Biodiversity and Agricultural Production Practices Toolkit

Presented to the Steering Committee for the Indicator of the Impact of Production Systems on Biodiversity Project

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1. Introduction

Commercial buyers of agricultural commodities are increasingly interested to ensure that their products are sourced in a way that has positive or at least neutral impacts on wild biodiversity (populations of both plants and animals) and on agrobiodiversity (agricultural species and varieties, and associated soil flora and fauna, pollinators and other.[1] Buyers must be able both to determine threats to biodiversity from agricultural systems and practices, and—where threats do exist and can potentially be mitigated—to engage with producers to address them.

This document serves as a guide to considering possibilities for sourcing agricultural raw materials from systems of agriculture that are well-managed to promote wild biodiversity and agrobiodiversity, and realize the many benefits that such systems generate.

Sustaining habitats for biodiversity in agricultural landscapes: Key principles

Modern commercial agricultural systems typically sought to minimize non-productive species in and around production areas, and also to simplify agroecosystems to focus on immediate benefits for the priority crop or product. By contrast, sustaining viable populations of wild plants and animals requires that their habitats contain all of the key features they need—year-round access to water and to food/nutrients, protection from predators and pests, access to tracks of seasonable movement, areas to nest, pollinators, and to species with which they have symbiotic relationships.

Thus, more biodiversity-friendly agriculture (sometimes called natural systems agriculture) requires building on concepts of heterogeneity and ecological resilience (Malézieux, 2012). Systems are developed that mimic habitat conditions and the properties of complex natural ecosystems such as pest control, nutrient cycling, carbon sequestration, and drought resistance on a self-sustaining basis (Daily, 2012; Naylor & Ehrlich, 2012). Mimicking natural ecosystems offers a framework for reducing external inputs and managing interactions among components of the production system to realize resilience and ecological sustainability benefits as well as profitable outputs (Lefroy *et al*, 1999). For example, perennial crops can mimic the features of natural grasslands and forests (Jackson, 2002).

In circumstances where the native ecosystem is grasslands and prairies, the environment is often prone to drought (Malézieux, 2012). Large-scale agriculture in this setting often requires high inputs of water and other amendments. The alternative of mimicking the plant biodiversity present in natural grasslands contributes significantly to the development of drought-resistant systems. Diverse mixtures of native plants and polycultures of cereals and grains that are well-

[1] The term biodiversity refers to the variety and variability of life on Earth; the totality of genes, species and ecosystems of a region. Agrobiodiversity, often called agricultural biodiversity, is the subset of biodiversity that encompasses the variety and variability of animals, plants and micro-organisms which are necessary to sustain key functions of the agroecosystem, its structure and processes for, and in support of, food production and food security". Wild biodiversity generally refers to all forms of life encountered in natural, rather than human-dominated habitats.

adapted to these types of stressors create managed systems that are self-sustaining through seasons of little water. Rather than isolated swaths of one crop distinguished from another, integrated systems have heightened resiliency.

Incorporating native perennial species into agricultural plans also heightens ecosystem stability. Landscapes that include a diversity of native grassland perennials – like grasses, legumes, trees, and shrubs – cultivate a sustainable resiliency mechanism that improves soil structure and decreases the vulnerability of agricultural systems to a variety of threats (McNeely and Scherr, 2002).

Benefits to soil health are a primary concern. In conventional agricultural strategies, large-scale deforestation and intensive tilling result in dramatic erosion of topsoil, and harsh soil additives introduce detrimental chemicals to the natural soil biome, further impairing soil health (Jackson, 2002). Specific practices that are often associated with intensive conventional agriculture, like tillage and mono-cropping, are detrimental to soil health by constraining the landscape's natural ability to resist erosion and sequester carbon (Blanco-Canqui & Lal, 2010).

Natural ecosystems are mixed landscapes of a diversity of flora and fauna that support soil health in a great variety of ways. Thus a key feature to consider is species and varietal diversity of agricultural species, as well as diversity of wild species, ecological communities and at the larger landscape scale. The challenge is in moving towards such models in ways that continue to sustain production levels and quality required for commercial viability.

As presented by the Rural Industries Research and Development Corporation, eight steps are required to move from an existing intensive managed system to a system modeled after a naturally functioning system (E. Lefroy & Hobbs, 1997). From the report, "Agriculture as a Mimic of Natural Systems", these steps are as follows:

1. Identify the system functions [e.g., wildlife habitat conditions] which are currently suboptimal in the managed system.
2. Identify the suite of species [in soils, fauna, flora] which carry out these functions in the natural ecosystem.
3. Within this suite of species, identify those with key functional roles, or identify analogs of these, i.e. well adapted species from elsewhere with these same functional roles.
4. Identify the likely range of environmental conditions and disturbances, and select the array of species needed to confer system resilience.
5. Consider how many of these species are required for the managed system, in the context of trading-off environmental risks versus long and short term costs and benefits. For instance, is it essential to install the full suite of species immediately, or can a phased approach be employed?
6. Decide whether it is most appropriate to integrate or segregate these functions with production; that is to have diversity at field or landscape scales or a mixture of both.
7. Assemble the suite of species required to achieve functional objectives within an adoption framework that a) has clear links to end users and b) demonstrates economic

viability and/or c) includes socio-economic instruments to facilitate implementation including incentives such as carbon tax trading.

8. Develop these systems in an adaptive management framework involving monitoring and the capacity to modify elements of the design as new information becomes available or as circumstances change.

Biodiversity-friendly agricultural practices

Important categories of biodiversity-friendly production practices that prove especially beneficial in promoting and restoring both wild biodiversity and agrobiodiversity, and that also foster the production of crops and livestock on a sustainable basis, include those listed below. Many of these types of production systems intersect and overlap. Thus, management practices that comprise them can be selected and combined to best address the conditions and goals of particular farms and landscapes, and to help realize the optimal management strategy for the landscape.

- Crop rotation and cover cropping
- Reduced tillage
- Integrated Pest Management
- Organic crop management
- Biodiversity-friendly pasture and livestock management
- Agroforestry and ecological forest plantation management
- Corridors (hedgerows and riparian buffers)
- Natural habitats
- Integrated agricultural landscape management

These and related systems of agricultural practice can be especially valuable building blocks for bringing about biodiversity-friendly landscapes (Landis, 2017).

Benefits of biodiversity

Production practices that improve biodiversity or reduce the negative impacts on biodiversity of producing crops and livestock are becoming more widely familiar and better understood as technically feasible, economically viable, socially acceptable and ecologically sustainable options in agriculture. Evidence is growing that agricultural management practices that benefit biodiversity also improve both the yield and the quality of the crops and livestock produced. Many such practices are associated with sustainable intensification strategies of agricultural development. Through sustainable intensification, agricultural yields are increased without adverse environmental impact and without the conversion of additional non-agricultural land (Pretty and Bharucha, 2014; Garbach, *et al*, 2016).

Furthermore, as agricultural biodiversity increases, invaluable benefits to farmers and the larger society are generated including soil erosion control, pest and disease control, pollination, soil quality, crop yields, and landscape resilience in addition to the conservation of wild biodiversity

(Bioversity International, 2017). Sustaining biodiversity can also enhance important ecosystem services-- such as water flow and quality, greenhouse gas emissions reduction or sequestration, modulation of microclimates, human health, human habitat and culture--for communities in the farming region, the larger landscape and society.

Organization of the Toolkit

The toolkit is designed to take the user through a process of inquiry concerning the production and resource management practices that are currently in place, and that potentially could be put in place, to ensure that a company's product sourcing strategy promotes biodiversity-friendly farms and landscapes.

The toolkit is divided into nine sections, each covering a set of practices. The first sections discuss how to enhance biodiversity in cultivated annual crops; then in pastures and livestock systems, agroforestry and forest plantations; then in non-cultivated areas in the farm; and finally how to link these practices to achieve thriving biodiversity in the whole landscape.

The first part of each section comprises a series of questions concerning the types of agricultural management systems that are known or believed to be in place in the region where new or expanded commodity procurement is being considered. These "decision trees" are followed by descriptions and discussions of the production practices concerned, and offer evidence about biodiversity and related benefits. The sub-sections on Tools to Guide Implementation provide links to guidance documents that will assist the user in determining how to initiate and manage each production system. Used together, these related parts of the toolkit will inform the user about how biodiversity-friendly their prospective sourcing strategy for a particular location appears to be, and provide ideas and information about ways that it could be improved through the application of the practices described.

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2. Crop Rotation and Cover Cropping

1. Does the farm have a plan for crop rotation that extends for several years into the future?

   ☐Yes ☐ No

2. Does the crop rotation plan include cover crops?

   ☐Yes ☐ No

3. Has the farm created a plan to reduce their reliance on synthetic (chemical, non-organic) pesticides?

   ☐ Yes ☐No

4. Does the plan include at least one of the integrated pest management (IPM) practices that are known to be generally effective (ex. seedbed sanitation, push-pull, controlled spraying)?

   ☐ Yes ☐No

If **YES** to all of the questions above, proceed to implement the plan.

