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Farmscaping: An ecological approach to insect pest management in agroecosystem

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Abstract
The interest to shift pest management strategies from the intensive use of agrochemicals to sustainable and eco-friendly practices has increased in recent years. Agricultural intensification has led to a dramatic decline in farmland biodiversity. This biodiversity is directly linked to the maintenance of some ecosystem services such as pollination and pest control. An alternative to conventional farming systems is the implementation of diversification practices that increase diversity in- and around- the field to increase the incidence of natural enemies, to reduce pest pressure and to enhance crop production. Farmscaping is an ecological approach to pest management that usually involves planting hedgerows, insectary or flowering plants to attract and support populations of beneficial organisms. Farmscaping plants are planted to attract and provide resources (viz. shelter, reproductive habitat and alternative or supplemental food sources) to beneficial insects that may not otherwise be available in a monoculture crop field. The concept of farmscaping is partly based on the knowledge that natural enemies require supplemental food sources to achieve maximum fitness and thereby to provide better pest control of pest species in agro-ecosystem.

Keywords: Farmscaping, biodiversity, beneficial organisms and pest management

1. Introduction
The amount of crop diversity per unit of arable land has decreased and the croplands are showing a tendency towards concentration [12]. Monoculture on the vast agriculture land resulted in simplification of agro-ecosystem, which concentrated resources for specialist crop herbivores and have increased the areas available for immigration of pests [20]. So, that farmscaping approach can be wisely utilised to improve crop diversity and habitat manipulation for long term pest control.

Farmscaping is a holistic (whole-farm) ecological approach to pest management over the conventional farming system. It can be defined as the use of hedgerows, insectary plants, cover crops and water reservoirs to attract and support populations of beneficial organisms such as insects, bats, and predatory birds. In some respects beneficial organisms should be considered and managed as mini-livestock and they need an adequate and nutritious diet to reproduce more readily and to survive. Interestingly, adequate supplies of nectar, pollen, and herbivorous insects and mites as food are only needed to sustain and increase their populations [26]. Though, in agro-ecosystems the best sources of these foods are flowering plants. Flowering plants are particularly important to adults of the wasp and fly families, which require nectar and pollen sources in order to reproduce the immature larval stages that parasitize or prey on insect pests [20]. However using a random selection of flowering plants to increase the biodiversity of a farm may favour pest populations over beneficial organisms. It is important to identify those plants, planting situations and management practices that best support populations of beneficial organisms [12]. Farmscaping like other components of sustainable agriculture requires more knowledge and management skills than conventional pest management approaches. Habitat manipulation aims to provide natural enemies of pests with resources such as nectar [1], pollen, physical refugia, alternative prey, alternative hosts [26] and oviposition sites [22]. Ideal farmscape plantings provide food and shelter for beneficial organisms, suppress weeds and grow in close proximity to the cash crop without competing for recourses viz. space, light, water and nutrients. In some cases the term "farmscaping" is broadened beyond just augmentation of insectary plants to include trap crops i.e. host plants that are more attractive to the pest than the cash crop that are planted near the cash crop to "trap" pests, thus reducing pest pressure and damage to the cash crop [19].

2. Why farmscaping?

2.1 Less difficult: easy approach: Working with and using natural processes, like farmscaping, will help to control pests sustainably earlier in the season. This will increase farms productivity with less direct intervention thus minimizing labour inputs. Farmscaping also helps to establish balance in agro-ecosystem that provides enhanced stability of agro-ecosystem [26].

2.2 Economical: Farmscaping lowers the production costs of crops by encouraging and using natural enemies to suppress pest species below the economic threshold. When conditions are right, natural enemies can hold these pest levels down sustainably and also natural diseases of pests are encouraged [26].

2.3 It's cheap and don't need much input: The only need to farmscape is about 5% or less of the field area. This means for every acre about 2200 square feet area is required for farmscaping. Seeds of farmscaping mixes are cheap. An ounce of prevention is truly worth 16 times its weight in cure here. Beneficial insects don't require health insurance, a form of identification and they will gladly work on holidays during the entire growing season.

