The New Zealand Sustainability Dashboard

ARGOS

EVIDENCE EVALUATION ASSESSMENT SYNOPSIS

Farm management practice: Shelterbelts present on farm

Background information and definitions

Hedges or windbreaks are lines of trees or shrubs grown along the margins of crop and pasture fields or along orchard and plantation boundaries. Growing crops between hedgerows or tree lines planted at regular intervals across crop fields or along slope contours is termed 'alley cropping'. Agricultural intensification, which has included increasing field size and pesticide use, can result in a loss of field margin habitats, such as hedgerows. These features can provide a relatively undisturbed habitat, heterogeneity in the landscape, and resources not found elsewhere for wildlife in intensively managed agricultural landscapes.

Key messages

Grassland plants (3 studies):

A replicated study from the UK found greater grass diversity in recently established hedgerows compared to recently sown field margins, and greater vascular plant diversity in hedgerows and mature field margins compared to recently sown field margins. A replicated site comparison from the USA (California) found greater floral abundance in hedgerows compared to unplanted margins of vegetable fields.

A replicated, randomized, controlled study from the Philippines found inconsistent effects of alley cropping on abundance of grass and forb species, with greater maximum abundance in alley cropped compared to conventional rice fields and greater grass abundance in alley cropped compared to conventional rice fields at a site with low fertility and high erosion.

The same study from the UK as above found lower grass abundance in recently established hedgerows compared to recently sown field margins, and lower vascular plant diversity and abundance of perennial wildflowers and mosses in recently established hedgerows compared to mature field margins.

The same study from the USA (California) as above found no difference in flower diversity and overall plant abundance in hedgerows compared to unplanted margins of vegetable fields.

Birds of open habitats (2 studies):

A before-and-after study from the USA (Maryland) found increased abundance of northern bobwhites following planting of hedges on a livestock farm.

A before-and-after study from the USA (Wisconsin) found decreased occurrence of male greater prairie chickens following planting of shelterbelts in a shrubland.

Soil life (3 studies):

A replicated study from Slovakia found increased diversity of oribatid mites near hedgerows compared to within corn fields. A review from sub-Saharan Africa reported increased activity of soil animals with alley cropping.

A replicated, randomized, and controlled study from Canada found inconsistent effects of tree intercropping, compared to conventional cropping, on diversity of arbuscular mycorrhizal fungi in cereal-legume fields, where number of phylotypes was greater with tree intercropping but species richness did not differ between treatments.

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The same study from Canada as above found no difference in activity of arbuscular mycorrhizal fungi in tree intercropped compared to conventionally cropped cereal-legume fields.

Beneficial insects (18 studies):

Two replicated studies (one randomized and controlled) from Kenya and the UK found increased abundance of spiders and wasps with alley cropping compared to conventional cropping in cereal and legume fields, and increased abundance and diversity of beetles (including rove beetles) and spiders in hedgerows compared to field margins. A replicated before-and-after study from the USA (California) found increased occurrence of bees and syrphid flies with planting of hedgerows along row crop fields, vineyards, and orchards, with greater occurrence of specialist bees and all flies in mature vs. recently established hedgerows. A study from France found greater abundance of a predatory ground beetle species and greater ground beetle diversity in a hedgerow than in the adjacent cereal crop field. Seven replicated site comparisons from the USA (California) found greater abundance and/or diversity of bees (including native bees, honey bees, and sunflower-specialist bees), syrphid flies, and/or parasitoids, and a higher ratio of natural enemies to pests, in hedgerows compared to unplanted field margins, and greater abundance and/or diversity of bees (including native bees and honey bees), invertebrate predators, and/or parasitoids in edges of fields with hedgerows compared to fields with unplanted margins of mixed cropland, vegetable, and sunflower fields. A review found two studies reporting greater abundance of ground beetles in recently established, compared to mature, hedgerows.

A replicated, randomized, controlled study from China found inconsistent effects of hedgerows on abundance of spiders in wheat and maize fields, where greater spider abundance was found in plots with hedgerows compared to plots without only in some years and for some species of hedge plants. A site comparison from Germany found presence of hedgerows near arable fields promoted dispersal of two of 85 ground beetle species sampled. Two replicated site comparisons from the USA (California) found bee species composition differed in hedgerows compared to unplanted margins, with many bee species only found in hedgerows and few bee species only found in unplanted margins.

