González-Chang et al. / Agro Sur 49(3): 45-50, 2021
DOI:10.4206/agrosur.2021.v49n3-05

Enhancing biodiversity in Chilean farms requires locally-adapted agroecological protocols

Aumentar la biodiversidad en predios chilenos requiere de protocolos agroecológicos adaptados localmente

González-Chang, M.[a,b]*, Faulkner, J.[c], Shields, M.[c], Lavandero, B.[d]

[a] Instituto de Producción y Sanidad Vegetal, Universidad Austral de Chile, Valdivia, Chile.
[b] Centro de Investigación en Suelos Volcánicos, Universidad Austral de Chile, Valdivia, Chile.
[c] Bio-Protection Research Centre, Lincoln University, Lincoln, New Zealand.
[d] Laboratorio de Control Biológico, Instituto de Ciencias Biológicas, Universidad de Talca, Talca, Chile.

ARTICLE INFO

Article history:
Received 01.10.2021
Accepted 30.03.2022

Keywords:
Agroecology
Sustainability
Farmer to farmer

View Point,
Special Issue: Biodiversity and crop management: key players for a productive and sustainable agriculture in temperate climatic conditions

**Corresponding author:*
Mauricio González-Chang
E-mail address:
mauricio.gonzalez.chang@uach.cl

Palabras clave: Agroecología, sustentabilidad, campesino a campesino

The need for a local understanding in harnessing farm biodiversity

In the 1992 Earth Summit held in Rio de Janeiro, Brazil, the concept of sustainable development, understood as the balance between economic, social, and environmental factors interacting in space and time, was recognized by representatives from 179 countries as vital to sustain human life without compromising the planet (United Nations, 1992). Nowadays, as humanity faces unseen anthropogenic problems such as climate change and biodiversity loss (IPCC, 2021), the concept of sustainable development has been recently highlighted by United Nations through the creation of 17 Sustainable Development Goals, aiming at improving environmental and human well-being globally (United Nations, 2015). Among these goals, attention has been made to ecosystem restoration, conservation, and sustainable use, of both marine and terrestrial environments. In this sense, the global food system based on monocultures, and subsequently the application of synthetic pesticides and fertilizers, has significantly contributed to ecosystem degradation by land use changes (Sala *et al*., 2000; Ramankutty *et al*., 2018) impacting local biodiversity and by releasing greenhouse gases. The latter is estimated to range between 21% and 37% of total anthropogenic global emissions, having a direct impact on climate change (IPCC, 2019). Therefore, a paradigm shift is needed to transform current food systems to contribute to the provision and regulation of multiple ecosystem services (benefits to humans) derived from the agricultural sector to enhance human well-being beyond just producing food for the increasing world population (LaCanne and Lundgren, 2018; Wratten *et al*., 2019). In this sense, feeding an estimated of 10 billion people by 2050, under rapidly changing climate change scenarios, requires a myriad of strategies that consider the whole food chain from applied in-field approaches, to national policies that promote the transition towards more sustainable agricultural systems (Wezel *et al*., 2020; Tscharntke *et al*., 2021).