Farmscaping mixes can be grown wherever wanted, according to the suitability of farm plan and possible benefits to be gained. Farmscaping is very less time consuming approach to cop up with pest problems in agro-ecosystems.

2.4 Erosion control/soil building: Farmscaping in contours between field's steep ditches or places that are more easily eroded gives stability to the soil. Farmscaping can be used as a buffer strip and has benefits to crops growing in fields nearby and additionally several farmscaping mixes are also good soil builders.

3. Development of a farmscaping plan: Following are the key considerations in crafting a farmscaping plan.

3.1 Ecology of pests and beneficial: What are the most important (economic) pests that require management, what are the most important predators and parasites of the significant pests, what are the primary food sources, habitat, and other ecological requirements of both pests and beneficial species (Where does the pest infest the field from, how is it attracted to the crop, and how does it develop in the crop, where do the beneficial species come from, how are they attracted to the crop and how do they develop in the crop) [26].

3.2 Timing: When do pest populations generally first appear, when do these populations become economically damaging, When do the most important predators and parasites of the pests appear, When do food sources (nectar, pollen, alternate hosts, and prey) for beneficial first appear, how long do they last and what native annuals and perennials can provide habitat.

3.3 Identification of strategies: Reduction of pest habitat (i.e., reduce/ alter overwintering pest sites, or reduce/alter locations from which pest invades). Augmentation of beneficial habitats viz., insectary establishment; consider both perennial options and permanent plantings such as hedgerows and annual options. Trap Crops planted specifically to be more attractive to the pest than is the crop to be harvested. This is due to the timing of the appearance of the trap crop or the fact that it is physiologically more attractive to the insect [26].

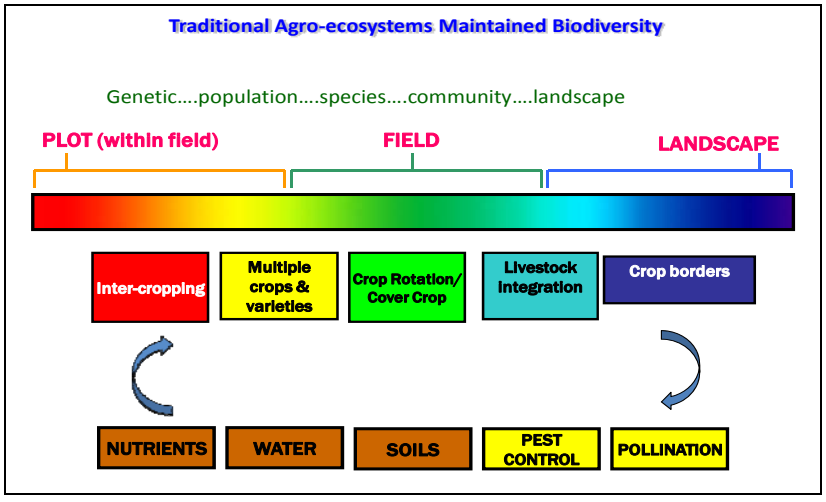


Fig 1: Traditional agro-ecosystems were diversified, not eroded, not flooded, not polluted and hence were healthy [20].

Traditional agro-ecosystems maintained diversity across ecological levels and from the plot to landscape spatial scale by using techniques such as inter-cropping, multiple-cropping, crop rotation, livestock integration and crop borders and thus naturally generated essential services that supported agriculture.

3.4 Beneficial insects and their attractive plants

3.4.1 Lacewings (Chrysopidae and Embiodiidae): Prey upon aphids, thrips, mealybugs, scale insects, caterpillars and mites. Commonly used plants to attract and conserve lacewings; viz., Carrot family, sunflower family, buckwheat holly, leaf cherry, corn and provide water during dry spells.