A replicated, randomized, controlled study from Kenya found lower abundance of ladybirds with alley cropping compared to conventional cropping in cereal and legume fields. Two replicated site comparisons from the USA (California) found lower abundance of generalist bees and ground-nesting bees in hedgerows than unplanted margins of sunflower fields.

A replicated, randomized, controlled study from Kenya found no difference in abundance of green lacewings with alley cropping compared to conventional cropping of cereal fields. A study from France found no difference in abundance of many ground beetle species in a hedgerow compared to the adjacent cereal crop field. A replicated before-and-after study from the USA (California) found no difference in occurrence of generalist bees in mature vs. recently established hedgerows along row crop fields, vineyards, and orchards. Five replicated site comparisons from the USA (California) found no difference in abundance of invertebrate predators and flower-visiting bees, ratio of natural enemies to pests, and diversity of syrphid flies and bees in hedgerows compared to unplanted margins of vegetable fields, and no difference in abundance of syrphid flies, honey bees, and total flower visitors in vegetable fields with hedgerows compared to fields with unplanted margins. A site comparison from Germany found no effect of hedgerows near arable fields on dispersal of ground beetles and harvestmen.

Supporting evidence from individual studies

1. **Open habitat birds:** A small 1967 before-and-after study on a 1,214 ha farm in Maryland, USA, found that after the introduction in 1957 of a number of management interventions, including planting 11.4 miles of new hedges, the number of coveys of northern bobwhites *Colinus virginianus* increased from five coveys identified in the winter of 1956/1957 to 38 in the winter of 1964/1965. Although this study does not isolate the effect of the individual interventions made, it is noted that 14 of 33 new coveys were located in multi-flora hedges planted during the eight years of management interventions. **Methods:** Interventions included planting shrub lespedeza *Lespedeza thunbergii* and sericea lespedeza *Lespedeza cuneata* strips, seeding 20 ha of grassland, and limiting livestock grazing. Sightings of coveys were reported by farm employees and hunting parties during each winter from 1956–1965.

2. **Beneficial insects:** An unreplicated site comparison study from 1982–1991 in western Germany (same study as Gruttke & Willecke 2000) found that only two ground beetle (Carabidae) species (out of 85 sampled) used a sequence of young hedge plantations as stepping stones for their dispersal. Two forest or forest-edge ground beetle species, present in nearby semi-natural habitat, gradually appeared along a meadow and hedge strip over the nine years following hedge planting (1982 to 1990). Twenty-five ground beetle species from the semi-natural habitat showed no tendency to use the hedge plantations as stepping stones. **Methods:** In 1982, nine small hedge islands (each 400 m^2) were planted at intervals along a 10 m-wide meadow strip, attached at one end to mixed wooded and open semi-natural habitats (woods, hedge fragments, ponds surrounded by small reeds, wet and dry meadows), and extending 1.6 km into arable fields. Ground beetles were sampled using six pitfall traps/section in hedge islands and meadow strips from 1982–1990. Semi-natural habitats and adjacent arable fields were sampled from 1990–1991.

3. **Beneficial insects:** A small-scale study in 1996 in France found that ground beetle (Carabidae) diversity declined with distance from a newly planted hedge in intensive arable farmland. Rare ground beetle species decreased with distance from the hedge: higher numbers of a predatory ground beetle *Pterostichus cupreus* were found in the hedge (273 catches/trap) than 10 m and 110 m into the adjacent barley *Hordeum vulgare* crop (23 catches). Other ground beetle (Carabidae) species, including the most abundant species *Pterostichus melanarius*, had similar numbers or were only slightly more numerous in the hedge than the crop. **Methods:** The hedge was planted in 1995 and comprised two 200 m sections of shrubs divided by a 100 m section of mixed fodder crop (oats *Avena sativa* and cabbages *Brassica oleracea*). It was separated from the adjacent barley crop by a 9 m-wide zone planted with oats and sorghum *Sorghum bicolor*. Ground beetles were sampled using pitfall traps in the hedge (15 traps) and at intervals between 10–110 m from the centre of the hedge in the adjacent crop (four traps at each of five distances). Traps were emptied every 2–4 weeks (April to mid-October 1996). Fenced pitfall traps (12 in the hedge and three 110 m into the crop) were used to estimate absolute densities and were emptied every day for eight days in June 1996.