At the farm level, recent research suggests that in-field biodiversity can provide multiple ecosystem services without compromising crop yield (Dainese *et al*., 2019; Tamburini *et al*., 2020; Ricciardi *et al*., 2021; Fenster *et al*., 2021; Tscharntke *et al*., 2021), while also contributing to the mitigation of climate change impacts on farm production (Altieri *et al*., 2015). However, similar farm principles applied to different crops and geographic areas can have different impacts on the outcome. For example, the concept of regenerative agriculture uses the principle of harnessing biodiversity that when applied to corn fields can reduced corn yield compared to conventionally-managed fields (LaCanne and Lundgren, 2018), while in almond orchards, the same principle was applied but no yield differences were found when compared to conventional almond orchards (Fenster *et al*., 2021). Despite these inconsistencies in yield responses, in both examples, net profit was higher in regenerative farms (LaCanne and Lundgren, 2018; Fenster *et al*., 2021), highlighting the economic feasibility of enhancing biodiversity in conventionally managed agroecosystems. Then, manipulating biodiversity in farms as a strategy to enhance specific ecosystem functions could also produce neutral or negative effects on multiple ecosystem services (Tamburini *et al*., 2020), likely as different socio-ecological factors interacting at a given time and space generate complex outcomes (Liu *et al*., 2007; Tscharntke *et al*., 2016; Karp *et al*., 2018). Thus, knowing the interactions and outcomes of harnessing biodiversity at local scales is crucial to advance into applied protocols that could benefit many farmers in a widespread area, such as in Africa with the Push-Pull system (Khan *et al*., 2014) and in Asia with Ecological Engineering in rice (Gurr *et al*., 2016). Additionally, impacts at greater scales may mitigate or modulate the farm level effects, by providing ecosystem services to greater geographical areas. However, much remains to be learned about how local habitat management is modulated by landscape effects and agricultural practices at different spatial and temporal scales (Karp *et al*., 2018; Ahmed *et al*., 2020; Iuliano and Gratton, 2020), which makes its influence on ecosystem service delivery uncertain and site-specific and thus, its implementation difficult. Indeed, interactions between ecological processes and agricultural practices are influenced not only by habitat management at the farm-scale (high in-field plant diversification), but also by the surrounding habitat structure at landscape level, as well as farming practices (e.g., pesticide use) (Lichtenberg *et al*., 2017). The enhancement of plant biodiversity, through enrichment of the farm matrix could increase the abundance and/or diversity of many key organisms, which provide important functions for agroecosystems (Altieri, 1999; Dainese *et al*., 2019; Tamburini *et al*., 2020). Therefore, the extent to which habitat diversification strategies can subsidize multiple ecosystem services (e.g., biological control, pollination, soil nutrition, water quality, among others) needs to be measured also considering the variety in landscape contexts. For example, farms in complex landscapes with rich semi-natural and natural habitats (e.g., field margins, hedgerows, woody and herbaceous habitats) which provide shelter, alternative hosts and sugar sources (SNAP *sensu* Barnes *et al*., 2009) may reduce the shortcomings of management at the farm scale by enhancing the cross-habitat movement of natural enemies, enhancing biological control (González-Chang *et al*., 2019). In addition, as biodiversity increases, complex interactions are generated where intraguild predation can be reduced, because natural enemies can complement each other to affect different pest species, increasing the efficacy of biological control (Snyder, 2019). On the other hand, simple landscapes, with poor non-crop habitat resources, which do not provide SNAP may not limit the effect of natural enemies, if local management practices provide sugar resources as floral nectar using flower rows or intercropping (Snyder, 2019) or as honeydew directly from the hosts of these parasitoids (Luquet *et al*., 2021). Therefore, landscape composition (i.e., number of habitats in the landscape) and configuration (i.e., shape, size, spatial arrangement) play a key role in delivering biodiversity-based ecosystem services (Haan *et al*., 2021), as small and isolated patches can accelerate species loss compared to larger ones (Chase *et al*., 2020). Also, the availability of complementary flower resources at the landscape scale can thus offset negative insecticide effects on ecosystem services (wild bee reproduction and pest control) in agriculture dominated landscapes (Klaus *et al*., 2021). In this manner, understand the extent to which the promotion of low-intensity farming practices limiting the input of habitat disturbances (e.g., pesticide use) and augmenting resource availability for natural enemies, pollinators, birds, mammals, among other groups, are mediated by landscape structure and its impact on ecosystem services will be essential for the maintenance of sustainable agroecosystems.

Adapting agroecological protocols through experimentation and trust

Despite the recent increase in the number of scientific research covering topics associated to maintaining and/or enhancing biodiversity in agroecosystems (González-Chang *et al*., 2020), the contribution of these has often not led to locally-adapted protocols that farmers can easily use. This reduces the likelihood of spreading agroecological protocols among farmers, and turning rare, biodiversity-rich farms into common biodiversity-rich landscapes (Nicholls and Altieri, 2018; Tscharntke *et al*., 2021). In a broadest sense, agroecology can multidisciplinary deal with the agrarian complexity occurring within landscapes through technological, cultural, and political perspectives that encourage a paradigm shift from our current food system (Wezel *et al*., 2020). In this manuscript an agroecological protocol is understood as a locally-adapted practice or set of farm practices that harness native or functional biodiversity to produce concrete socio-ecological outcomes (González-Chang *et al*., 2020; Wyckhuys *et al*., 2020) based on scientific, traditional and/or indigenous knowledge (Wezel *et al*., 2020). However, this knowledge is not always widely available or accessible to farmers, nor adapted to their local socio-ecological context. Recently, González-Chang *et al*. (2020), proposed a theoretical framework consisting of 11 steps describing the ideal pathway from the concept of biodiversity to create agroecological protocols to enhance socio-ecological transformations at the farm level. This approach aims to guide efforts towards understanding biodiversity interactions in agroecosystems to promote multiple ecosystem services and highlight the importance of considering the involvement of different stakeholders, such as farmers, farmer networks, policy makers, and scientists, to advance in the co-creation of locally-adapted protocols that harness biodiversity. Therefore, the well-accepted principles behind different agroecological approaches (Altieri, 1999; LaCanne and Lundgren, 2018; Wezel *et al*., 2020) can be translated into specific farm practices (González-Chang *et al*., 2020), which can improve one or multiple ecosystem services (Dainese *et al*., 2019; Tamburini *et al*., 2020).

