marginal farmland containing native plants in field margins [92], perform a meaningful natural function as point of provision for forage, safe havens and distribution passageways for pollinators [93] and insect predators [94]. It also forms an area of separation against agrochemical drift into the surrounding agrarian countryside and water bodies [95]. As a transitional ecotone, field margins contain a combination of weeds and pioneering species, which are befitting of disruption in agroecosystems [96]. Furthermore, the variety of vegetation in hedgerows and field margins, reach the goal of conferring a variety of valuable additions of seeds to seedbank diversity [32].

Field margins enclosing crops serve as a safe haven for large numbers of taxa and provide refuge from adjacent field disturbances. Field margins also functions as a habitat and a corridor for some organisms such as insect predators that provide natural pest control [90]. Since field margins are very important for the perpetuation of ecosystem services, it influences insect movements into cropped fields after disturbances such as agrochemical applications [92].

Advancing habitat heterogeneity is decisive for biological diversity at the spatial range, since disparate native safe havens may present various niches and by that uphold several species [97]. Finally, reference [98] alluded to a general agreement that production areas that retain semi-native havens such as field margins in combination with slightly smaller cultivated farmland, advance greater biological diversity in agricultural landscapes. A study by reference [99] on the Poaceae (*i.e.* *Lolium* spp.), which are notorious for quickly developing weed resistance and acknowledged as abundant producers of wind-dispersed pollen, revealed that relatively small quantities of its pollen from savannas are passing through field margins.

4. Conclusions

The plethora of challenges facing efficient agricultural production might seem insoluble, especially in view of the rise in the human population growth rate and taking into account the needs and wants for a higher standard of living worldwide [100]. Adhering to these demands requires adjusting of production processes in order to grow extra and safe and sound foodstuffs, fodder, and fibre on more limited farmland even though taking into consideration circumstantial ecological influences [100], notably cross-resistant weeds and climate change.

Reference [100] suggested that the focal point emanating from viable invasive and problem plant control strategies, is to maintain semi-natural safe havens and nurturing of conserved habitats.

Reference [101] emphasized that different weed control tactics and crop production structures, will ensure dissimilarity among problem plant populations. Accordingly, it will promote elasticity against weeds that could affect the entire production regimen. This may safeguard production systems in opposition to the ascendancy of some invasive problem plants prone to cross-resistance against herbicides [101]. Reference [16] reported fascinating results that indicate widely differing practices and cropping systems with a lesser impact on farmlands and surrounding conserved habitats that can raise yields by promoting ecosystem service arrangement.

A study by reference [102] showed that conserved habitats that contain a superior collection of species reveal a progressive extent of opposition to unfavourable surroundings. To this end, reference [103] confirmed that the scope and diversity in vegetation of hedgerows and field margins as well as crop variety [76] have definite influences on species assortment in the agricultural landscape. However, due to the great variety in climatic zones and soil types of the agrarian countryside, the plant population structure for utilisation in field margins and hedgerows should be site-specific [32]. Finally, ecological responses to in-field and landscape management are highly variable because they are species and context-dependent [104] and tailored to specific landscapes [105].

Clearly, evidence in the literature supports the introduction of crop mosaics, cover crops, living and biomass mulches, in combination with hedgerows and field margins playing the role of semi-natural habitats, as the most prominent ecological practices to sustain agricultural yields. Similarly, it might be worthwhile to incorporate practices that promote beneficial soil microbes, microbial nitrogen immobilization and weed seed predation into existing production systems. Furthermore, farmland and agricultural landscapes are not typically managed for variety, and attempts at increasing structural heterogeneity are slow, complex and long term measures, in order to brace it for sustainability. Production practices that promote more heterogeneous cropping systems and combine high density semi-natural safe havens and habitat conservation in agroecosystems will benefit species diversity across trophic levels and contribute to agricultural production stability and food safety.

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: investigation. MIF: resources. MIF: writing-original draft preparation. MIF: writing-review and editing. MIF: visualisation. 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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Conflicts of Interest

The author declares no conflict of interests.

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