4. **Beneficial insects:** A 1999 review of literature found two unpublished studies showing that newly planted hedges supported field species of ground beetle (Carabidae). In one study, the youngest hedge, three years old, had more ground beetles than 5-, 9- or 40-year old hedges. Another study in Germany (and summarized above) showed that newly planted hedges linking patches of semi-natural habitat were not used as corridors by forest or openland ground beetle species (Gruttke 1994).

5. **Beneficial insects:** The same unreplicated site comparison study as Gruttke 1994, between 1982 and 1998 found marked differences in the effectiveness of the hedge-island and meadow habitat strip as a dispersal corridor for four invertebrate taxa: ground

beetles (Carabidae), harvestmen (Opiliones), and spiders (Araneae). Nine years after planting, the hedge-island and meadow strip did not (or not yet) function well as a dispersal corridor for ground beetles or harvestmen. Spiders had a high proportion of immigrating species, but many of them were not present in the source habitat and may have passively 'ballooned' in from the surrounding area, rather than using the strip as a dispersal corridor. The authors conclude that while the hedge islands appear to be working as stepping stones for species able to travel passively, this is not true for actively moving invertebrates, such as ground beetles or harvestmen, perhaps because of the age, size or connectedness of hedge islands at the time of study. **Methods:** In addition to the sampling regime described in Gruttke 1994, invertebrates were sampled from the surrounding area in 1992–1994 and 1997–1998. Spiders, harvestmen and ground beetles were sampled using pitfall traps (in 1984, 1987 and 1990). Results for snails are not presented here.

6. **Beneficial insects:** A replicated study in winter 2002 in Oxfordshire, UK, found that the total abundance, species richness and diversity of beetles (Coleoptera) and spiders (Araneae), as well as abundance and species richness of rove beetles (Staphylinidae) was higher in hedge bases than in field margins, but there was no difference between recently planted (2–5 years old) and mature hedgerows (40–60 years old). **Grassland plants:** Grass cover was lower, but the number of grass species higher, in the bases of recently established hedgerows compared with recently sown grass margins (3–4 years old). The diversity of vascular plant species was greater in recently established and mature hedgerows, as well as mature field margins (ca. 50 years old), compared with recently sown grass margins. The bases of recently planted hedgerows had fewer vascular plant species and lower cover of tall perennial wildflowers and mosses compared with mature field margins. **Methods:** Five geographically separate replicates of each of the four habitats were sampled for beetles and spiders in February 2002 by taking 12 soil core samples in a 70 m-long sampling section. Percentage cover of vascular plant species, moss and bare ground was estimated, and biomass (dry matter) and organic carbon content were measured.

7. **Beneficial insects:** A randomised, replicated, controlled trial in 1995–1996 in Machakos, Kenya, found more wasps (Hymenoptera) (65 vs. 45) and spiders (Araneae) (96 vs. 71) but fewer ladybirds (Coccinellidae) (14 vs. 23) in alley cropped plots compared to conventional plots. **Methods:** Hedges were planted 8 m upslope of 10 x 10 m plots in 1993 using nine tree/shrub species (calliandra *Calliandra calothyrsus*, croton *Croton megalocarpus*, flemingea *Flemingia macrophylla*, gliricidia *Gliricidia sepium*, grevillea *Grevillea robusta*, lantana *Lantana camara*, mulberry *Morus alba*, siamea *Senna siamea*, and spectabilis *Senna spectabilis*) and pruned to 0.5 m. Beans were grown in the short- and maize in the long-rain season. There were four replicates/hedge species (alley cropping was replicated 36 times total) and four replicates of conventional cropping. Two yellow pan traps and two pitfall traps were placed in each plot (one of each near the hedge, one of each 4 m away) and monitored every 10 days. Results for crop pests and hedge species effects are not presented here.