An interesting approach that has helped to translate agroecological principles into locally-adapted practices are the so-called "agroecological lighthouses" (*sensu* Nicholls and Altieri, 2018), which are experimental field stations where different practices are tested and adapted using participative and horizontal educative methods, such as *Campesino a Campesino* (Holt-Giménez, 2008). When farmers perceive that the success of a certain practice can increase their well-being, by reducing production costs and/or increasing profit, they tend to be inclined to try to adapt such a practice (Kleijn *et al*., 2019). This approach helps the agroecology practice spreading through the local farming community as other farmers observe the successes of their colleagues and tend to trust and adapt their colleagues' approaches rather than directly implement suggestions from scientists and/or policy makers (Nicholls and Altieri, 2018). Thus, through concepts like "agroecological lighthouses" agricultural practices could be developed and adapted to local conditions and socio-ecological challenges (Nicholls and Altieri, 2018; González-Chang *et al*., 2020; Wyckhuys *et al*., 2020). Trialing and then demonstrating the successful practices in agroecological lighthouses enables farmers to avoid the unknown costs of experimenting themselves as well as some of the negative impacts of conventional farming (Garibaldi *et al*., 2017; Nicholls and Altieri, 2018), if they can adopt the locally adapted agroecological practices (González-Chang *et al*., 2020). In Chile, examples of agroecological lighthouses exist across the country, but a remarkable one is the managed by CET (Centro de Educación y Tecnología), a non-governmental organization (NGO) that since the 1980s has been promoting locally-adapted practices to enhance biodiversity and food sovereignty among small farmers (Nicholls and Altieri, 2018). For example, in the last 20 years, more than 130,000 people had visited CET in the Biobío region, suggesting the role of such a place in the spreading of adapted agroecological practices in Chile (Nicholls and Altieri, 2018).

However, to disseminate this kind of knowledge and overcome the simplicity of the conventional biocide approach to pests, weeds, and diseases (Bernhardt *et al*., 2017; Gould *et al*., 2018), local farmers should be involved in co-creating the necessary practices to adapt their agricultural systems to more diversified ones (González-Chang *et al*., 2020; Wezel *et al*., 2020). By promoting the co-creation of knowledge, the likelihood of socio-ecological transformations in farming systems can be enhanced. This is essential to increase the reliability and efficacy of agroecological practices (Wezel *et al*., 2020) and builds the trust between scientists and farmers that is required for the acceptance and adoption of agroecological protocols (Warner, 2007). Different literature reviews have shown that a lack of fundamental applied knowledge based on agroecological principles is one of the biggest barriers farmers faces in transitioning towards diversified farming systems (Wratten *et al*., 2012; Westphal *et al*., 2015; Garibaldi *et al*., 2017; Gonzalez-Chang *et al*., 2020). Co-developed knowledge's basis would allow farmers to be involved in the entire process but also ensure that the knowledge and science being produced is both in line with farmers needs and in forms that are both useful and easy for them to follow (Warner, 2007; Holt-Giménez, 2008; Garibaldi *et al*., 2017; Nicholls and Altieri, 2018; González-Chang *et al*., 2020; Wezel *et al*., 2020).

In addition to the need to involve farmers from the conception of trials and demonstrate agroecological successes, a greater integration to understand the interactions of current biocide use and agroecological practices is crucial for future farming and increase the adoption of agroecological protocols. Conventional agriculture uses broadly applied prophylactic management approaches that rely on strong chemistry to overcome different local challenges (Brzozowski and Mazourek 2018; Wratten *et al*., 2019). This is based on the acceptance that agrochemicals are currently considered a necessity in at least some capacity for many cropping systems (Gould *et al*., 2018). However, most agrochemicals have negative impacts on biodiversity and ecosystem services (Bernhardt *et al*., 2017). For instance, most pesticides negatively impact soil invertebrates regardless of the types of pesticides and invertebrates involved (Gunstone *et al*., 2021), also increasing the likelihood of pest resistance against the chemical compounds applied (Gould *et al*., 2018). Therefore, the direct and indirect effects of pesticides, particularly sub-lethal doses, and long-term effects, on agroecosystems needs to better be understood, especially as these compounds reduce the efficacy of biodiversity-based approaches (Brzozowski and Mazourek 2018; Dainese *et al*., 2019; Fenster *et al*., 2021). Nevertheless, if correctly assessed, agroecological practices can reduce the need for chemical inputs by restoring missed ecological functions (Altieri 1999; Gurr *et al*., 2016; Tamburini *et al*., 2020; Wezel *et al*., 2020). Thus, these knowledge gaps need to be approached with the aim of reducing chemical inputs and allowing the enhancement of multiple ecosystem services through harnessing biodiversity in farms, for the transition towards more sustainable agricultural systems (Wratten *et al*., 2019).