If **NO** to any of the questions above, we recommend that farmers revise the partial plan to create an inclusive crop rotation plan for a 4- year period into the future (to line up with other plan recommendations including IPM and reduced tillage). See the Crop Rotation and Cover Cropping section below for guidance..

Overview of Crop Rotation and Cover Cropping

Conventional cropping systems, which plant the same crop in the same place continuously, result in degraded soil quality and require increasing inputs as compared with systems that implement rotations (Forcella et. al., 1996). In a cover-cropping system, a placeholder plant that is not necessarily harvested and sold but which has ecological benefits (SARE, 2017) is planted alongside the crop that will be harvested. This system is also sometimes referred to as ‘intercropping’. Some documented benefits of cover crops are nitrogen fixation, increased organic matter, weed suppression, pest life cycle disruption, and prevention of soil erosion (Snapp et. al. 2005).

Cover crop options vary widely and should be selected to suit the farmer's needs and the local context, but nearly every farmer can benefit from some sort of cover crop. Below is a chart provided by the USDA of potential cover crop options and their benefits. Also included is a chart specific to the tropics provided by ECHO. This list is not exhaustive and farmers may opt to use a local plant or one which is not included in these lists as a cover crop, so long as it provides an ecological benefit to the farm and supports their farm's crop rotation plan.

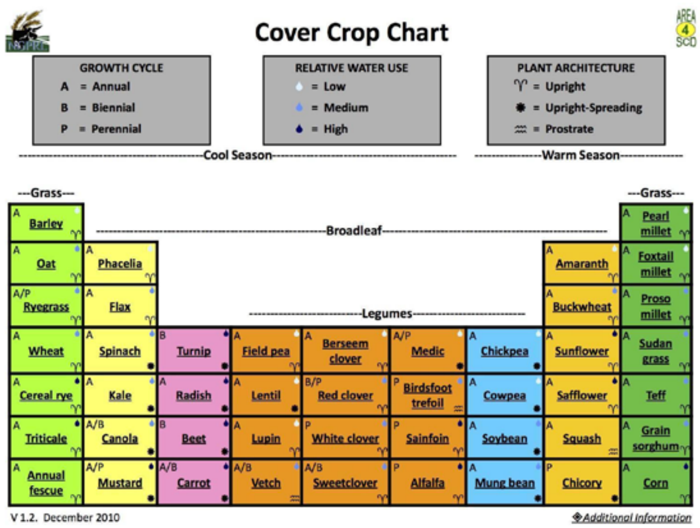

Figure 1 (USDA 2015)

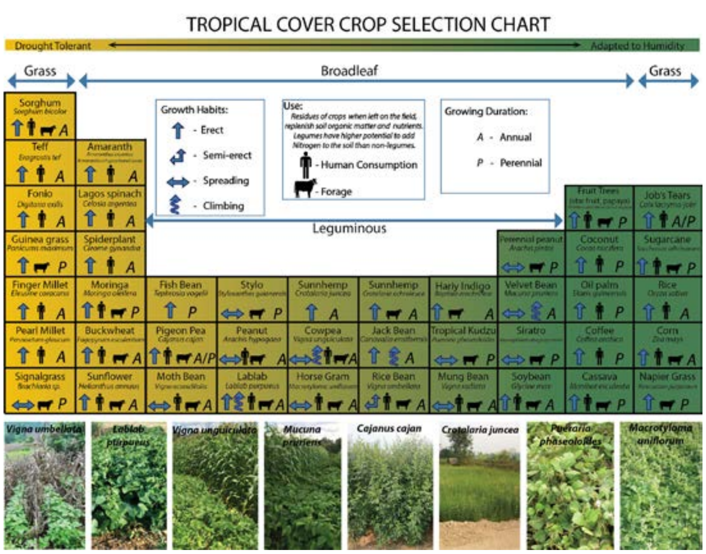

Figure 2 (ECHO Community, 2017)

Farmers Should Create and Implement a Multi-Year Crop Rotation Plan

The crop rotation plan that the farmer submits should be comprehensive and explanatory, meaning that it should outline what is being planted, when it will be planted, and where it will be planted as well as explaining the reasoning behind each decision. A multi-year crop rotation plan is important for promoting soil health and improving biodiversity on the farm. Therefore farmers should create and implement a plan for rotating which crops are planted on any given site at least 4 years into the future. Below is a simplified schematic of crop rotations in general.

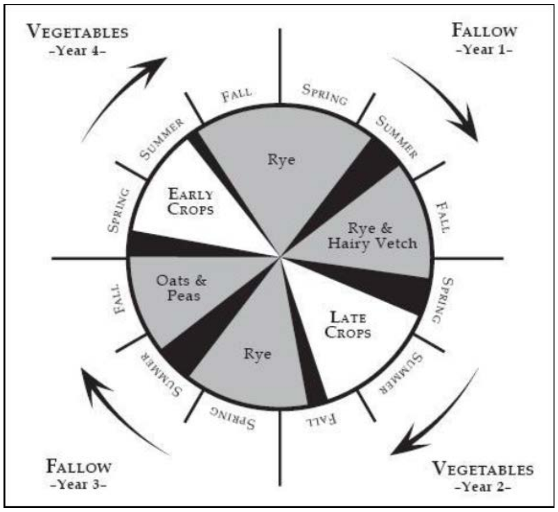

Figure 3 (Maher 2017)

Tools to Guide Implementation

- Natural Resources Conservation Service, USDA (2015). Virginia NRCS Cover Crop Planning Manual 1.0. Virginia Technical Note https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_030443.pdf
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3. Reduced Tillage

1. Does the farm have a plan for the next few years to reduce the use of conventional tillage?

   ☐Yes ☐ No

2. Does the farmer know about and intend to implement reduced tillage practices, such as no-till, ridge-till, conservation tillage or others so that less than the total area in cultivation is tilled?

   ☐Yes ☐ No

   If **YES** to questions 1 and 2, continue implementing these best practices.

   If **NO** to questions 1 and/or 2, we recommend that farmers create a plan for a 4 year period into the future (to line up with our other plan recommendations) to improve biodiversity of the farm's soil that is under cultivation by reducing disturbance of biotic processes. The plan should include annual measurement of soil organic matter. See the Reduced Tillage section below.

Overview of Reduced Tillage

Tillage in agriculture is the process of loosening and aerating the soil in preparation for planting by mechanical means of agitation such as digging, stirring, and overturning. Conventional tillage, commonly referred to as intensive tillage, generally involves multiple operations, repeated annually, with implements such as a mold board, disk, and/or chisel plow, that leave less than 15% crop residue in farm fields. Numerous environmental problems stemming from this practice have been analyzed including soil erosion and fertility loss, in addition to GHG emissions and related impacts. Agrobiodiversity loss is prominent among the negative impacts of intensive tillage.

The biodiversity of a farm's soil that is under cultivation can be improved by reducing the disturbance of biotic processes. Reducing how much a field is tilled by conventional means increases biodiversity of microorganisms, many of which perform essential ecological processes (Hobbs, 2008). Additionally, many studies have shown that after changing planting practices to reduce soil disturbance farmers see increases in their yields from the improved preservation of the ecological services that the otherwise-harmed micro-organisms provide (SARE, 2003).

Tillage disturbance reduction practices that are generally effective include those described below.

No-Til: Using specialized equipment to implant the seed directly into the soil. Uses conventional tilling plow heads only for emergency weed control (CTIC, 2017).

Ridge-Til: Leaving ridges of plant residue in between rows where the crop is planted (CTIC, 2017).

Conservation Tillage: Covering the area tilled for planting with plant residues to reduce topsoil erosion and damage to microorganisms (CTIC, 2017).

These practices are directly related to others described in this document, especially:

Cover Cropping: Cover crops can provide plant material used for cover in conservation tillage, and may reduce the needs for emergency tilling to control weeds.

IPM Strategies: Seedbed sanitation (especially practices like using cover tarps) can disrupt pest plant lifecycles and reduce the need to till to prevent weeds.

Tools to Guide Implementation

- Idowu, J, Angadi, S, Darapuneni, M, and Ghimire, R. Reducing tillage in arid and semi-arid cropping systems: an overview. College of Agricultural, Consumer, and Environmental Sciences, New Mexico State University. http://aces.nmsu.edu/pubs/_a/A152.pdf
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4. Integrated Pest Management

1. Has the farm created a plan to reduce its reliance on synthetic (chemical, non-organic) pesticides?

   ☐Yes ☐ No

   If **NO**, consider creating a plan to reduce reliance on synthetic pesticides. See the Integrated Pest Management section below.

   If **YES**, continue:

   a. Does the pest management plan include at least one of the integrated pest management (IPM) practices generally considered effective (ex., seedbed sanitation, push-pull, controlled spraying*)*?

      ☐Yes ☐ No

   If **NO**, consider including one or multiple of these IPM practices in your pest management plan. See the Integrated Pest Management section below.

   If **YES**, continue implementing these best practices and continue updating and evaluating the plan into the future. See the Integrated Pest Management section below,.

