POSSIBLE BREAKTHROUGHS
MIXED FARMING SYSTEMS

Most research and agricultural development has focused on increasing yields and improving farming technologies for a reduced number of crops, preferably grown in monocultural systems. The benefits and potential of multiple cropping and agroforestry systems – not only for the provision of ecosystem services, such as increased biodiversity, but more importantly in terms of pest control, improved resource-use efficiency and resilience to resource-limited environments – have been largely overlooked. Moreover, faced with increasing demands for food, by intensifying crop production into time and space, multiple cropping systems are a means to maximize land productivity per unit area.[1]

[1]Gliessman 1985

Description

Multiple cropping systems imply within-field crop diversification, either in time (i.e., rotations) or in space (e.g., intercropping), with the objective of optimizing ecological interactions between crops that trigger positive synergies. In agroforestry, trees are included in the cropping system or combined with livestock production. These systems lead to improved nutrient uptake and nitrogen use, increased soil fertility, increased water-use efficiency, and reduced incidence of pests.

Ecological approaches to pest reduction become relevant in light of the vulnerability of major monocultured crops to pests and diseases.[2] As not all mixtures provide suppressive capacity against specific pathogen populations, a deep understanding of both ecological interactions in variety combinations and pest pathogenesis is needed. Most leguminous crops have the capacity to develop symbiotic nodules with soil bacteria (e.g. *Rhizobium*) that convert inert atmospheric nitrogen into ammonia (NH_3). Biological nitrogen fixation by leguminous crops becomes particularly interesting – not only are legumes nitrogen self-sufficient, but they also transfer fixed nitrogen to consociated crops via their root system, reducing the amount of nitrogenous fertilization needed by the consociated staple crop. The contribution of biological nitrogen fixation to food production is certainly important, although there are controversies as to the potential shares. Some argue that biological nitrogen fixation could feed the current global population,[3] others counter that only half of the required food could be produced by naturally fixed nitrogen on current cropland.[4]

In conclusion, intercropping can significantly increase nutrient and water-use efficiency, which reduces the use of fertilizers and irrigation. Curbing the use of pesticides also reduces environmental pollution and health hazards. Agroforestry systems present many of the advantages of multiple cropping systems. Benefits are tangible in the provision of ecosystem services, such as biodiversity conservation, water and soil quality enhancement, and, not least, carbon storage. In terms of production, they support a variety of complementary products encompassing food, feed, fuel wood, timber and energy.

[2]Waddington et al. 2010; Hartman et al. 2011; Ratnadass et al. 2012, [3]Bagdley et al. 2007; Goulding et al. 2009, [4]Erisman and Sutton 2008; Smil 2001

Geography

The benefits of multiple cropping systems are not new to traditional farming in Mesoamerica. These systems also still constitute the major farming and food provision system in sub-Saharan Africa, for a number of reasons, most importantly because they are better adapted to local environmental conditions and the general low fertility of tropical soils. For instance, cereal-legume intercropping is a well-established production system throughout tropical developing countries.[5] As the best lands with good soil, easy water control, and that are easy to mechanize are already cultivated, multiple cropping represents a potentially effective means to make marginal lands increasingly productive.[6] In general, tropical environments lend themselves better to multiple cropping due to greater rainfall, longer growing periods, and a warmer climate. Yet even in environments with limited or variable resource availability (nutrients, water), multiple cropping can make a more efficient use of the resource endowment.

Future perspectives

For the private sector, exploiting the potential of multiple cropping opens up new business opportunities, particularly in sub-Saharan Africa and China, where one-third of the total cultivated area and half of total yields come from multiple cropping systems. At the Centre for Crop Systems Analysis at Wageningen University, researchers emphasize the relevance of multiple cropping systems for the development of high-quality plant production in sustainable agro-ecosystems. According to Dr. Niels Anten and Dr. Tjeerd-Jan Stomph, efforts will have to be directed towards breeding for combinability (e.g., synchronizing crop cycles to have similar critical growth stages, finding cultivars/species that best exploit synergistic benefits) and developing smart technologies and machinery that can handle multiple crops, such as robotic machines.

A basic principle of multiple cropping is that of “complementary crops” and timing, so as to avoid competition for space, light, nutrients and water, or inhibition by toxic compounds produced by the previous crop. This requires greater understanding of the biological and agronomic factors behind certain crop responses. The fact that decision-makers still think poorly of multiple cropping limits the research funding available to make these systems viable alternatives.