3.4.2 Ladybird Beetles (Coccinellidae): Plants to attract and conserve coccinellids; nectar plants with small flowers, caraway – dill parsley, fennel Queen Anne's – white lace clover angelica, goldenrod mustard – tansy yarrow, sunflower hairy vetch – buckwheat, cowpea, common native grasses knotweed crocuses – spearmint grains, buckthorn black locust and saltbush [26].

3.4.3 Parasitic Wasps: Prey upon a variety of crop pests viz., aphids, armyworm, cabbageworm, codling moth, beetle larvae, flies and caterpillars etc. Commonly used Plants to attract and conserve parasitic wasps are nectar plants like small flowers caraway – dill, parsley – fennel, Queen Anne's - white clover lace mustard, tansy yarrow – sunflower hairy vetch, buckwheat cowpea - common knotweed and crocuses – spearmint [26].

3.4.4 Predaceous Ground Beetles (Carabidae): Prey upon, slug, snail, cutworm, tent caterpillar, cabbage-root maggot, Colorado potato beetle and gypsy moth. Commonly used Plants to attract and conserve ground beetles permanent plantings amaranth white and clover mulch.

3.4.5 Predaceous True Bugs (Nabidae and Pentatomidae): Prey upon aphids, thrips, leaf-hopper, Tree hopper and small caterpillars. Commonly used Plants to attract and conserve predaceous true bugs are sunflower and goldenrod yarrow alfalfa [26].

4. Elements of farmscaping: Following are the elements of farmscaping.

4.1 Intercropping

Intercropping is one of the important cultural practice in pest management and is based on the principle of reducing insect pests by increasing the diversity of an ecosystem. Intercropping is the practice of growing two or more crops (usually different families) in the same area. Strip cropping is a derivation of intercropping and is the practice of growing two or more crops in alternating strips across a field [14]. Both practices serve to increase biodiversity and make the habitat less congenial for pest development. Pests find it easier to locate host plants when grown in a monoculture versus a mixed planting. This is based on the "Resource Concentration Hypothesis" which says that plant-feeding insects are more likely to find and stay in more dense and less diverse patches of their host plants [15]. Rao *et al.* (2012) [14] conducted on-farm experiments in villages of semi-arid tropical (SAT) India to identify the appropriate combination of castor (*Ricinus communis* L.) (Malpighiales: Euphorbiaceae) and intercropping in relation to pest incidence. The on-farm diversity was enhanced by introducing cluster bean, cowpea, black gram, or groundnut as intercrops in castor (1:2 ratio proportions), which was resulted in reduction of incidence of insect pests viz., semilooper (*Achaea janata* L.), leaf hopper (*Empoasca flavescens* Fabricius), and shoot and capsule borer (*Conogethes punctiferalis* Guenee). It was found that the minimum incidence of *A. Janata* and *C. punctiferalis* was observed in Caster and cluster bean inter-cropping system. Similarly, caster and sunflower inter-cropping system resulted in lowest incidence of *T. Ricini*. These intercropping systems also provided congenial environment for build-up of natural enemy population (Microplitis, coccinellids, and spiders) of the major pests of castor and resulted in the reduction of insect pests. Further, these systems were more efficient agronomically and economically, and were thus more profitable than a castor monocrop. Other exciting examples of intercropping in the context of insect pest management in different agro-ecosystems viz., Cabbage + Indian mustard, Beans+ Corn etc., can be explored for eco-friendly pest management.

4.2 Mixed cropping - Push Pull System: A 'push–pull' strategy is a cropping system in which specifically chosen companion plants are grown in between and around the main crop. These companion plants release semiochemicals that (i) repel insect pests from the main crop using an intercrop which is the 'push' component; and (ii) attract insect pests away from the main crop using a trap crop which is the 'pull' component [3]. Such a system requires a good understanding of the chemical ecology of plant–insect interactions on the different crops. Candidate crops need to be systematically evaluated in field trials. While a push–pull system was developed specifically for the control of cereal stem borers using 'push–pull' strategy in smallholder maize production in Kenya, it was discovered that certain intercrops (silverleaf, *Desmodium uncinatum*, and greenleaf, *D intortum*,) had further benefits in terms of suppression of Striga weed. This effect is just as important as stem borer control for achieving higher yield. However, this underpinning mechanism has an allelopathic effect which is because of intercrop root exudates (non-volatile) that suppresses germination of Striga and hence only requires the intercrop component of the push–pull system [9].