Overview of Integrated Pest Management

The maintenance of natural systems, in this case to control pests, and the lowered use of synthetic chemicals can benefit soil health. Some IPM tactics like using perennial plants as habitat for beneficial insects, or as purposeful draws for pests, prevent erosion by maintaining soil integrity over longer periods of time than annual plants offer (Lal, 2016). Additionally the maintenance of native insect species allows natural processes that keep organic matter in the soil to continue. For example, the continued presence of native burrowing bees that would otherwise have been killed by pesticide application allows for the life cycles of below ground parasites, and symbiotic organisms to continue (Watson, 2011). IPM can have wide reaching benefits that include soil health as well as improving the health of aboveground biota.

Recommended Practices

Targeted Spraying and Reduced Application of Chemicals

The easiest way to start reducing application of synthetic chemicals is to better target their use by making accurate maps of the affected area and to time spraying to more effectively match the pest life cycle. Better targeted spraying reduces need, introduces fewer harmful elements into the ecosystem, and reduces costs (Downey *et. al*., 2011).

Creating Habitat for Pollinating Insects

Creating habitats for beneficial insects by targeting your spraying and leaving intact natural habitat can have multiple benefits for your production system. Increasing habitat for natural pollinators (for example indigenous bees) can increase yields in many production systems where the crop requires pollination (Watson, 2011).

Additionally, habitat for pollinators may be beneficial for predatory insects. A variety of predatory insects have similar lifecycles to those of pollinators. Protecting habitat for predatory insects can decrease the populations of pests without added costs and without the application of synthetic chemicals (Kevan, 1996).

Push-Pull Planting Techniques

Push-Pull techniques involve planting a species that repels harmful insects inside the rows of your main crop, and planting a species that attracts the harmful insects away from your main crop. This strategy has been proven to be effective in mitigating the effects of many species of insect pests by increasing yields because of the decreased stress (Yan *et. al*., 2015).

Long Term IPM

The above strategies are generally effective. Because IPM takes time to see results and requires frequent changes in tactics, however, it is important to measure efficacy of your interventions and make a long term plan.

An IPM plan comprises a farm and field-specific strategy for reducing the use of synthetic compounds and supporting natural processes which promote the growth of crops. IPM offers a spectrum of management possibilities that must be tailored to particular needs. We recommend that a farmer develop and submit their own IPM plan that extends a minimum of 4 years into the future. The plan should:

- Acknowledge and record current practices
- Identify the farm's most pressing pest organism issues
- Outline a series of steps that moves the farm gradually towards more sustainable pest management techniques and away from the application of synthetic compounds

After the plan is created, farmers should:

- Document pest outbreaks by type of organism, what the problem was, and at what scale it occurred
- Keep a record of dates of outbreaks to help plan future management techniques

- Evaluate and update their plan every two years based on the data they have collected and their observations.

Tools to Guide Implementation

- FAO Trials in East Africa http://www.fao.org/agroecology/database/detail/en/c/472748/
- For a list of IPM strategies in tropical latitudes see the FAO Integrated Production and Pest Management Programme in Africa: http://www.fao.org/agriculture/ippm/ippm-home/en/
- FAO guide on pollinators in production systems http://www.fao.org/3/a-i3821e.pdf
- Sustainable Agriculture Research and Education (SARE). (2003). A Whole Farm Approach to Managing Pests. Sustainable Agriculture Network Publications. https://www.sare.org/Learning-Center/Bulletins/A-Whole-Farm-Approach-to-Managing-Pests

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Yan, H., Zeng, J., & Zhong, G. (2015). The push–pull strategy for citrus psyllid control. Pest management science, 71(7), 893-896.

5. Organic Crop Management

1. Will the production landscape be continuously used for a monocrop?

   ☐Yes ☐ No

   If **YES**, consider diversifying your crop production for better organic management outcomes. See the Organic Crop Management section below.
   If **NO,** continue:

2. Will chemical fertilizers be used on the production landscape?

   ☐Yes ☐ No

   If **YES**, consider how you will monitor your usage and application practices. This is no longer organic crop management. See the Organic Crop Management section below.
   If **NO,** continue:

3. Will chemical pesticides be used on the production landscape?

   ☐Yes ☐No

   If **YES**, consider how you will monitor your usage and application practices. This is no longer organic crop management. See the Integrated Pest Management section below.
   If **NO,** continue:

4. Will chemical herbicides be used on the production landscape?

   ☐Yes ☐ No

   If **YES**, how will you be monitoring your usage and application practices? This is no longer organic crop management. See the Organic Crop Management section below.
   If **NO,** continue:

5. Will crop rotation be used on the production landscape?

   ☐Yes ☐ No

a. Does the farm have a plan for crop rotation that extends for several years into the future?

☐Yes ☐ No

b. Does the crop rotation plan include cover crops?

☐Yes ☐ No

c. Has the farm created a plan to reduce their reliance on synthetic (chemical, non-organic) fertilizers?

☐ Yes ☐No

If **YES** to a-c**,** continue:
If **NO,** consider utilizing these practices to reduce soil erosion while increasing soil fertility and quality, while better controlling pests and diseases that can be established in the soil over time. See the Organic Crop Management section below.

6. Will low tillage practices be used on the production landscape?

☐Yes ☐ No

a. Does the farmer know about and intend to implement reduced tillage practices, such as no-till, ridge-till, conservation tillage or others so that less than the total area in cultivation is tilled?

☐Yes ☐ No

If **YES** to 6 and 6a**,** you have completed this section.
If **NO,** consider utilizing this practice to enhance water-holding capacity of the soil. See the Organic Crop Management section below.

Overview of Organic Crop Management

Conventional large-scale farming practices utilize pesticides, herbicides, and fertilizers, most often in a monocrop system. Organic farming operates without pesticides, herbicides, or inorganic fertilizers, and usually involves a more diverse crop rotation (Bengtsson, Ahnström, & Weibull, 2005). These organic practices contribute to biodiversity conservation by keeping harmful chemicals out of the ecosystem. Other beneficial practices related to organic crop management include crop rotation, cover cropping, and reduced tillage (outlined in previous sections).

In place of chemical pesticides, herbicides, and fertilizers, natural materials can be substituted. Natural fertilizers such as compost or farmyard manure are high in organic matter and when paired with crop rotation can enhance soil fertility. Natural pesticides include those made from other home materials such as garlic, hot peppers, and onions to prevent damage of crops. In place of synthetic herbicides, practices such as cover cropping and mulching can help to control weeds in a natural way.

The types of biodiversity that have been demonstrated to benefit from organic crop management practices are arbuscular mycorrhizal fungi (AMF), birds, arthropods, predatory insects, carabidae, non-predatory arthropods, soil organisms, plants, insects, non-predatory insects, spiders, earthworms, micro-arthropods, fungi, microbial activity/biomass, vascular plants, and endangered farm-associated wildlife. Though results show that organic farming often has positive effects on species richness and abundance, its effects are likely to differ between taxa, geographic region, and landscape context (Bengtsson *et al.,* 2005). An ecosystem-level benefit associated with organic crop management is enhancement of soil C and N concentrations. Crop rotations, especially those that include cover crops, sustain soil quality and productivity by enhancing soil C, N, and microbial biomass (McDaniel, Tiemann, & Grandy, 2014).

Two meta-analyses reviewed how organic crop management practices have been implemented with cash crops as well as cover crops, and whether they enhanced biodiversity. The reviewed studies were conducted in European countries and were done at plot (sub-farm), farm, and landscape scale. The effect of organic farming was largest in studies performed at the plot scale. In studies at the farm scale, when organic and conventional farms were matched according to landscape structure, the effect of organic practices was significant but highly heterogeneous. It was suggested that positive effects of organic farming on species richness can be expected in intensively managed agricultural landscapes, but not necessarily in heterogeneous landscapes comprising many other landcover types as well as agricultural fields. Measures to preserve and enhance biodiversity should be more landscape- and farm-specific than is presently the case (Bengtsson et al., 2005).

There is a long-term economic incentive to transition to organic crop management, in that ceasing to apply pesticides, herbicides, and fertilizers lowers input costs. Crop yield will also increase over time as these management practices enhance soil fertility. Yield may initially decrease, but is expected to increase over time and ultimately exceed the yield achieved prior to implementation of organic practices. Organic crop management can also be economically beneficial if the cover crop chosen to be used in the rotation of the cropping system has economic value. Ongoing management of the organic crop system is necessary for the long-term success of the system. This added time and effort will pay off not only in soil fertility but also in biodiversity and species richness. Although there are time and financial costs associated with the initial switch to organic crop management, maintaining the system requires little effort over the long term, with only small adjustments required when crops are added or taken out of the system.