[5]Ofori and Stern 1987, [6]Gliessman 1985

Energy

- Improving pest control through biological interactions between multiple crops reduces pesticide use and thus limits the use of tractors, which ultimately reduces energy inputs into the system.
- In India, nitrogen savings of 35-44 kg/ha were registered when a leguminous crop preceded rice or wheat, while intercropping of soybean with maize could save up to 40-60 kg nitrogen (N)/ha.[7]

Water, nutrient, and light use efficiency

Crops with different nutritional requirements, timing of peak needs, and diverse and deeper root structures are grown on the same land simultaneously[8] thus optimizing nutrient and water use.

- Water-use efficiency in intercropping is often 18% higher and can be as much as 99% higher than in sole crops.[9]
- Studies have shown higher water-use efficiency in maize-bean intercropping in Africa as a result of the live mulching activity of beans.[10]
- Faba beans also enhance phosphorus uptake by maize.[11]
- By optimizing plant architecture and different light requirements, multiple cropping systems ensure best use of available light and increase photosynthetic potential.[12]

[7]Venkatesh and Ali 2007, [8]Gliessman 1985, [9]Morris and Garrity 1993, [10]Tsubo et al. 2003, [11]Zhang and Li 2003, [12]Gliessman 1985

Productivity

Yield advantages and improved soil fertility

- Several studies show higher yields per unit area (expressed in relative yield total or land equivalent ratio) than in monocultured systems under the same management level. In corn-bean-squash mixtures in Mexico, corn yields were substantially higher than in monoculture.[13]
- Biological nitrogen fixation, green manure and organic matter reincorporated into the soil lead to increased soil fertility, humidity conservation and microbiological stimulation. These all ensure long-term productivity.[14]
- Maize-bean intercropping has proven more productive than sole maize in various regions of Africa.[15] The fertilization benefits for the cereal crop when associated with a nitrogen-fixing leguminous crop can be ascribed to nitrogen excretion[16] and nodule decomposition[17] of the latter crop during the growing period.
- There is also evidence that competition between cereals and leguminous crops stimulates atmospheric nitrogen absorption and fixation by the leguminous crop.[18] Morgado and Willey[19] found highest efficiency of maize-bean intercropping when applying nitrogen at 50 kg/ha, which led to higher maize cob yields than in maize sole cropping.

Improved pest control

- Mutual pest control exercised by symbiotic relations between crops leads to higher yields and less harvest losses.
- Intraspecific diversity of rice (*Oryza sativa*) has been tested on large-scale fields in Yunnan, China, whereby two different rice varieties – one disease-susceptible (glutinous variety) and one disease-resistant (non-glutinous variety) – were grown in the same field. In addition, the different heights of these two varieties allowed for better aeration, creating less conducive conditions for rice blast, the major rice disease. Yields of glutinous rice were 89% greater and pest incidence 94% lower than in monocultured systems. Yields of hybrid (non-glutinous) rice were nearly equal to those of monocultures.[20]
- Other successful implementations of within-field genetic diversity are found in the U.S. where wheat mixtures are grown under highly mechanized conditions. Similarly to mixtures of different cultivars of wheat, interspecific mixtures of wheat and barley have shown greater disease reduction than by the application of fungicides.[21]
- Other examples are those of vegetable mixtures (e.g. carrot-onion, leek-celery) that limit attacks and damage by pests.[22]

[13]Ibid. [14]Ibid. [15]Tsubo et al. 2003, [16]Eaglesham et al. 1981, [17]Saito 1982; Bonetti 1991, [18]Fan et al. 2006, [19]Morgado and Willey 2003, [20]Zhu et al. 2000, [21]Vilich-Meller 1992; Kaut et al. 2008, [22]Uvah and Coaker 1984

Costs and benefits

- Less dependence on external inputs (fertilizers and pesticides) and lower costs.
- Yet, in some circumstances, the complexity of activities required makes these systems economically unviable.
- By making best use of space and labor, multiple cropping systems can offer greater profit per unit area to smallholders while providing for a more nutritious diet.[23]
- Diverse food outputs are obtained through multiple cropping, thus providing greater choice.
- Multiple cropping also provides market benefits as growing a variety of crops helps farmers protect themselves against market fluctuations and low prices in one crop.