Agroecological protocols have been shown to be economical, scalable and provide multiple ecosystem services, however there is an increasing gap between the growing agroecology-related scientific literature and farmer adoption worldwide (González-Chang *et al*., 2020). To mitigate the increasing environmental, economic, and social issues facing agriculture, agroecological protocols need to become more integrated with conventional practices and effectively communicated through demonstration in local conditions through practices locally validated by farmers, in a language that farmers can easily understand. In Chile, some advances have been made in terms of understanding biodiversity effects on agriculture. For example, a recent study demonstrates that adding native flowering vegetation strips in avocado orchards in Central Chile can increase fruit yield through pollination (Muñoz *et al*., 2021). In addition, efforts to harness biodiversity in horticulture (Salas, 2019) and vineyards (Díaz-Forestier *et al*., 2021) have also started to be explored, which highlight the growing interest of farmers for understand, apply and benefit from biodiversity-based protocols within their farming systems. Nevertheless, Chilean policies related to the use of natural resources are mainly conceived as extractive activities that diminish biodiversity (Urbina *et al*., 2021), in which conventional agricultural systems heavily rely on monocultures and agrochemicals, partly contributing to the degradation of natural ecosystems, and thereby, affecting human wellbeing. Despite that, the theoretical approach proposed by González-Chang *et al*. (2020) can contribute to the creation and dissemination of agroecological protocols by guiding through the necessary steps involved in socio-ecological transformations at farm and landscape scales, a responsible governance is also needed for complement, support, articulate and spread the findings arising from this approach, efficiently. Through understanding the importance and role of native and functional biodiversity in agroecosystems, and the associated ecosystem services it regulates, maintains, and supports, Chilean agriculture can advance to fulfill the Sustainable Development Goals proposed by the United Nations related to zero hunger, good health and wellbeing, climate action, life on land and below water. In addition, Chile has today the chance to move forward to a greener and sustainable economy as elected constituents create a new constitution (Urbina *et al*., 2021). Thus, environmental integrity should be placed at the center of economic growth, encouraging the design of sustainable and biodiversity-rich agroecosystems that provide multiple ecosystem services.

Acknowledgements

We would like to acknowledge distinguished professor Stephen D. Wratten for his guidance, council, knowledge, and care during each of our PhD studies. By researching with passion aspects of insect ecology, agriculture and ecosystem services, Steve realized about the importance of harnessing biodiversity in farms to enhance multiple ecosystem services to promote humankind wellbeing, encouraging us to pursue the understanding of ecological dynamics in agricultural systems.

References

Ahmed, H.S., Chen, J., Chen, W., Pozsgai, G., Senyo, K., Furqan, M., You, M., Gurr, G., 2020. Local management and landscape structure determine the assemblage patterns of spiders in vegetable fields. Scientific Reports 10, 15130. https://doi.org/10.1038/s41598-020-71888-w

Altieri, M., 1999. The ecological role of biodiversity in agroecosystems, in: Paoletti, M.G. (Ed.), Invertebrate Biodiversity as Bioindicators of Sustainable Landscapes. Elsevier Science, Padova, Italy, pp. 19–31. https://doi.org/10.1016/B978-0-444-50019-9.50005-4

Altieri, M.A., Nicholls, C.I., Henao, A., Lana, M.A., 2015. Agroecology and the design of climate change-resilient farming systems. Agronomy for Sustainable Development 35, 869–890. https://doi.org/10.1007/s13593-015-0285-2

Barnes, A., Wratten, S., Sandhu, H., 2009. Harnessing biodiversity to improve vineyard sustainability. Outlooks on Pest Management 20 (6), 250–255.

Bernhardt, E.S., Rosi, J., Gessner, M.O., 2017. Synthetic chemicals as agents of global change. Frontiers in Ecology and the Environment 15 (2), 84–90. https://doi.org/10.1002/fee.1450

Brzozowski, L., Mazourek, M., 2018. A sustainable agricultural future relies on the transition to organic agroecological pest management. Sustainability 10 (6), 2023.