Tools to Guide Implementation

- Weidmann, G. Step by Step Conversion to Organic Agriculture. Research Institute of Organic Agriculture (FiBL), FAO http://teca.fao.org/read/8364
- Coleman, P. (2012). Guide for Organic Crop Producers. National Center for Appropriate Technology and USDA. https://www.ams.usda.gov/sites/default/files/media/GuideForOrganicCropProducers.pdf (see p. 18-24)

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6. Biodiversity-Friendly Pasture and Livestock Management

1. Does the livestock management system include integrated farming practices?
   ☐Yes ☐ No

2. Does the integration process include holistic livestock management?
   ☐Yes ☐ No

3. In the farming process, is there an integration of crop and livestock production systems?
   ☐Yes ☐ No

   If NO to questions 1, 2 and/or 3, develop a framework to guide your company and the farmers you work with in integrating crops and livestock and practicing holistic management. See the Biodiversity-Friendly Pasture and Livestock Management section below.

   If YES to Questions 1, 2 and/or 3, continue;

4. Are management decisions based upon ecological relationships within components such as wild and managed biodiversity, water, soil and other natural resources?
   ☐Yes ☐ No

   If **NO**, use your integrated management framework (see questions 1-3 above) to detail a plan for decision-making. See the Biodiversity-Friendly Pasture and Livestock Management section below

   If **YES** continue;

5. Does the livestock management system employ extensive grazing and frequent applications of agrochemicals?
   ☐Yes ☐ No

   If **YES,** prepare your company to develop a holistic management decision-making framework and plan. See the Biodiversity-Friendly Pasture and Livestock Management section below.
   If **NO**, continue to implement these best practices.

Overview of Biodiversity-Friendly Pasture and Livestock Management

The loss of biodiversity in the modern era, at rates unparalleled since the major extinction events in the distant geological past (Anderson, 2001), is a matter of considerable policy concern. Livestock grazing is a widespread land management practice in both commercial and subsistence farming systems and the ecological costs of this nearly ubiquitous form of land use can be intense, with effects such as loss of biodiversity; lowering of population densities for a wide variety of taxa; disruption of ecosystem functions, including nutrient cycling and succession; change in community organization; and change in the physical characteristics of both terrestrial and aquatic habitats (Fleischner, 1994). Likewise, it is easy to recognize a clear-cut forest, but it often takes a trained eye to comprehend damage to rangelands. This destruction caused by livestock grazing is so pervasive and has existed for so long that it frequently goes unnoticed.

In the face of these challenges, biodiversity may benefit from integrated farming techniques (Robinson & Sutherland, 2002) such as holistic management (HM) decision-making framework (Savory & Butterfield, 1999) whereby ranchers modify their pasture and livestock management systems so as to minimize their negative effects on biodiversity. Under HM, management decisions are based upon ecological relationships, including among wild and managed biodiversity, water, soil and other natural resources. In terms of biodiversity conservation and long-term productivity, HM has been shown to be a better pasture and livestock management method than conventional methods, which typically employ extensive grazing and frequent applications of agrochemicals, threatening biodiversity and long-term soil and ecosystem health.

There is need for farmers who still use the conventional methods to have a new livestock production paradigm based upon increasing plant diversity and biomass, protecting and restoring soils, protecting water resources and increasing livestock productivity. Ferguson *et. al.* (2013) suggest that there is still need for quantifying the ecological benefits of holistic management for landscape connectivity, wildlife habitat, fire prevention, nutrient cycling, climate change mitigation and soil and watershed protection so as to justify investment in holistic management.

Nonetheless, adopting a holistic management decision making framework is something that farmers can afford to do because it introduces strategies that lead to greater ecological and economic sustainability (Ferguson *et. al.*, 2013). In livestock and pasture management, overgrazing is the result of prolonged grazing without adequate recovery of the vegetation, and is not necessarily a function of livestock density as often assumed. Higher livestock densities may be beneficial in actively herded systems but without proper management, overgrazing may result in the deterioration of streambanks and surface water quality (Strauch et al, 2009).

While herd size is a key conventional measure of land productivity in livestock and pasture management for livelihood models, a broader and more balanced suite of performance measures of human, social, natural, physical and financial capital is needed to ascertain the success and sustainability of a livelihood system, and will include rangeland biodiversity as well as ecological resilience and soil structure. Modifying the conventional grazing methods by taking up a holistic management decision-making process to come up with alternative grazing management systems (i.e. derivations of rotational grazing systems) that more closely simulate natural herbivore behavior will improve habitats, water quality, minimize land degradation and reduce biodiversity loss.

Soil properties and hydrological processes improve with prolonged grazing deferment following intensive grazing, and rotational grazing maintains higher infiltration rates than continuous grazing at high stocking rates (Thurow *et al.,* 1988; Thurow, 1991). Integration of pastures and crops has several advantages, including maintenance of physical, chemical and biological soil characteristics, erosion control, more efficient use of natural resources and pollution control (Moraes *et al,*.2002). Faccio *et al*. (2010) observed that in integrated farming systems that used moderate, controlled grazing intensities, soil aggregation was significantly improved, as well as soil microbial activity. Positive impacts were also observed in the chemical attributes of associated variables, such as total and particulate organic carbon and nitrogen, phosphorus availability and potassium cycling and balance.

Intensification and specialization of agricultural systems in industrialized countries has come with increasingly negative impacts on the environment (Tilman *et al*., 2002), including water contamination, rising atmospheric greenhouse gas concentrations and loss of biodiversity (Franzluebbers *et al*., 2011). Integrated crop-livestock management systems are another form of modified pasture and livestock management. Harnessing the potential of well-integrated crop and livestock systems at various levels of scale (on-farm and area-wide), and that often have agro-forestry and forestry inputs, is a powerful entry point to address needs for biodiversity conservation and human livelihood security.

The integration of crop and livestock production systems increases the diversity, along with environmental sustainability, of both sectors. At the same time it provides opportunities for increasing overall production and economics of farming. This would reduce the preference for specialized livestock production systems, in view of their problems with environmental and economic sustainability (FAO, 2017). Local integration of cropping with livestock systems would allow better regulation of biogeochemical cycles and decreased environmental fluxes to the atmosphere and hydrosphere, more diversified and structured landscape mosaics that would favor diverse habitats and trophic networks; and greater flexibility of the whole system to cope with potential socio-economic and climate change induced hazards and crises (Lemaire *et al.,* 2014).

Tools to Guide Implementation

- Joint FAO/WHO Expert Committee on Food Additives (JECFA) http://apps.who.int/iris/bitstream/10665/246173/1/9789241511155-eng.pdf?ua=1
- Farmer Field School Guidance Document: Planning for quality programmes http://www.fao.org/3/a-i5296e.pdf

- Participatory training and curriculum development for Farmer Field Schools in Guyana and Suriname: A field guide on Integrated Pest Management and aquaculture in rice http://www.fao.org/3/a-ba0031e.pdf

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7. Agroforestry and Ecological Forest Plantation Management

1. Are trees and/or shrubs (woody perennials) retained and managed within and around herbaceous crop and/or livestock producing areas?

   ☐Yes ☐ No

   If **YES** continue to question 2;
   If **NO**, refer to Recommendation 1 in the Agroforestry and Ecological Forest Plantation Management section below

2. Are mixtures of woody perennials integrated throughout the landscape as opposed to concentrated at the fringes of the property, or being absent altogether?

   ☐Yes ☐ No

   If **YES** continue to question 3;
   If **NO**, refer to Recommendation 2 in the Agroforestry and Ecological Forest Plantation Management section below

3. a) Are trees present on the landscape in a way that allows different species to use various vegetation strata as habitat?

   ☐Yes ☐ No

   If **YES,** continue to question 3c;
   If **NO**, continue to question 3b, and refer to Recommendation 3 in the Agroforestry and Ecological Forest Plantation Management section below

   b) Can more trees be planted throughout the agricultural system in ways that benefit crop production?

   ☐Yes ☐ No

   If **YES,** continue to question 4;
   If **NO**, refer to Recommendation 4 in the Agroforestry and Ecological Forest Plantation Management section below

c) Are principles of sustainable forest management applied in producing wood and other forest products from the landscape?

If **YES,** continue to question 4;
If **NO**, refer to Recommendation 4 in the Agroforestry and Ecological Forest Plantation Management section below

4. When there are places in the agricultural system that are performing sub-optimally, is species diversity and other principles of nature-based system design used to guide decision-making?

☐Yes ☐ No

5. Is there an adaptive management plan in place?

☐Yes ☐ No

If YES to 3 and/or 4, continue these practices;
If NO, refer to Recommendation 5 in the Agroforestry and Ecological Forest Plantation Management below and create a plan.

Overview of Agroforestry and Ecological Forest Plantation Management

In agroforestry systems, crops and trees are grown in combinations that are highly complementary or even synergistic, to generate production, economic and/or ecological benefits. The trees, shrubs or palms may be grown in close inter-cropping systems with annual crops, in linear features within or on the boundaries of the crop field, or in tree crop or forest plantations in fields within the agricultural mosaic. Many agroforestry systems, where the tree species is carefully selected and managed, including the tree component as mixed or linear intercrops have major benefits for productivity and resilience of the associated crops (Buck et al., 1999).

Tree species may produce economic products that serve as food, feed, medicines, timber or building materials, spices and other products, and if managed effectively they also benefit soils, watershed functions, and provide windbreaks for other economic crops or human settlements. There is also considerable evidence that agroforestry systems and well-managed forest plantations can enhance biodiversity in the farms and landscapes where they are used, and can play a role in habitat connectivity with protected areas (Swallow *et al* 2006).