8. **Beneficial insects:** A randomised, replicated, controlled study in 2005–2007 in Sichuan, China, found similar activity densities of ground-dwelling spiders (Araneae) in plots with hedges (averaging 123–212 captures/three pitfall traps) and control plots without hedges (118–208 captures). Differences in spider densities between hedges and adjacent crops (within plots) varied between years, crops and hedge types. All hedges had higher spider densities than wheat *Triticum* sp. (averaging 26–52 vs. 16–20 captures/three traps) in 2005–2006, but in 2006–2007 only sabaigrass and alfalfa hedges had higher densities (34–46 captures) than adjacent wheat (16–17 captures). Sabaigrass and alfalfa hedges had higher spider densities (35–46 captures) than maize *Zea mays* (21–23 captures) in 2006, but hedges had similar densities to maize in 2007. **Methods:** Vetiver *Vetiveria zizanioides* hedges, false indigo-bush *Amorpha fruticosa* hedges and

bare control strips were tested in one field and sabaigrass *Eulaliopsis binate* hedges, alfalfa *Medicago sativa* hedges and control strips were tested in another. Fields were divided into 7 x 6.5 m plots with each treatment replicated three times. Hedge species effects are not presented here.

9. **Soil life:** A 1997 review of case studies in sub-Saharan Africa gathered from published literature reported that woody species in alley cropping systems can encourage soil animal activity. Legume species suitable for alley cropping include: gliricidia *Gliricidia sepium*, Leucaena *Leucaena leucocephala*, pigeon pea *Cajanus cajan*, calliandra *Calliandra calothyrsus*, mountain immortelle *Erythrina poeppigiana*, apa apa *Flemingia macrophylla*, and Christ thorn *Dactyladenia barteri*. In alley cropping multipurpose trees and shrubs and food crops are intercropped (two or more crops grown between the rows of another). Results for soil nutrients and stability and crop yield are not presented here.

10. **Soil life:** A replicated study in 1996 on alluvial soils near to the Ondava River, Slovakia, showed that soil conditions close to or beneath uncultivated field margins (willow *Salix alba* hedgerows) can be beneficial for oribatid mite (mites which live in the topsoil) diversity. The willow hedgerow was found to have greater diversity than the other four sampled transect sites. **Methods:** Sampling was carried out along a transect incorporating a range of habitats over 212 m, in a corn *Zea mays* field. At each site, eight soil samples were collected from random locations within a 9 m^2 plot, at 12 weekly intervals. The sampling sites along the transect were: willow hedgerow, corn field, depression in field, followed by two more sites located further into the corn field.

11. **Beneficial insects:** A replicated, paired, site comparison in 1999–2000 in mixed cropland in Yolo County, California, USA, found more natural enemies than pests in hedgerow shrubs, and more pests than natural enemies in weedy field edges. On hedgerow shrubs, natural enemies were more abundant than pests (1–3 vs 0.2–1.0 insects/m^2). In weedy edges, pests were more abundant than natural enemies in summer (15 vs. 8 insects/sample), but were not significantly different in spring (6 vs. 4) or fall (9 vs. 4). A higher proportion of insects were natural enemies in hedgerow shrubs than in weedy edges (0.81–0.88 vs 0.32–0.46). **Methods:** On the edges of four crop fields, native shrubs (hedgerow shrubs), bordered by native grasses (hedgerow grasses), were planted in 1996 (305–550 m), and compared to the weedy edges of the same fields every two weeks in March–November 1999–2000. Insects were observed on hedgerow shrubs (four minutes/shrub species), collected from shrubs by shaking, and collected from hedgerow grasses and weedy edges with sweep nets (10 sweeps/sample; four samples each).

12. **Beneficial insects:** A replicated site comparison in 2005–2006 on organic vegetable farms on the Central Coast, California, USA, found similar ratios of natural enemies to pests in hedgerows compared to weedy edges, and in fields with hedgerows compared to fields with weedy edges. The ratio of natural enemies to pests (2005: 11:1 enemies:pests; 2006: 15:1) was not significantly different between fields with hedgerows and fields with weedy edges, either at the edge (30:1 vs. 6:1 enemies:pests), or 50–100 m into the field (3:1 enemies:pests). **Methods:** Two fields with hedgerows (>2 years old, toyon *Heteromeles arbutifolia* or coyote bush *Baccharis pilularis*) and two fields with weedy edges were compared. Insects were sampled using yellow sticky cards (2005: five cards each at 0, 50, and 100 m into fields, collected after three days) and vacuums (2005: 30 seconds/plant in hedgerows; 2006: 60 seconds/plant). Hedge species effects are not presented here.