Chase, J.M., Blowes, S.A., Knight, T.M., Gerstner, K., May, F., 2020. Ecosystem decay exacerbates biodiversity loss with habitat loss. Nature 584, 238–243.

Dainese, M., Martin, E., Aizen, M., Albrecht, M., Bartomeus, I., Bommarco, R., Carvalheiro, L.G., Chaplin-Kramer, R., Gagic, V., Garibaldi, L.A., Ghazoul, J., Grab, H., Jonsson, M., Karp, D.S., Kennedy, C.M., Kleijn, D., Kremen, C., Landis, D.A., Letourneau, D.K., Marini, L., Poveda, K., Rader, R., Smith, H.G., Tscharntke, T., Andersson, G.K.S., Badenhausser, I., Baensch, S., Bezerra, A.D., Bianchi, F.J.J.A., Boreux, V., Bretagnolle, V., Caballero-Lopez, B., Cavigliasso, P., Ćetković, A., Chacoff, N.P., Classen, A., Cusser, S., da Silva e Silva, F.D., de Groot, G.A., Dudenhöffer, J.H., Ekroos, J., Fijen, T., Franck, P., Freitas, B.M., Garratt, M.P.D., Gratton, C., Hipólito, J., Holzschuh, A., Hunt, L., Iverson, A.L., Jha, S., Keasar, T., Kim, T.N., Kishinevsky, M., Klatt, B.K., Klein, A.-M., Krewenka, K.M., Krishnan, S., Larsen, A.E., Lavigne, C., Liere, H., Maas, B., Mallinger, R.E., Pachon, E.M., Martínez-Salinas, A., Meehan, T.D., Mitchell, M.G.E, Molina, G.A.R., Nesper, M., Nilsson, L., O'Rourke, M.E., Peters, M.K., Plećaš, M.K., Potts, S.G., Ramos, D.L., Rosenheim, J.A., Rundlöf, M., Rusch, A., Sáez, A., Scheper, J., Schleuning, M., Schmack, J.M., Sciligo, A.R., Seymour, C., Stanley, D.A., Stewart, R., Stout, J.C., Sutter, L., Takada, M.B., Taki, H., Tamburini, G., Tschumi, M., Viana, B.F., Westphal, C., Willcox, B.K., Wratten, S.D., Yoshioka, A., Zaragoza-Trello, C., Zhang, W., Zou, Y., Steffan-Dewenter, I., 2019. A global synthesis reveals biodiversity-mediated benefits for crop production. Science advances 5 (10), eaax0121. https://doi.org/10.1126/sciadv.aax0121

Díaz-Forestier, J., Abades, S., Pohl, N., Barbosa, O., Godoy, K., Svensson, G., Undurraga, M., Bravo, C., García, C., Root-Bernstein, M., Armesto, J., Celis-Diez, J., 2021. Assessing ecological indicators for remnant vegetation strips as functional biological corridors in Chilean vineyards. Diversity 13 (9), 447.

Fenster, T., Oikawa, P., Lundgren, J., 2021. Regenerative almond production systems improve soil health, biodiversity and profit. Frontiers in Sustainable Food Systems 5, 664359. https://doi.org/10.3389/fsufs.2021.664359

Garibaldi, L.A., Gemmill-Herren, B., D'Annolfo, R., Graeub, B.E., Cunningham, S.A., Breeze, T.D., 2017. Farming approaches for greater biodiversity, livelihoods, and food security. Trends in ecology & evolution 32(1), 68–80. http://dx.doi.org/10.1016/j.tree.2016.10.001

González-Chang, M., Tiwari, S., Sharma, S., Wratten, S., 2019. Habitat management for pest management: limitations and prospects. Annals of the Entomological Society of America 112(4), 302–317.

González-Chang, M., Wratten, S.D., Shields, M.W., Costanza, R., Dainese, M., Gurr, G., Johnson, J., Karp, D.S., Ketelaar, J.W., Nboyine, J., Pretty, J., Rayl, R., Sandhu, H., Walker, M., Zhou, W.W., 2020. Understanding the pathways from biodiversity to agroecological outcomes: a new, interactive approach. Agriculture, Ecosysteme & Environment 301, 107053. https://doi.org/10.1016/j.agee.2020.107053

Gould, F., Brown, Z., Kuzma, J., 2018. Wicked evolution: Can we address the sociobiological dilemma of pesticide resistance? Science 360(6390), 728–732.