Two contrasting systems are described below.

Tropical multi-strata agroforestry systems
Much as mimicry of natural systems in the context of grassland ecosystems manifests as a mosaic of crops on the ground, mimicry of natural systems manifests as multistrata forested systems in tropical agroforests (Malézieux, 2012). By mimicking the multilayered vegetation characteristics of natural forests, the plant diversity in managed agroforest systems provides a variety of ecosystem services that support soil and water management. Layering vegetation increases the diversity of economically viable crops produced by the system, which increases its productive capacity. In tropical agroforestry systems, a diversity of plants supports a network of diverse fauna which also contributes to the resiliency of the system.

Many tropical tree crops, especially coffee and cocoa, are particularly interesting components of agroforestry systems given the often high biodiversity value of the multi-strata systems and the high market value of the products, commonly with potential for certification.
By linking existing farm level certification mechanisms with broader landscape and ecosystem service management approaches and/or expanding current certification models to consider the landscape itself as the certified unit, the potential for stimulating natural systems agriculture grows (Tscharntke *et a*l., 2015).

Ecologically-managed forest plantations
Natural forested landscapes are rich in biodiversity and provide a range of habitats and valuable ecosystem services. Thus, traditional large-scale monoculture plantations for timber production that replace natural forests can result in negative impacts on biodiversity and inhibit ecosystem function. In the context of plantation forestry, mimicking natural ecosystems manages the plantation as an activity embedded within a larger landscape mosaic. Plantations that follow principles of sustainable forest management and that are managed in balance with other ecosystems and land uses within a landscape can provide benefits such as carbon sequestration, air and water purification, erosion control, wildlife habitat and recreational opportunities (Jeffries, 2017).

The New Generations Plantation (NGP) Platform, established by the World Wildlife Fund (WWF) in 2007, exemplifies new ways of thinking and innovative plantation forestry practices. The NGP concept considers the entire environmental, economic, and social landscape within which the plantation forest management unit operates. The NGP vision specifies that plantations should be managed around four key principles: 1) maintain ecosystem integrity, ensuring that key ecological processes, such as water, nutrient, carbon, and biodiversity cycles, are able to function; 2) protect and enhance high conservation values, including rare or threatened species, crucial ecosystem services, or sacred or historical sites; 3) be developed through effective stakeholder involvement processes, building plantation owners' "social license" to operate; and 4) contribute to economic growth and employment by fostering inclusive, sustainable local development. A 10-year review of progress in implementing the NGP approach illustrates numerous examples worldwide of these principles in practice (Jeffries, 2017).

General Management Recommendations

1. Consider incorporating perennial shrubs, trees and palms into the landscape.
2. Consider implementing a landscape design that integrates perennials in a mosaic pattern.
3. Explore ways to develop multi-strata systems that allow for flora at multiple levels (understory, mid-level, high canopy).
4. Look into ways that trees can be integrated into the existing agricultural system as a way to strengthen soil health, provide habitat for more diverse birds and fauna, and to introduce shade into the system.
5. Identify species and relations in the ecosystem that fill the role that is problematic in the managed system. Consider following some or all of the steps outlined in the Introduction, to move towards natural systems agriculture approach supported by an adaptive management plan.

Tools to Guide Implementation

Agroforestry and ecologically managed forest plantations can be implemented on a spectrum of intensities and is flexible to various timeframes and scales. For additional support and information, the set of links below provide guidance:

- World Agroforestry Centre, An Agroforestry Guide for Field Practitioners
- FAO Agroforestry
- WWF New Generation Plantations for People, Planet and Prosperity
- University of Manitoba, Natural Systems Agriculture

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8. Corridors: Hedgerows and Riparian Buffers

1. Does the production landscape include corridors (hedgerows or riparian buffers)?

   ☐Yes ☐ No

2. Are corridors a part of an integrated management plan for the production landscape?

   ☐Yes ☐ No

   If **NO** to questions 1 or 2, consider if want to incorporate corridors into management plan. See the Corridors: Hedgerows and Riparian Buffers section below.

   If **YES** to questions 1 and/or 2, continue:

   a. Do the corridors contain trees?

      ☐Yes ☐ No

      If **NO**, consider increasing plant species richness of corridors. See the Corridors: Hedgerows and Riparian Buffers section below.
      If **YES**, continue:

   b. Are the corridors species-rich (more than 3 species of woody shrub or tree)?

      If **NO**, consider increasing plant species richness of corridors. See the Corridors: Hedgerows and Riparian Buffers section below.
      If **YES**, continue:

   c. Do the corridors include dense vegetated or flowering understory?

      ☐Yes ☐ No

      If **NO**, consider enhancing understory vegetation of corridors. See the Corridors: Hedgerows and Riparian Buffers section below.
      If **YES**, continue:

   d. Do the corridors (hedgerows) contain gaps >2m across (bad)?

☐Yes ☐ No

If **NO**, consider increasing plant species richness of corridors. See the Corridors: Hedgerows and Riparian Buffers section below.
If **YES**, continue:

e. Are there parallel rows of corridors running across the farm(s)?

☐Yes ☐ No

If **YES**, are the hedgerows spaced at >500m (bad, but actual value landscape dependent)

☐Yes ☐ No

f. Are the corridors stand-alone (i.e. on-farm only, isolated)?

☐Yes ☐ No

If **NO,** do corridors connect to retained natural habitat patches or riparian zones in the landscape?

☐Yes ☐ No

If **YES**, does each corridor connect to a single retained natural habitat patch?

☐Yes ☐ No

If **NO**, are the corridors designed in a holistic network linking multiple natural habitat areas across the production landscape (i.e. landscape-scale)?

Overview of Corridors: Hedgerows and Riparian Buffers

Land-use change is the single biggest driver of global biodiversity loss (Jetz *et al*, 2007). In both temperate and tropical regions, conversion of forest to intensive agriculture threatens biodiversity because many fewer species can persist in open, monoculture production landscapes than in primary forest or diversified agriculture (e.g. shade-grown coffee or silvopasture) (Frishkoff *et al*, 2014, Karp *et al*, 2012). While some species can thrive in disturbed landscapes (Karp *et al,* 2012), many species depend on the complex vegetation structure typical of forested habitats for food and nutrient resources, appropriate microclimatic conditions, refuges from predators, and physical structures for foraging and breeding (Benton et al 2013).

Conversion of forest to agricultural land threatens forest-dependent species not only through habitat loss, but also through fragmentation, which divides populations into "islands" of smaller populations (Harrison and Bruna, 1999). Even if patches of forest remain in the broader landscape, distance or landscape elements like roads often impede animal movement among habitat patches (Shirk *et al*, 2010). Movement across the landscape enables many biological processes, including gene flow, migration, foraging, mating, and nest prospecting (Zeller et al 2012), and is vital for long-term population persistence.

An important management practice that can mitigate local biodiversity loss in production landscapes is the implementation of hedgerows, riparian buffer zones, and other types of corridors both on-farm and across the broader landscape. These physical structures can increase habitat heterogeneity, provide on-farm resources and refuges for forest species, and enhance connectivity between natural habitat patches that are retained within the working landscape. Vegetated corridors come in many varieties. Hedgerows are linear features of woody vegetation that vary widely in size, configuration, and level of plant species richness and vegetation structural complexity (Burel, 2010). For example, a hedgerow may comprise a single monospecific row of trees, a wide row of low shrubs, or a tall and species-rich forest strip. Riparian buffers are linear strips of trees, shrubs, or tall grasses that are planted along streams or rivers and provide a "buffer zone" of natural vegetation bordering a waterway (NYDEC). Linear vegetated features can provide some habitat and resources per se, but are perhaps more important in their role as corridors between larger patches of natural or semi-natural habitat that are retained on or adjacent to the farm (Hinsley and Bellamy, 2000).

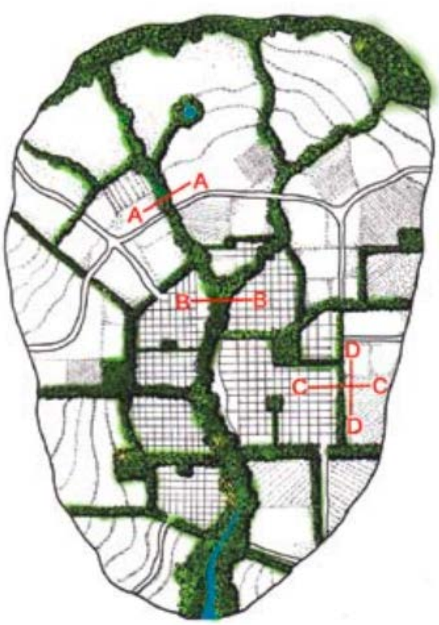

Fig. 1 Schematic for linking hedgerows, riparian buffer zones, habitat patches, and ponds into a network (Bentrup, G. 2008)

Hedgerows and riparian buffers have been documented to benefit biodiversity in a variety of geographic regions and ecological systems and across many taxa, including species that provide yield-enhancing or cost-reducing ecosystem services to farmers (Garratt *et al* 2017). Hedgerows have been shown to provide valuable habitat and food resources for invertebrates (Amy *et al* 2015, Staley *et al* 2016), plants (Critchley *et al* 2013), and birds, as well as for groups such as pollinators and natural enemies that are of particular importance to ecosystem function and agricultural yield (Hanley and Wilkins 2015, Sardinas and Kremen 2015, Ponisio *et al* 2016, Amy *et al* 2015). Birds and carabid beetles, for example, provide vital ecosystem services through seed dispersal, pollination, and control of insect pests (Aviron *et al* 2005). Forest carabid beetles were found to increase in abundance with increasing numbers of hedgerows and woodland patches on the landscape, especially at the scale of 500 m^2 (Aviron *et al* 2005).