4.3 Trap crops: A trap crop is a crop that is planted to lure insect pests away from the cash crop. The trap crop can be a different plant species a different variety or just a different growth stage of the same species as long as it is more attractive to the pests when they are present. The trap crop must be more attractive to the pest than the cash crop and steps must be taken to ensure that the pests in the trap crop don't later migrate to the cash crop. Thus, successful use of trap crops is challenging [21]. Trap crops are not effective against pests that are weak fliers and/or are wind-dispersed (e.g., aphids, spider mites). Trap crops were originally designed to be used in conventional systems where insecticides could be used to kill the pests in the trap crop. In organic systems approved insecticides can be used but pests can also be eliminated by crop destruction. The timing is critical – destruction too early or too late can negate the trap crop effects or even result in mass pest migration to the cash crop. A success story of push–pull' strategy by using trap crop (Napier grass, *Pennisetum purpureum*, and Sudan grass, *Sorghum sudanensis*) as a "pull" component for stem borer management in maize and sorghum, is a best example of successful pest management by trap crops.

Key concepts of trap crops

1. Must select planting that is more attractive to key pest(s) than the economic crop.
2. Trap crop must be attractive during target protection periods.
3. Trap crop must be a sink, not a source.
4. Must have population management strategy: viz., biological control, hand picking, insecticide, vacuuming etc.

Interestingly, in the cotton agro-ecosystem Bheemanna *et al.* (2010) [2] demonstrated the effect of Bt-cotton as an ovipositional trap crop with different proportions in conventional cotton insect-pest management on American bollworm population (*Helicoverpa armigera*). The studies revealed that larval population of *H. armigera* on cotton when *Bt*-cotton was used as trap crop indicated minimum incidence in cotton IPM treatment. The minimum damage to green bolls and very low incidence of pink bollworm was registered in cotton IPM treatment. Cotton IPM package and Bt-cotton border experiments recorded maximum good opened bolls with least bad opened bolls. Trap crops also play a significant role in minimising pest population in different agro-ecosystems (Table: 1)

Table 1: Examples of trap cropping to cop up with pest problems in agro-ecosystem.

Trap crops	Main crop	Method of planting	Pest controlled	References
Alfalfa	Cotton	Strip intercrop	Lygus bug	Shelton and Perez (2006) [16]
Marigold	Garlic	Border crops	Thrips	Eze and Echezona (2012) [6]
Chinese cabbage, Mustard & raddish	Cabbage	Planted in every 15 row of cabbage	Cabbage webworm & Mustard aphid	Muniappan *et al*., (2001) [11]
Caster	Cotton	Border crop	*Heliotis Sp*.	Shelton and Perez (2006) [16]
Chickpea	Cotton	Block trap crop at 20 plant/sq m	*Heliotis Sp*.	Eze and Echezona (2012) [6]
Green beans	Soybean	Row intercrop	Mexican bean beetle	Ellis and Bradley (1996) [5]
Napier Grasses	Corn	Inter crop and border crop	Stemborer	Khan *et al.,* (2006) [10]
Okra	Cotton	Border crop	Flower cotton weevil	Hasse (1986) [7]