Gunstone, T., Cornelisse, T., Klein, K., Dubey, A., Donley, N., 2021. Pesticides and soil invertebrates: A hazard assessment. Frontiers in Environmental Science 9, 643847. https://doi.org/10.3389/fenvs.2021.643847

Gurr, G.M., Lu, Z., Zheng, X., Xu, H., Zhu, P., Chen, G., Yao, X., Cheng, J., Zhu, Z., Catindig, J.L., Villareal, S., Chien, H.V., Cuong, L.Q., Channoo, C., Chengwattana, N., Lan, L.P., Hai, L.H., Chaiwong, J., Nicol, H.I., Perovic, D.J., Wratten, S.D., Heong, K.L., 2016. Multi-country evidence that crop diversification promotes ecological intensification of agriculture. Nature Plants 2, 16014. https://doi.org/10.1038/nplants.2016.14

Haan, N.H., Iuliano, G., Gratton, C., Landis, D., 2021. Designing agricultural landscapes for arthropod-based ecosystem services in North America. Advances in Ecological Research 64, 191–250. https://doi.org/10.1016/bs.aecr.2021.01.003

Holt-Giménez, E., 2008. Campesino a campesino. Voces de Latinoamerica. Movimiento campesino para la agricultura sustentable. Managua, Nicaragua: SIMAS.

IPCC, 2019. Climate change and land. An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Available online < https://www.ipcc.ch/site/assets/uploads/2019/08/4.-SPM_Approved_Microsite_FINAL.pdf> (Accessed September 29, 2021).

IPCC, 2021. AR6 climate change 2021: The physical science basis. Available online < https://www.ipcc.ch/report/ar6/wg1/> (Accessed September 29, 2021).

Iuliano, B., Gratton, C., 2020. Temporal resource (dis) continuity for conservation biological control: From field to landscape scales. Frontiers in Sustainable Food Systems 4, 127.

Karp, D., Chaplin-Kramer, T., Meehan, T., Martin, E.A., DeClerck, F., Grab, H., Gratton, C., Hunt, L., Larsen, A.E., Martínez-Salinas, A., O'Rourke, M.E., Rusch, A., Poveda, K., Jonsson, M., Rosenheim, J.A., Schellhorn, N.A., Tscharntke, T., Wratten, S.D., Zhang, W., Iverson, A.L., Adler, L.S., Albrecht, M., Alignier, A., Angelella, G.M., Anjum, M.Z., Avelino, J., Batáry, P., Baveco, J.M., Bianchi, F.J.J.A., Birkhofer, K., Bohnenblust, E.W., Bommarco, R., Brewer, M.J., Caballero-López, B., Carrière, Y., Carvalheiro, L.G., Cayuela, L., Centrella, M., Ćetković, A., Henri, D.C., Chabert, A., Costamagna, A.C., De la Mora, A., de Kraker, J., Desneux, N., Diehl, E., Diekötter, T., Dormann, C.F., Eckberg, J.O., Entling, M.H., Fiedler, D., Franck, P., van Veen, F.J.F., Frank, T., Gagic, V., Garratt, M.P.D., Getachew, A., Gonthier, D.J., Goodell, P.B., Graziosi, I., Groves, R.L., Gurr, G.M., Hajian-Forooshani, Z., Heimpel, G.E., Herrmann, J.D., Huseth, A.S., Inclán, D.J., Ingrao, A.J., Iv, P., Jacot, K., Johnson, G.A., Jones, L., Kaiser, M., Kaser, J.M., Keasar, T., Kim, T.N., Kishinevsky, M., Landis, D.A., Lavandero, B., Lavigne, C., Le Ralec, A., Lemessa, D., Letourneau, D.K., Liere, H., Lu, Y., Lubin, Y., Luttermoser, T., Maas, B., Mace, K., Madeira, F., Mader, V., Cortesero, A.M., Marini, L., Martinez, E., Martinson, H.M., Menozzi, P., Mitchell, M.G.E., Miyashita, T., Molina, G.A.R., Molina-Montenegro, M.A., O'Neal, M.E., Opatovsky, I., Ortiz-Martinez, S., Nash, M., Östman, Ö., Ouin, A., Pak, D., Paredes, D., Parsa, S., Parry, H., Perez-Alvarez, R., Perović, D.J., Peterson, J.A., Petit, S., Philpott, S.M., Plantegenest, M., Plećaš, M., Pluess, T., Pons, X., Potts, S.G., Pywell, R.F., Ragsdale, D.W., Rand, T.A., Raymond, L., Ricci, B., Sargent, C., Sarthou, J.-P., Saulais, J., Schäckermann, J., Schmidt, N.P., Schneider, G., Schüepp, C., Sivakoff, F.S., Smith, H.G., Whitney, K.S., Stutz, S., Szendrei, Z., Takada, M.B., Taki, H., Tamburini, G., Thomson, L.J., Tricault, Y., Tsafack, N., Tschumi, M., Valantin-Morison, M., Trinh, M.V., van der Werf, W., Vierling, K.T., Werling, B.P., Wickens, J.B., Wickens, V.J., Woodcock, B.A., Wyckhuys, K., Xiao, H., Yasuda, M., Yoshioka, A., Zou, Y., 2018. Crops pests and predators exhibit incosistent responses to surrounding landscape composition. Proceedings of the National Academy of Sciences 115(33), E7863-E7870. https://doi.org/10.1073/pnas.1800042115