A review of the value of hedgerows to birds in the UK reported that increasing hedge size, abundance of trees within hedgerows, and density of hedgerow understory vegetation enhanced bird species richness and abundance (Benton *et al* 2003). Hedgerows were also shown to increase the on-farm abundance of bumblebees and aphid-eating spiders, which provide pollination and pest-control services, respectively (Garratt *et al* 2017). Hedgerows were particularly beneficial for these groups when they contained more than three woody plant species, were structurally solid (no gaps wider than 2 m), and included flowering plants in the hedgerow understory. The activity and abundance of pest-eating spiders declined with distance from the hedgerow into the open field (by 80 percent 50 m away from the hedge), which suggests that minimizing the distance between hedgerows in a farm field can enhance their pest-control benefits (Garratt *et al* 2017). However, the benefits of higher hedgerow density for biodiversity and pest control must be balanced with the costs of planting, maintenance, and lost crop space.

Hedgerows have been shown to enhance biodiversity not only by providing habitat and resources, but also by facilitating movement of species among habitat patches. In the southeastern US, experimental corridors increased the species richness and abundance of native trees, shrubs, and herbs in small habitat patches such that connected patches contained 20% more species than unconnected patches after 5 years (Damschen *et al* 2006). In a fragmented tropical dry forest in Costa Rica, riparian buffers facilitated inter-habitat movement of a forest specialist bird (Gillies and St. Clair, 2008). While this latter study focused on a single species, the species is representative of a sensitive group of dispersal-limited, highly specialized and forest-dependent tropical birds that are often the first to disappear from human-disturbed landscapes (Powell *et al* 2015). The demonstrated ability of riparian corridors to enhance movement for this species indicates that corridors may enable sensitive species to persist in agricultural landscapes.

Corridors benefit biodiversity directly by providing habitat and linkages between other habitat patches on the landscape; they also have indirect effects on plant, aquatic, and soil microbial diversity by reducing soil erosion and stream sedimentation, and by enhancing soil moisture and fertility. Soil erosion reduces the depth of fertile topsoil, which can negatively impact plants and soil biota by reducing habitat availability, and drives sedimentation of waterways, which can negatively impact aquatic species (Lovell and Sullivan, 2006). Corridors prevent soil erosion by acting as windbreaks and stabilizing soil via their root systems. Wind broken by a physical barrier loses velocity and has less energy to dry out or dislodge soil, and so corridors that are planted perpendicularly to the direction of prevailing winds can reduce soil erosion (Bentrup, 2008). Hedgerows and riparian buffers also effectively trap nutrients, which limits nutrient leaching and can enhance soil organic matter. Corridors capture and retain snow during the temperate winter, which in northern agricultural areas contributes over 20% of annual soil moisture (USDA, 1999). Buffers can reduce sedimentation of streams by filtering runoff: Lee *et al* (2003) found that buffers can remove up to 97% of sediment in surface water before it enters streams and other waterways. Finally, corridors can contribute to soil health by hosting phytoremediating plants (those that remove contaminants from soil and water by converting metals, mine waste, and other pollutants into a non-toxic form) (Bentrup, 2008).

Hedgerows are ubiquitous in farming landscapes of Europe, and can be implemented in most geographic regions, crop types, and ecological contexts (Garratt *et al* 2017). Linear vegetated elements are used in fields that produce cereals, beans, corn, coffee, and many other cash crops, as well as in vineyards, orchards and livestock pastures (Garratt *et al* 2017, Nicholls *et al* 2001, Nicholls and Altieri 2004). The concept of corridors to connect natural habitat fragments is applicable not only to cleared agricultural land in naturally forested landscapes, but also to naturally open habitats that have been converted to monocultured tree plantations. For example, in the experimental study from the southeastern US, corridors were built to connect patches of native, open longleaf pine savanna that had previously been isolated within a matrix of dense pine plantations (Damschen *et al* 2006).

Vegetated corridors are also amenable to a range of spatial scales and can be implemented on-farm or across the broader landscape. For example, Nicholls et al (2001) experimentally bisected a 2.5 ha vineyard in California with a 5m-wide, 300m-long corridor composed of 65 different species of flowering plants to assess its effect on the abundance of natural enemies. They found that the corridor increased the dispersal of pest predators from the adjacent riparian forest into the center of the production field, compared to a control field with no bisecting corridor. While single corridors can enhance on-farm biodiversity, corridors are most beneficial for maintaining regional biodiversity when they connect multiple natural habitat patches in a network across a large region.

Unilever Tea Kenya has implemented corridors and riparian buffer zones in a holistic, landscape-oriented way at the Kericho Tea Estates through its Sustainable Agriculture program (Githiru *et al* 2009). An independent report assessing avian diversity within the Kericho tea production area describes the current landscape: “Dispersed throughout the tea monocultures today are patches of forest, small wetland areas, windbreaks consisting of indigenous and exotic trees, and riparian forests which alone make up over 10 percent of the entire landscape” (Githiru *et al* 2009). The report, which found high avian species richness in the production landscape following implementation of forested elements, highlighted the importance of habitat heterogeneity on the landscape for maintaining the full suite of bird species. Thirty-one bird species were found in primary forest patch edges, compared with only 13 in the tea plantations themselves. Of 174 total species, most specialized on only one or two of the seven habitat types found within the production landscape. This indicates that retaining a variety of land cover types, and in particular patches of primary forest and riparian strips, is vital to maintaining high bird and other diversity in the farming landscape.

As the Unilever example demonstrates, variety is key in implementing hedgerows, riparian buffers, and other connectivity-enhancing elements in farming landscapes (Hinsley and Bellamy, 2000). Hinsley and Bellamy, focusing on bird species, note that because species have a variety of habitat needs and use hedgerows in different ways, 'there is no single prescription for hedgerow structure and management that fits all bird species in a given locality.' The same caveat applies to other taxa. Thus, it is important to include a variety of hedgerow structures, sizes, and plant species compositions in order to provide habitat and refugia for as much biodiversity as possible. However, broad guidelines do exist for incorporating corridors in a way that effectively and efficiently benefits biodiversity.

Birds tend to prefer hedgerows whose plant composition and structure most closely resembles their native breeding habitat; species that are naturally found in woodland habitat prefer tall, wide hedgerows with many trees, whereas open-adapted species are able to use short, sparse hedgerows (Hinsley and Bellamy, 2000). Despite these different preferences for hedge height, width, and number of trees, bird species richness generally increases with increasing hedgerow plant species richness. Hinsley and Bellamy suggested a minimum hedge width of 2 m, and prescribed dense vegetation cover at the base of hedgerows.

Finally, as exemplified by the success of Unilever's holistic landscape management program in increasing avian diversity across the landscape, rather than focusing on single hedgerows it is necessary to design landscape-scale networks of corridors connecting natural and semi-natural areas like stands of native woodland and ponds in order to make production landscapes compatible with high levels of native biodiversity over the long term. Hedgerows should ideally be implemented as connecting features and not as the only available habitat per se.

The costs of planting hedgerows and riparian buffers, especially with mostly native plant species, as well as maintaining them in the long term, are often prohibitive for small-holder farmers (Brodt *et al* 2009). However, hedgerows and riparian buffers can provide long-term economic benefits by enabling natural pest control, stabilizing soil and improving water quality, and providing shade for livestock (Brodt *et al* 2009). Farmer-to-farmer extension of technical information regarding corridor implementation can make other farmers in the community more likely to plant hedgerows and riparian buffers on their land. Further, programs that provide financial assistance to farmers to install conservation-oriented management practices can remove the barrier of up-front planting costs.

In the US, the Conservation Reserve Program pays farmers to install riparian buffers and wildlife habitat reserves on their production lands; the Environmental Quality Incentives Program likewise funds up to 75 percent of the cost of installing hedgerows, riparian strips, and other conservation features. Similarly, in Nicaragua, a payment-for-ecosystem-services (PES) program has enabled farmers to increase tree cover on their pastureland in the form of forest patches, riparian strips, living fences, and stand-alone trees. Since the program began, the area of degraded pasture has dropped by 66 percent, forest cover across the landscape has increased to 31 percent, and landscape connectivity has increased, with 67 percent of forest patches connected to neighboring fragments. While some of the farmers who were granted PES stopped maintaining tree cover on their land after the payment program ended, most have noticed enhanced productivity on their farms and are continuing to maintain the conservation landscape features.