13. **Beneficial insects:** A replicated, paired, site comparison in May–August 2009–2010 in tomato fields in the Sacramento Valley, California, USA, found more natural enemies in fields or field edges with planted hedgerows, compared to fields or field edges without hedgerows. In sweep-net samples, more parasitoids (6 vs. 2 individuals/sample) but similar numbers of predators (6 vs. 6) were found in hedgerows compared to weedy

edges. In shake samples, more predators (10 m: 0.25 vs. 0.05 individuals/sample; 100 m: 0.15 vs. 0.05; 200 m: 0.30 vs. 0) were found in fields with hedgerows than in fields with weedy edges. In sticky-card samples, more parasitoids, but not more predators, were found in hedgerows than in weedy edges; more parasitoids were found in fields with hedgerows than in fields with weedy edges, up to 100 m into the crop (number of individuals not reported). **Methods:** Native perennial shrubs (305–550 x 7 m), bordered by native perennial grasses (3 m), were planted in 1996–2003 on the edges of six fields (hedgerows) and compared to the unplanted edges of six fields (weedy edges). Invertebrates were sampled four times/year using sweep nets (40 cm diameter; six sweeps/edge) and sticky cards (7.6 × 12.7 cm; six cards/edge and six cards/crop), and by shaking plants (late May only). Results for crop pests are not presented here.

14. A replicated, paired, site comparison in May–August 2009–2010 in tomato fields in the Sacramento Valley, California, USA, found more individuals and species of flower-visiting bees and syrphid flies in hedgerows than in weedy field edges, and more individuals and species of bees but not syrphid flies in fields with hedgerows than in fields with weedy edges. Similar numbers of flower species and similar amounts of plant cover were found in planted hedgerows and unplanted field edges. **Beneficial insects:** More individuals (10 m: 1.2 vs. 0.3 individuals/sample; 100 m: 0.8 vs. 0.3; 200 m: 0.5 vs. 0.2) and more species (10 m: 0.63 vs. 0.25 species/sample; 100 m: 0.54 vs. 0.22; 200 m: 0.39 vs. 0.16) of native bees were found 10–100 m, but not 200 m, into fields with hedgerows than in fields with weedy edges. More honey bees were found 10 m into fields with hedgerows, but there was not a significant difference between these fields in honey bees or syrphid flies at greater distances (honey bees: 10 m: 0.50 vs. 0.14 individuals/sample; 100 m: 0.13 vs. 0.04; 200 m: 0.20 vs. 0.17; syrphid flies: 10 m: 0.63 vs. 0.60; 100 m: 0.50 vs. 0.67; 200 m: 0.20 vs. 0.56). Flower-visitor communities had more species and greater diversity in hedgerows than in weedy edges (bees: 5.7 vs. 3.6 species; syrphid flies: 2.7 vs. 1.8 species). Twenty bee species were found only in hedgerows, not in weedy edges. Uncommon bee species (species represented by <1% of collected individuals) had larger populations in hedgerows than in weedy edges (6 vs. 1 individuals), but uncommon syrphid fly species did not (numbers not reported). Honey bee, native bee, and syrphid fly species had larger populations in hedgerows than in weedy edges (numbers of individuals not reported). **Grassland plants:** The number of flower species and the amount of bare ground did not differ significantly between hedgerows and weedy edges (6 vs. 4 species; amount of bare ground not reported), but floral cover was higher and there was more dead wood in hedgerows (amounts not reported). **Methods:** Native perennial shrubs (305–550 x 7 m), bordered by native perennial grasses (3 m), were planted in 1996–2003 on the edges of six fields (hedgerows) and compared to the unplanted edges of six fields (weedy edges). Insects were netted if they touched the reproductive parts of flowers (in field borders) or they were identified landing on flowers or flying through quadrats (1 m^3 quadrats; four minutes/quadrat; three quadrats/field-edge; six quadrats/field).

15. **Beneficial insects:** A replicated, before-and-after study in April–August of 2006–2013 in field borders in the Central Valley, California, USA (same study as M'Gonigle *et al.* 2015), found that flower-visiting insect species were more likely to be present after woody hedgerows were planted than before. Insects that specialize in relatively few flower species (specialists) were more likely to be present six years after planting, compared to the first year after planting (bee species: 0.3 vs. 0.0 probability of occurrence/transect; syrphid fly species: 0.1 vs. 0.02), and so were generalist syrphid fly species, but not generalist bee species (syrphid fly species: 0.12 vs. 0.07; bee species: 0.2 vs. 0.2). **Methods:** Field borders (350 x 3–6 m) were planted with native shrubs and trees in 2007–2008 in five fields, and unplanted borders in ten fields were used as controls. Fields borders had an irrigation ditch or slough. Fields were approximately 80 acres of row crops, vineyards, or orchards. Hedgerows were watered and weeded for three years. At least three times per year, insects were collected from flowers on one-

hour transects at each site.