Khan, Z.R., Midega, C.A.O., Pittchar, J.O., Murage, A.W., Birkett, M.A., Bruce, T.J.A., Pickett, J.A., 2014. Achieving food security for one million sub-Saharan African poor through push-pull innovation by 2020. Philosophical Transactions of the Royal Society B: Biological Sciences 369(1639), 20120284. http://dx.doi.org/10.1098/rstb.2012.0284

Klaus, F., Tscharntke, T., Bischoff, G., Grass, I., 2021. Floral resource diversification promotes solitary bee reproduction and may offset insecticide effects-evidence from a semi-field experiment. Ecology Letters 24(4), 668–675.

Kleijn, D., Bommarco, R., Fijen, T.P.M., Garibaldi, L.A., Potts, S.G., van der Putten, W.H., 2019. Ecological intensification: bridging the gap between science and practice. Trends in ecology & evolution 34(2), 154–166.

LaCanne, C.E., Lundgren, J.G., 2018. Regenerative agriculture: merging farming and natural resource conservation profitably. PeerJ 6, e4428. https://doi.org/10.7717/peerj.4428

Lichtenberg, E.M., Kennedy, C.M., Kremen, C., Batáry, P., Berendse, F., Bommarco, R., Bosque-Pérez, N.A., Carvalheiro, L.G., Snyder, W.E., Williams, N.M., Winfree, R., Klatt, B.K., Åström, S., Benjamin, F., Brittain, C., Chaplin-Kramer, R., Clough, Y., Danforth, B., Diekötter, T., Eigenbrode, S.D., Ekroos, J., Elle, E., Freitas, B.M., Fukuda, Y., Gaines-Day, H.R., Grab, H., Gratton, C., Holzschuh, A., Isaacs, R., Isaia, M., Jha, S., Jonason, D., Jones, V.P., Klein, A.-M., Krauss, J., Letourneau, D.K., Macfadyen, S., Mallinger, R.E., Martin, E.A., Martinez, E., Memmott, J., Morandin, L., Neame, L., Otieno, M., Park, M.G., Pfiffner, L., Pocock, M.J.O., Ponce, C., Potts, S.G., Poveda, K., Ramos, M., Rosenheim, J.A., Rundlöf, M., Sardiñas, H., Saunders, M.E., Schon, N.L., Sciligo, A.R., Sidhu, C.S., Steffan-Dewenter, I., Tscharntke, T., Veselý, M., Weisser, W.W., Wilson, J.K., Crowder, D.W., 2017. A global synthesis of the effects of diversified farming systems on arthropod diversity within fields and across agricultural landscapes. Global Change Biology 23(11), 4946–4957. https://doi.org/10.1111/gcb.13714

Liu, J., Dietz, T., Carpenter, S.R., Alberti, M., Folke, C., Moran, E., Pell, A.N., Deadman, P., Kratz, T., Lubchenco, J., Ostrom, E., Ouyang, Z., Provencher, W., Redman, C.L., Schneider, S.H., Taylor, W.W., 2007. Complexity of coupled human and natural systems. Science 317(5844), 1513–1516. https://doi.org/10.1126/science.1144004

Luquet, M., Parisey, N., Hervé, M., Desouhant, E., Cortesero, A., Peñalver-Cruz, A., Lavandero, B., Anton, S., Jaloux, B., 2021. Inferring insect feeding patterns from sugar profiles: a comparison of statistical methods. Ecological Entomology 46 (1), 19–32.

Muñoz, A., Plantegenest, M., Amouroux, P., Zaviezo, T., 2021. Native flower strips increase visitation by non-bee insects to avocado flowers and promote yield. Basic and Applied Ecology 56, 369–378.

Nicholls, C.I., Altieri, M.A., 2018. Pathways for the amplification of agroecology. Agroecology and Sustainable Food Systems 42(10), 1170–1193. https://doi.org/10.1080/21683565.2018.1499578

Ramankutty, N., Mehrabi, Z., Waha, K., Jarvis, L., Kremen, C., Herrero, M., Rieseberg, L.H., 2018. Trends in global agricultural land use: Implications for environmental health and food security. Annual Review of Plant Biology 69, 789–815.