General Management Recommendations

1. Heterogeneity is key, both at the landscape-scale and in terms of hedgerow characteristics; include a variety of hedgerow structures, sizes, and plant species compositions in order to provide habitat and refugia for as much biodiversity as possible.
2. Species are best supported by hedgerows and riparian buffers that mimic their preferred natural habitat. Identify species of concern for multiple taxa and tailor hedgerow design to those species' habitat preferences.
3. Where possible, maximize plant species diversity within hedgerows to maximize use by a broader suite of insect, bird, and mammal species.
4. Single hedgerows are better than none, but where possible implement networks of hedgerows and/or riparian buffers connecting natural habitat patches.

Tools to Guide Implementation

- *Conservation Corridor Planning at the Landscape Level: Managing for Wildlife Habitat* (from United States Department of Agriculture Natural Resources Conservation Service's National Biology Handbook, 1999) - This highly detailed, extension-oriented document provides a comprehensive discussion of corridors as tools for conservation in agricultural or otherwise-disturbed landscapes. The report defines corridors and describes their many possible forms; discusses various ways in which corridors benefit biodiversity, soil health, ecosystem services, and local economies and crop yield; and includes multiple case studies of corridor implementation in North America. See p. 613-57 for general design principles that apply to most wildlife planning projects, and see p. 612-64 for concrete recommendations for corridor design with various specific objectives in mind. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/16/nrcs143_009912.pdf
- *Agroforestry and Biodiversity Conservation in Tropical Landscapes* (Schroth et al 2004) - This book is broadly about conservation biology and landscape ecology as they relate to tropical agroforestry, but see p. 55-60 for a discussion of specific features of corridors in tropical agricultural systems that benefit various kinds of biodiversity. http://library.uniteddiversity.coop/Permaculture/Agroforestry/Agroforestry_and_Biodiversity_Conservation_in_Tropical_Landscapes.pdf
- *Conservation Buffers: Design Guidelines for Buffers, Corridors, and Greenways* (Bentrup, G. 2008, Gen. Tech. Rep SRS-109. Asheville, NC: Department of Agriculture, Forest Service, Southern Research Station) - In this manual, "over 80 illustrated design guidelines for conservation buffers are synthesized and developed from a review of over 1,400 research publications. These science-based guidelines are presented as easy-to-understand rules of thumb for facilitating the planning and designing of conservation buffers in rural and urban landscapes." See section 2 (p.

43-60) for guidelines for designing corridors for biodiversity, and section 3 (p. 61-66) for guidelines on designing corridors for soil health.
https://nac.unl.edu/buffers/docs/conservation_buffers.pdf

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9. Natural Habitat Patches and Networks

10. Is there any non-pasture or cropland within the farm?

☐Yes ☐ No

11. Of the non-pasture and cropland area, is it populated with native species?

☐Yes ☐ No

12. Is it populated with naturalized species?

☐Yes ☐ No

If **NO** to questions 1, 2, or 3, we recommend integrating natural areas into the agricultural landscape. See the Natural Habitat section below.

If **YES** to questions 1, 2, and 3, continue:

13. Is the natural area an appropriate size? (This should be determined by the amount of land the farmer has decided/can commit)

☐Yes ☐ No

If **NO**, consider increasing the size of natural areas present.

If **YES,** continue:

14. Are there an appropriate number of natural areas? (This should be determined by the amount of land the farmer has decided/can commit.)

☐Yes ☐ No

If **NO**, consider increasing the number of natural areas present.

If **YES**, are the natural areas connected by corridors, hedgerows, or other mechanisms?

If **NO**, we recommend increasing the connectivity between natural areas. See the Corridors: Hedgerows and Riparian Buffers section above

15. Is the natural area(s) negatively affected by farming practices?

   a. Do synthetic fertilizers reach it?

   ☐Yes ☐ No

   b. Do herbicides reach it?

☐Yes ☐ No

c. Do pesticides reach it?

☐Yes ☐ No

d. Has its water source been polluted or diverted/reduced?

☐Yes ☐ No

If **YES** to any 6a-6d, we recommend altering farming practices to prevent them from reaching the natural area(s). One method could be organic crop management. See the Organic Crop Management section above.

Overview of Natural Habitat Patches and Networks

"The conversion of natural habitats into agricultural production, particularly intensive monocrop systems, represents the single most important source of biodiversity loss arising from agriculture" (Potts *et al*., 2017). There is a growing trend in agriculture toward landscape simplification, where regions that once included diverse systems like forests, fencerows, woodlots, streams, pastures, and wetlands shift toward the more profitable (at least in the short term) monoculture crop production systems (Woltz *et al.*, 2012).Preserving natural areas is a way to combat the threat of landscape homogenization. Natural areas, which are often patches or fragments of forest, native savanna, or other ecosystems natural to the region, can provide critical habitat to support a variety of species' needs including food sources, mating and breeding grounds, and protection from predators. The benefits of retained natural areas vary across different taxa and geographic and ecoregions, but multiple studies have found that some level of heterogeneity in the landscape generally promotes biodiversity, especially perennial habitats (Woltz, 2012), and that remnant habitats provide important source populations for agrobiodiversity (Duelli, 2003).

The integration and preservation of natural habitats into agricultural landscapes can involve a wide variety of actions. Examples of this practice include riparian buffers (vegetated strips between an agricultural field and a body of water), interspersing natural vegetation within crops (e.g. planting native trees among coffee trees), leaving patches of natural vegetation at the edges of adjacent farm plots, establishing natural habitat corridors across farmed landscapes, and other related strategies and configurations. Essentially, the approach involves reversing the growing trend toward landscape simplification.

Studies have shown that preserving natural habitats can benefit a variety of taxa including birds, bats (Harvey, 2007), mammals (Smith, 2017), insects (Morandin and Winston, 2006), and plants (Farah, 2017). Both wild biodiversity and agrobiodiversity have been demonstrated to benefit from retaining natural areas on the landscape. Agriculture has a clear economic interest in preserving agrobiodiversity, but wild biodiversity can have indirect yet strong benefits for agricultural production as well. For example, wild bees serving as pollinators benefit from the preservation of uncultivated land, and have been shown to increase crop (canola in this case) yield and profit (Morandin and Winston, 2006).

Preservation and promotion of natural areas has been tested and proven successful in a variety of biomes including wetlands (Duelli, 2003), tropical forest (Harvey, 2007) (Hylander, 2017), temperate forest (Alison, 2017), boreal forest (Vali), and grassland (Smith, 2017). While there is no reason to discourage individual efforts to increase natural habitats, there is little expectation that this practice will be effective on a small scale. Simplified landscapes will need to be altered at scales requiring planning and coordination in order to have a significant impact (Woltz, 2012). As such, this tactic will need both individual farm commitments and policy support to ensure adequate incentives (IISD). The composition, size, shape, number, and spacing of natural areas will need to be tailored to the specific region in which they are implemented, as well as in accordance to the current state of the agricultural landscape and the scale on which the practice is to be implemented.

Preservation and restoration of natural habitats provides an opportunity for decomposition to occur naturally which enriches the organic matter present in soil. This in turn provides a more hospitable environment for soil microbes. In short, the soil should return to its natural state prior to the introduction of agriculture (Lal, 2016). While natural habitats don't directly benefit soil health in agricultural fields, they may act as a source for microorganisms and nutrients depending on their number and spacing within the agricultural landscape as well as the irrigation and natural water systems.

Tools to Guide Implementation

- This document goes through the steps a group in Ireland took to establish natural habitats within agricultural landscapes. It is lengthy; we recommend reading through the executive summary to gain an understanding of the challenges and objectives of natural habitat integration. If it is decided that natural habitats will be pursued, then the document should be read more thoroughly to find the most applicable case study. Particular attention should be given to the Overview of Potential Measures section.
  http://www.nuigalway.ie/applied_ecology_unit/documents/methods_to_create_and_enhance_farmland_habitats_literature_review.pdf

- This document focuses specifically on preserving and promoting pollinators in agricultural landscapes which benefits production and profit. For information on integrating natural habitats to achieve this end, find pages 11 and 22-28.

http://pollinator.org/assets/generalFiles/LandManagerGuide.Ontario.Farms.FINAL.PDF

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10. Integrated Agricultural Landscape Management

1. Does the production landscape have an integrated landscape management plan?

   ☐Yes ☐ No

2. Is there evidence that biodiversity-friendly farming systems are established in the landscape?

   ☐Yes ☐ No

   If NO to questions 1 and/or 2, consider if your company would like to participate in developing an integrated management plan for the landscape that may include an integrated agricultural landscape approach to promoting biodiversity-friendly farming, and learn more.

   If **YES** to Questions 1 and/or 2, continue:

   a. Does the landscape management plan involve the relevant stakeholders in the landscape?

      ☐Yes ☐ No

      If **YES**, have the stakeholders agreed to viable integrated agriculture and biodiversity conservation strategies?

   b. Is the landscape managed for biodiversity preserves that benefit local farming communities?