16. **Beneficial insects:** A replicated site comparison in April–August of 2006–2013 in field borders in the Central Valley, California, USA (same study as Kremen & M'Gonigle 2015), found more species of bees and syrphid flies in planted hedgerows than in unplanted field borders, but only after several years of hedgerow growth. More species of bees and syrphid flies were estimated to be present in planted hedgerows than in unplanted field borders, 4–6 years after planting (2013: 65 vs. 45 species; 2012: 60 vs. 40; 2011: 55 vs. 40), but not 0–3 years after planting (2010: 50 vs. 40 species; 2009–2008: 45 vs. 40; 2007: 35 vs. 35). **Methods:** Field borders (350 x 3–6 m) were planted with native shrubs and trees in 2007–2008 in five fields, and unplanted borders in ten fields were used as controls. Fields borders had an irrigation ditch or slough. Fields were approximately 80 acres of row crops, vineyards, or orchards. Hedgerows were watered and weeded for three years. At least three times per year, insects were collected from flowers on one-hour transects at each site.

17. **Beneficial insects:** A replicated site comparison in 2007–2013 in farmland in the Central Valley, California, USA, found greater bee diversity in mature hedgerows compared to weedy field edges or immature ("maturing") hedgerows. Greater bee diversity was found in mature hedgerows compared to weedy field margins or immature hedgerows, but not in immature hedgerows compared to weedy field margins (data was reported as beta-diversity, which is change in the diversity of species between sites). Twenty-eight percent of bee species were found only in hedgerows. Thirteen percent were found only in weedy edges. **Methods:** Native, perennial shrubs and trees (3–6 x 350 m) were planted 1–10 years (immature hedgerows) or >10 years (mature hedgerows) before bees were collected. Bees were collected if they touched the reproductive parts of flowers, in one-hour samples of 21 hedgerows and 24 weedy edges, 2–5 times/year, in April–August 2007–2013.

18. **Beneficial insects:** A replicated, paired site comparison in 2012–2013 in sunflower fields in the Central Valley, California, USA, found more bees, more sunflower-specialist bees, fewer generalist bees, and more bee species in hedgerows than in bare/weedy edges. Bee abundance and species richness were higher in hedgerows than in bare/weedy edges (abundance: 17 vs. 6 individuals/sample; richness: 5 vs. 2 species/sample). More sunflower-specialist bees, but fewer generalist bees, were found in hedgerows than in bare/weedy edges (specialists: 0.6 vs. 0.1 relative abundance; generalists: 0.0 vs. 0.3). **Methods:** In field edges, when >90% of sunflower heads were blooming in adjacent fields, bees were netted for 16 minutes/field (2012: 10 fields; 2013: 8 fields), and bees that touched the reproductive parts of flowers were counted for 2 minutes/plot in 8 plots/field (visitation rates). Half of fields had bare/weedy edges (managed by burning, scraping, or herbicides). Half had hedge rows (3–6 x 250–300 m, 5–12 years old). Sunflower specialists and generalists were netted in 26 hedgerows and 21 bare/weedy edges (one hour/sample; five samples in April–August 2012–2013).

19. **Beneficial insects:** A replicated, paired site comparison in 2009–2011 in tomato fields in Yolo County, California, USA, found more native bees in fields next to planted hedgerows, compared to fields next to conventional edges. More native bees were found on canola flowers in fields next to hedgerows, compared to fields next to unplanted edges (4.2 vs. 1.0 visitors/observation), but similar numbers of honey bees (1.4 vs. 2.6), syrphid flies (2.9 vs. 3.5), or total visitors (8.4 vs. 7.1) were found. **Methods:** Hedgerows (300–350 m length) were planted along the edges of four treatment fields, but not four control fields, about 10 years before this study began. The edges of control fields were mown, disced, or sprayed with herbicide. Tomatoes were grown in all fields, but pollination was measured in clusters of potted canola plants, placed at four distances from the edges (0, 10, 100, and 200 m), in 2010 and 2011. Flower visitors were observed for four minutes/cluster (one observation period in 2010 and four in 2011).