Ricciardi, V., Mehrabi, Z., Wittman, H., James, D., Ramankutty, N., 2021. Higher yields and more biodiversity on small farms. Nature Sustainability 4, 651–657.

Sala, O.E., Chapin III, F.S., Armesto, J.J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L.F., Jackson, R.B., Kinzig, A., Leemans, R., Lodge, D.M., Mooney, H.A., Oesterheld, M., Poff, N.L., Sykes, M.T., Walker, B.H., Walker, M., Wall, D.H., 2000. Global biodiversity scenarios for the year 2100. Science 287(5459), 1770–1774. https://doi.org/10.1126/science.287.5459.1770

Salas, C., 2019. Plants as food for adult natural enemies, in: Souza, B., Vázquez, L., Marucci, R. (Eds.), Natural enemies of insect pests in Neotropical agroecosystems. Biological control and functional biodiversity. Springer Nature, Cham, Switzerland, pp. 35–47.

Snyder, W.E., 2019. Give predators a complement: Conserving natural enemy biodiversity to improve biocontrol. Biological Control 135, 73–82.

Tamburini, G., Bommarco, R., Wanger, T., Kremen, C., van der Heijden, M., Liebman, M., Hallin, S., 2020. Agricultural diversification promotes multiple ecosystem services without compromising yield. Science advances 6(45), eaba1715.

Tscharntke, T., Karp, D.S., Chaplin-Kramer, R., Batáry, P., DeClerck, F., Gratton, C., Hunt, L., Ives, A., Jonsson, M., Larsen, A., Martin, E.A., Martínez-Salinas, A., Meehan, T.D., O'Rourke, M., Poveda, K., Rosenheim, J.A., Rusch, A., Schellhorn, N., Wangera, T.C., Wratten, S.D., Zhang, W., 2016. When natural habitat fails to enhance biological pest control - five hypotheses. Biological Conservation 204, 449–458. https://doi.org/10.1016/j.biocon.2016.10.001

Tscharntke, T., Grass, I., Wanger, T., Westphal, C., Bátary, P., 2021. Beyond organic farming – harnessing biodiversity-friendly landscapes. Trends in Ecology & Evolution 36(10), 919–930.

United Nations, 1992. Conference on environment and developmnet, Earth Summit. Available online < https://www.un.org/en/conferences/environment/rio1992> (Accessed September 29, 2021).

United Nations, 2015. Sustainable development summit. Available online < https://sustainabledevelopment.un.org/post2015/summit> (Accessed September 29, 2021).

Urbina, M., Guerrero, P., Jerez, V., Lisón, F., Luna-Jorquera, G., Matus-Olivares, C., Ortiz, J., Pavez, G., Pérez-Alvarez, M., Riquelme-Bugeño, R., Santos-Carvallo, M., Sepúlveda, M., Victoriano, P., Gomez-Uchida, D., 2021. Extractivist policies hurt Chile's ecosystems. Science 373(6560), 1208–1209.

Warner, K.D., 2007. Agroecology in action: extending alternative agriculture through social networks. MIT Press Ltd. Cambridge, Mass., United States.

Westphal, C., Vidal., Horgan, F., Gurr, G., Escalada, M., van Chien, H., Tscharntke, T., Heong, K., Settele, J., 2015. Promoting multiple ecosystem services with flower strips and participatory approaches in rice production landscapes. Basic and Applied Ecology 16(8), 681–689.

Wezel, A., Herren, B., Kerr, R., Barrios, E., Rodrigues, A., Sinclair, F., 2020. Agroecological principles and elements and their implications for transitioning to sustainable food systems. A review. Agronomy for Sustainable Development 40, 40.

Wratten, S. D., Gillespie, M., Decourtye, A., Mader, E., Desneux, N., 2012. Pollinator habitat enhancement: Benefits to other ecosystem services. Agriculture, Ecosystems & Environment 159, 112–122. https://doi.org/10.1016/j.agee.2012.06.020

Wratten, S., Shields, M., González-Chang, M., 2019. Prospects for regenerative agriculture in Chile. Agro Sur 47(2), 1–6.

Wyckhuys, K.A.G., González-Chang, M., Adriani, E., Albaytar, A., Albertini, A., Ávila, G., Beltran, M.J., Boreros, A., Zainal, M., Nguyên, D.C., Nguyên, G., Nurkomar, I., Tiwari, S., 2020. Delivering on the promise of biological control in Asia's food systems: A Humboldtian perspective. Frontiers in Sustainable Food Systems 4, 140.