      ☐Yes ☐ No

   c. Is the landscape managed for habitat networks that link farmed and non-farmed areas?

      ☐Yes ☐ No

   d. Is the landscape managed for reducing habitat conversion by improving farm productivity?

      ☐Yes ☐ No

   e. Is the landscape managed for minimizing agricultural pollution?

☐Yes ☐ No

f. Is the landscape managed to improve the natural capital value of soil, vegetation and water resources by applying agroecological principles?

☐Yes ☐ No

g. Is the landscape managed to encourage farming systems to mimic natural ecosystems?

☐Yes ☐ No

Overview of Integrated Agricultural Landscape Management

Integrated landscape management (ILM) is an approach to protecting and regenerating biodiversity and ecosystem services that is compatible with agricultural production.[2] ILM emerged in response to the growing recognition that farming and biodiversity conservation, and their effects on one another, often are best recognized and managed at a landscape scale. ILM also aims to ensure that economic value generated from the landscape is invested in the livelihood security and development of people and organizations who live and work there and have an interest in the landscape's long- term health and resilience (Denier *et al*., 2015; Sayer *et al*, 2014; FAO, 2017).

The approach is explicitly concerned with developing management plans for landscape mosaics that optimize synergies and reduce trade-offs between agricultural production and biodiversity conservation (McNeely and Scherr, 2003; Scherr *et al*., 2014). ILM literatures analyze and quantify relationships between the production of crops, livestock and forest products, and the conservation of wild and agrobiodiversity. They also describe, evaluate and recommend particular working landscape management strategies and associated farm management practices that are biodiversity-friendly (Buck *et al*, 2004; Scherr and McNeely, 2007; Scherr and McNeely, 2008).

Integrated agricultural landscape management strategies, within which particular farm and landscape level management practices can be embedded, include (McNeely and Scherr, 2003):

- Creating biodiversity preserves that benefit local farming communities
- Developing habitat networks in non-farmed areas
- Reducing land conversion by increasing farm productivity (sustainable intensification)
- Minimizing agricultural pollution
- Modifying management of vegetation, soil and vegetation resources

[2] More than 90 different terms are in use that refer to different approaches or communities of practice that seek to achieve such integrated agricultural landscapes, often with an 'entry point' of particular interest or philosophy of implementation (Scherr, Shames, Friedman, 2013). Examples include: ecoagriculture landscape, integrated watershed management, biological corridors in productive landscape, agroecological landscape.

- Modifying farming systems to mimic natural ecosystems

Figure 1 depicts an integrated agricultural landscape.

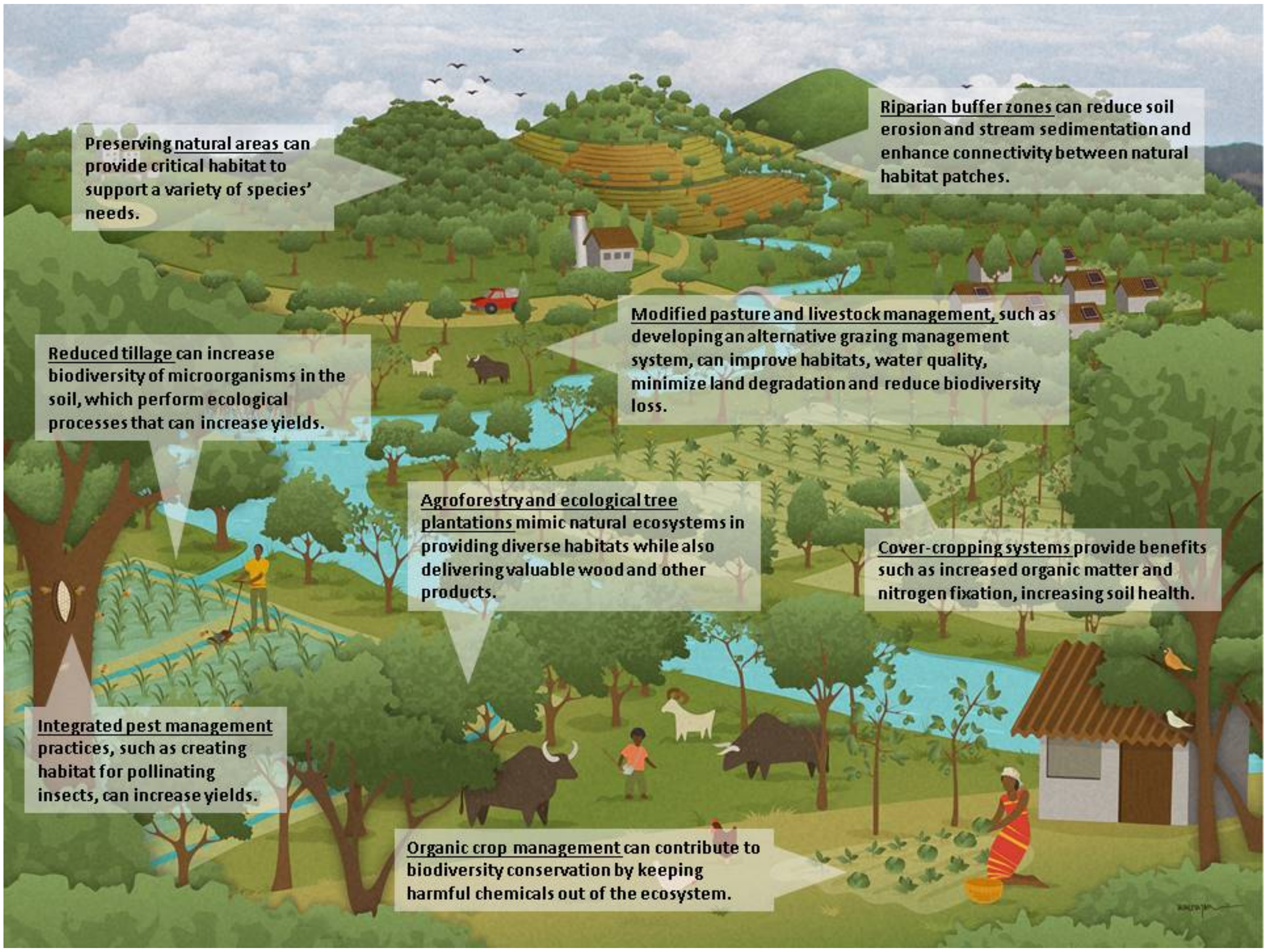

Figure 1. An integrated agricultural landscape promotes biodiversity through a variety of complementary production practices.

The process of developing an integrated agricultural landscape management plan involves six main steps:

1. **Assessing the state of the landscape** with respect to production, conservation, livelihoods and institutional capacity for coordinated action
    a. Evaluate current production practices in relation to biodiversity, natural resources, and human livelihoods
    b. Identify negative impacts of current production practices and potential areas for improvement
    c. Understand the local legal, political, and economic context, and identify structures already in place to facilitate coordinated action

2. **Establishing a multi-stakeholder platform**, or coordinating body that assumes responsibility for the management planning process
    a. Ideally include all stakeholders who may impact the landscape in question
    b. Understand the motivations of various stakeholders to engage with the landscape
    c. Understand the legal context of the nation or region in which you are operating, and tailor outreach to the specific needs and structures of each stakeholder group
3. **Identifying potential intervention strategies** and evaluating synergies and trade-offs among them
    a. Agree on objectives (e.g. enhancing wild or agrobiodiversity, improving soil health, protecting watersheds, increasing yield, improving worker livelihoods)
    b. Develop scenarios that explore the outcomes of various implementation plans under different conditions (e.g. climate change)
        i. InVEST tool enables planners to evaluate synergies and tradeoffs of alternative land management plans and includes models tailored to terrestrial and aquatic ecosystems (see p. 83)
4. **Designing optimal interventions**, or changes in practice at landscape and farm level
    a. Identify the scale of alternative practices and interventions
    b. Once a suite of desired interventions is identified, prioritize the interventions that will best fit stakeholder needs, interests, and capacity for implementation
5. **Implementing the changes** in practice
    a. Define roles and responsibilities of each stakeholder group in implementing management changes
    b. Design landscape plan such that both short-term and long-term 'wins' will be realized
    c. Engage research partners to gain a deeper understanding of landscape processes and tailor practices to local ecological context
6. **Monitoring the effects of the changes** in practice, and re-assessing the state of the landscape
    a. Establish a monitoring system to assess progress made towards pre-defined objectives, including environmental, economic, and social goals
        i. Analysing landcover change over time is a quantifiable metric that provides insight into multiple goals
        ii. Frequency of data collection should depend on anticipated pace of changes resulting from altered practices
    b. Effectively communicate results and lessons from monitoring to all stakeholder participants in ILM plan

Tools to Guide Implementation

- Little Sustainable Landscapes Book (Denier et al., 2015) (see pages 58-96) https://ecoagriculture.org/publication/the-little-sustainable-landscapes-book/
- Public-private-civic partnerships for sustainable landscapes: a guide for conveners. https://ecoagriculture.org/blog/conveners-guide-to-build-landscape-coalitions/

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