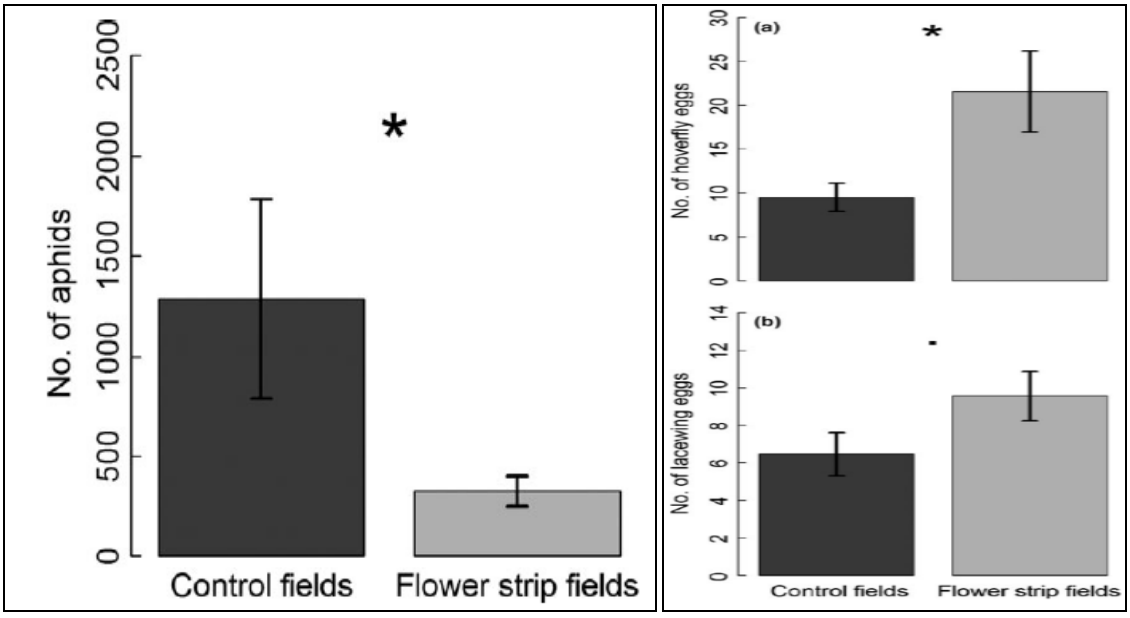
4.4 Cover crops: Living mulches, green manures and catch crops can all be referred to as cover crops. Some cover crops often legumes or grasses, are grown to prevent soil erosion and suppress weeds while others are incorporated into the soil to provide nitrogen and organic matter to the subsequent crop. Cover crops alter the microclimate by affecting soil moisture and soil temperature. They can also provide habitat for beneficial organisms such as spiders and ground beetles over the winter. Certain cover crops are also insectary plants such as buckwheat, sweet clover, vetch, red and white clover and some brassicas (mustards, oilseed radish). Of course farmers don't want the beneficial organisms to live only on the cover crops—the beneficial organisms are needed on the actual crops. The beneficial organisms will move from the cover crop to the crops once the cover crops have stopped blooming but to encourage an earlier move, mow the cover crops when the beneficial organisms are needed on the main crop. Mowing alternate rows of cover crops can increase the range of habitat for beneficial organisms and extend the flowering period. Another unique strategy to manage pests using cover crops is the use of brassicas to control soil nematode populations. Mustard, oilseed, canola and radish can also be sown as cover crops and then ploughed into the soil where substances released during decomposition harm nematodes [4].

4.5 Companion planting: This is a broad aspect that refers to the addition of specific plants to enhance the growth and quality of nearby crops. In a pest management context companion plants are usually added to deter or repel pests. The African marigold, for example releases thiopene a nematode repellent making it a good companion for a number of garden crops [8].

4.6 Banker plants: Banker plants serve as a site for rearing bio-control agents in the greenhouse by providing them with an alternative food source. The banker plants can consist of the same crop/crop pest as that you are trying to control, or can be an alternate host and prey. Bird cherry aphid on wheat for green peach aphid control. Greenhouse whitefly on eggplant for greenhouse whitefly control [13].

4.7 Tailored flower strips

The seed mixture of the annual flower strip was targeted to provide continuous and high amounts of floral and extra-floral resources that are attractive and accessible to key natural enemies of aphids during the period when aphid control by natural enemies is required (end of May to beginning of August in the study region). Plant species were selected based on an extensive literature survey of studies indicating positive effects of flowering species on the abundance and performance of key natural enemies of aphids. The following plant species were selected: *Anethum graveolens* L. (Apiaceae), *Anthemis arvensis* L. (Asteraceae), *Anthriscus cerefolium* Hoffm. (Apiaceae), *Bellis perennis* L. (Asteraceae), *Calendula arvensis* L. (Asteraceae), *Camelina sativa* (L.) Crantz (Brassicaceae), *Centaurea cyanus* L. [24].