Results for pollination deficits are not presented here.

20. **Beneficial insects:** A replicated site comparison in farmland in the Central Valley, California, USA (years of study not reported), found fewer ground-nesting bees in planted hedgerows, compared to unplanted field edges. Fewer ground-nesting bees were found in planted hedgerows, compared to unplanted edges (13 vs. 33 individuals/site), but there were similar numbers of flower-visiting bees (data reported as statistical results), and similar numbers of bee species (2.9 vs. 3.2 rarified species richness). Indicators of ground-nesting bee habitat did not differ between planted hedgerows and unplanted edges (data on bare ground, soil compaction, particle size, and surface heterogeneity reported as statistical results). **Methods:** Eight field edges with planted hedgerows (mostly Californian native shrubs and forbs, at least five years after planting) were compared to eight field edges without planted hedgerows. Ground-nesting bees were sampled with emergence traps (0.6 m^2, 30 traps/site/sample, three samples in two years, in May–August). Foraging bees were netted on inflorescences (one hour/site/sample, within 10 days of emergence samples). Nesting indicators were assessed using soil samples (0–10 cm depth, two samples/site) and visual estimates.

21. **Open habitat birds:** A before-and-after study in shrubland in 1962–1964 in Wisconsin, USA, found that the erection of a windbreak of 4 m high pines *Pinus* spp. appeared to disrupt lekking behaviour in male greater prairie chickens *Tympanuchus cupido*, with several males vacating their territories after trees were erected nearby.

22. **Beneficial insects:** A randomised, replicated, controlled trial in 1992–1995 at two sites in Kenya found that alley cropping had no effect on natural enemies of the pest maize stem borer *Chilo partellus* in maize *Zea mays* plots. Green lacewing *Chrysopa* spp. (natural enemy) egg abundance was similar between treatments. Hedgerow spacing (width of alleys) had mixed effects. **Methods:** White leadtree *Leucaena leucocephala* hedgerows were established in 1992 and were 1.5 m (two plots), 2.25 m (six plots) or 3 m (two plots) apart with one, two or three maize rows between hedges, respectively. One plot per site was maize-only. Hedges were cut before cropping and the cuttings were mulched. Plots were 18 x 12 m (five replicates) or 12 x 10 m (four replicates). Results for parasitism and predation of pests are not presented here.

23. **Grassland plants:** A randomised, replicated, controlled trial in 1987–1988 at two sites in Mindinao, Philippines, found that the weight of grass and broadleaved weeds averaged 3.4–86.1 g/m² and 0.7–51.3 g/m², respectively, in alley cropped plots of rice *Oryza sativa* compared to 1.2–16.4 g/m² and 2.6–35.6 g/m² in conventional plots. Grass weight was greater in alley cropped plots than controls at a site with low soil fertility and high erosion. **Methods:** Rice was planted in alleys between gliricidia *Gliricidia sepium* and cassia *Cassia spectabilis* hedgerows. Hedgerows followed contour lines and were spaced 3–6 m apart. Twenty-four alley crop plots (across two 0.6 ha sites) were compared with two plots receiving conventional farmers' practice. Alley crop plots (grouped in this summary) comprised mulched, green manured, mulched and green manured, or non-amended treatments. Results for crop pests and damage are not presented here.

24. **Soil life:** A randomized, controlled, replicated study in 2008 on sandy-loam soil in Ontario, Canada, found a greater diversity of arbuscular mycorrhizal fungi (AMF) under tree-based intercropping (6 phylotypes) compared with conventional cropping (4.7 phylotypes). Colonization of corn *Zea mays* roots was greater than 50% in both intercropped and conventional treatments, and AMF richness was similar in both treatments. Different tree species supported distinctive AMF communities. **Methods:** Trees were intercropped annually with corn, soybean *Glycine max*, winter wheat *Triticum aestivum* or barley *Hordeum vulgare* using no-till cultivation. The tree rows accounted for 16% of the crop area and were spaced 12.5–15 m apart. Tree species included silver maple *Acer saccharinum*, white ash *Fraxinum americana*, hazelnut *Corylus avellana*,

black walnut *Juglans nigra*, Norway spruce *Picea abies*, hybrid poplar *Populus deltoides*, red oak *Quercus rubra*, black locust *Robinia pseudoacacia*, willow *Salix discolor* and white cedar *Thuja occidentalis*.

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