(A) (B)

Fig 2 (A): Effects of flower strips on aphid density (B) Effects of flower strips on natural enemy eggs

Tailored flower strips enhance biological control of aphids in nearby potato crops and pr ovide complementary benefits for natural enemy biodiversity. The high pest reduction levels and reduced probability that action thresholds are reached, observed in combination with increased natural enemy diversity, suggest that tailored flower strips established in target crops can attenuate pest outbreaks and reduce insecticide use. The decision of a farmer to establish tailored flower strips will, however, depend on weighing the potential benefits of enhanced crop yield or spared costs for insecticide treatments against costs associated with the establishment of flower strips, such as sowing and land opportunity costs and potentially a higher amount of invested labour. Tailored flower strips may therefore need to be promoted through agri-environmental payments as an additional economic incentive for farmers to invest in this management tool [24].

5. Farmscaping plants selection Ecological engineering has been extensively researched in many temperate crop systems than the others. Incorporation of optimal forms of botanical diversity is an integral part of ecological engineering for pest management, to suppress pests, by promoting their natural enemies [16]. Interestingly, a study reports the influence of various plant species on the performance of a key natural enemy of rice plant hopper, predatory mirid bug, *Cyrtorhinus lividipennis*. Survival of adult males and females was increased by the presence of flowering plants viz., *Tagetes erecta*, *Trida procumbens*, *Emilia sonchifolia* (Compositae), and *Sesamum indicum* (Pedaliaceae) compared with water or nil controls. However, all flower treatments resulted in increased consumption of brown plant hopper, *Nilaparvata lugens,* and for female *C. lividipennis, S. indicum* was the most favorable. Moreover, *S. indicum* most strongly promoted prey eggs predation by *C. lividipennis* and adult longevity and fecundity of *Cnaphalocrocis medinalis* and *Marasmia patnalis*, was significantly reduced when fed on *S. indicum* flowers. Findings indicate that *S. indicumis* well suited for use as an ecological engineering plant in the margins of rice crops. *Sesame indicum*
can be a valuable crop as well as providing benefits to *C. lividipennis* whilst denying benefit to key pests [26]. Another study Timothy *et al.,* 2011 [23] evaluate potential farmscaping plants for utilization in organic vegetable production systems, the effects of the nectar of three flowering plant species were examined viz., swe*et al*yssum (*Lobularia maritima*), buckwheat (*Fagopyrum sagittatum*), and licorice mint (*Agastache foeniculum*), on the lifespan and body nutrient levels of the wasp, *Microplitis croceipes* (Cresson) (Hymenoptera: Braconidae), a key parasitoid of some caterpillar pests of vegetable crops in the USA. The greatest longevity was recorded for honey-fed wasps (positive control). Similarly, buckwheat significantly increased the lifespan of female and male wasps by at least two-fold relative to wasps provided water only. Licorice mint also significantly increased female longevity and numerically increased male longevity. Swe*et al*yssum slightly increased longevity of both sexes but this was not significantly different from the water only control. Females had a significantly longer longevity than males on all the diet treatments. The greatest carbohydrate nutrient levels (sugar content and glycogen) were recorded in honey-fed wasps followed by wasps fed buckwheat, whereas very little nutrients were detected in wasps provided swe*et al*yssum, licorice mint or water only (fig: 3). However, female wasps were observed to attempt to feed on all three flowering plant species. Thus, the low nutrient levels detected in wasps provided swe*et al*yssum or licorice mint may be because the nectars were not accessible or were of poor quality.

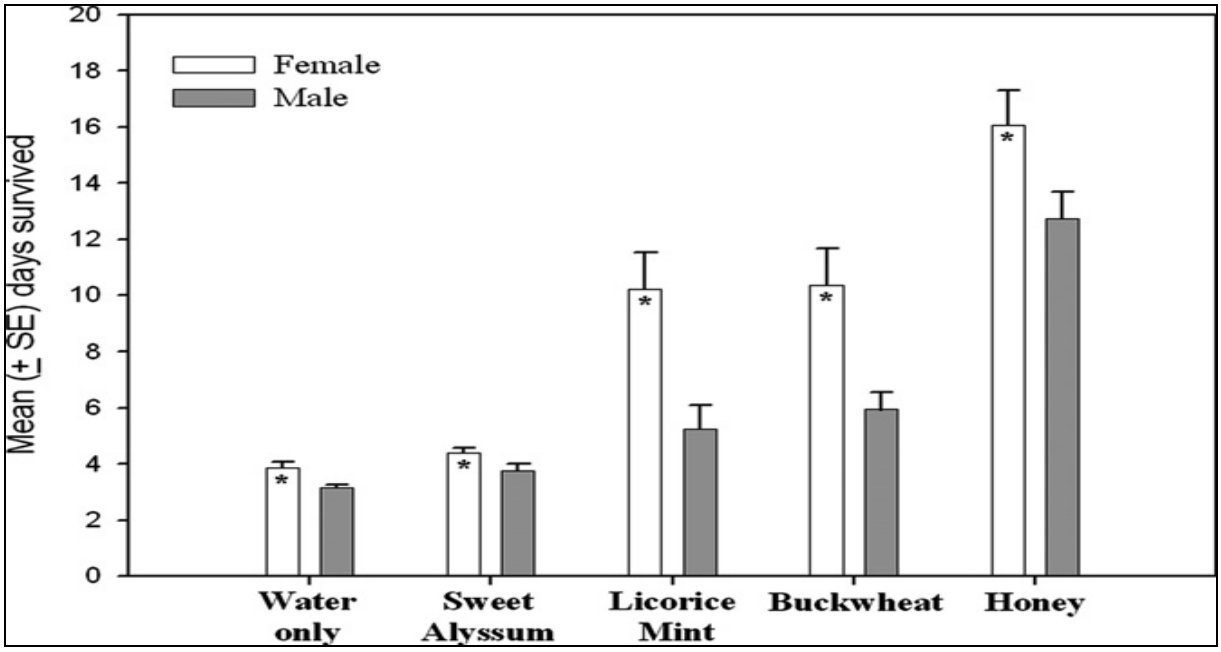


Fig 3: Longevity (mean days ± SE) of female (A) and male (B) *M. croceipes* provided different diet treatments [23].

6. Advantages of Farmscaping: Farmscaping reduces the need for pesticides, lowering costs and reducing exposure to potentially harmful chemicals by farm workers and consumers. Farmscaping is also simple and generally inexpensive to implement. In many areas, costs can be lowered even further by conservation incentives or cost-share programs. In addition to the ecological and environmental benefits of providing habitat for wildlife and increasing biodiversity, farmscaping also increases natural beauty. Farmscaping can also contribute to side businesses for farmers, including beekeeping, cut flowers, and fish farming.

7. Conclusion

Farmscaping is a potential approach to enhance on- farm biodiversity that will result in long lasting stability of agro-ecosystem. Farmscaping also enhances natural enemy activity thereby insect pest population can be reduced below economic damage levels. It is an economically sound and ecologically practical and socially acceptable practice. It is essential to keep good records of where, when, and what pests occur on the farm and gather information about key pest and natural enemy life cycles and habitat requirements. Make a list of available strategies to go into the farmscaping "toolbox" that can be implemented to create a friendlier habitat for the beneficial species, and a more unfriendly habitat for pests. Selection of a combination of strategies from the toolbox that best fit to farm the plan (i.e., location of fields, crops grown and rotation plans) as important as selection of appropriate annual and perennial insectary plants. Enhancement of on-farm diversity and natural enemy activity will sustain the farm production and will lower the risk of pest outbreaks.

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