Climate change

Biological diversity is crucial for smallholder farmers to create resilience to climate change as it creates capacity to absorb shocks and adapt to changing sets of circumstances.[24]

[23]Gliessman 1985, [24]FAO-OECD 2012

References

Bagdley, C. J. Moghtader, E. Quintero, E. Zakern, J. Chappell, K. Avilés-Vazquez, A. Samulon, I. Perfecto, 2007. "Organic agriculture and the global food supply". *Renew. Agric, Food Syst.* 22, 86-108.

Bonetti , R. 1991. "Transferencia de nitrogenio do feijao para o milho consorciado: avaliaçao pelo metodo de diluiçao isotopica do N e efeito da associaçao micorrizica". PhD thesis. Escola Superior de Agricultura Luiz de Queiroz, Piracicaba.

Eaglesham, A.R.J., A. Ayanaba, V.R. Rao, D.L. Eskew, 1981. "Improving the nitrogen nutrition of maize by intercropping with cowpea". *Soil Biology and Biochemistry*, 13, 169-171.

Erisman, J.W., M.A. Sutton, 2008. "Reduced nitrogen in ecology and the environment: Special issue of the ESF-FWF Conference in partnership with LFUI, October 2006". *Environmental Pollution* 154, 357-358.

FAO-OECD (Food and Agriculture Organization of the United Nations-Organisation for Economic Co-operation and Development), 2012. *Sustainable Agricultural Productivity Growth and Bridging the Gap for Small Family-Farms*. Interagency Report to the Mexican G20 Presidency.

Fan, F., F. Zhang, Y. Song, J. Sun, X. Bao, T. Guo, L. Li, 2006. "Nitrogen fixation of faba bean (*Vicia faba* L.) interacting with non-legume in two contrasting intercropping systems". *Plant Soil* 283, 275-286.

Gliessman, S.R., 1985. "Multiple Cropping Systems: A Basis for Developing an Alternative Agriculture." In *Innovative biological technologies for lesser developed countries: workshop proceedings*. Congress of the U.S. Office of Technology Assessment. Washington, DC, pp. 67-83.

Goulding, K.W.T., A.J. Trewavas, K.E. Giller, 2009. *Can organic farming feed the world? A contribution to the debate on the ability of organic farming systems to provide sustainable supplies of food*. Proceedings of the Conference of the International Fertilizer Society, Cambridge, UK, 11 December 2009.

Hartman, G.L., E.D. West, T. K. Herman, 2011. "Crops that feed the World 2. Soybean-worldwide production, use, and constraints caused by pathogens and pests". *Food Security* 3, 5-17.

Kaut, A.H.E.E., H.E. Mason, H. Navabi, J.T. O'Donovan, D. Spaner, 2008. "Organic and conventional management of mixtures of wheat and spring cereals". *Agron. Sustain. Dev.* 28, 363-371.

Ofori, F., W.R., Stern, 1987. "The combined effects of nitrogen fertilizer and density of the legume component on production efficiency in a maize/cowpea intercrop system". *Field Crops Research* 16, 43-52.

Morgado, B.L., R.W. Willey, 2003. "Effects of plant population and nitrogen fertilizer on yield and efficiency of maize-bean intercropping". *Pesq. Agropec. Bras.* 38(11), 1257-1264.

Morris, R.A., D.R. Garrity, 1993. "Resource capture and utilization in intercropping". *Field Crops Research* 34, 303-317.

Ratnadass, A., P. Fernandes, J. Avelino, R. Habib, 2012. "Plant species diversity for sustainable management of crop pests and diseases in agro-ecosystems: a review". *Agron. Sustain. Dev.* 32, 273-303.

Saito, S.M.T., 1982. "The nitrogen relationship of maize/bean associations". In: Graham, P.H., S.C. Harris, (eds). *Biological nitrogen fixation*. Cali: Centro Internacional de Agricultura Tropical, 631-639.

Smil, V., 2001. *Feeding the World: A Challenge for the Twenty-first Century*. MIT Press, 360 pp.

Tsubo, M. E., Mukhala, H.O. Ogindo, S. Walker, 2003. "Productivity of maize-bean intercropping in a semi-arid region of South Africa". *Water SA* 29(4), 381-388.

Uvah, I.I.I., T.H. Coaker, 1984. "Effect of mixed cropping on some insect pests of carrots and onions". *Entmol. Exp. Appl.* 36, 159-167.

Venkatesh, M.S., M. Ali, 2007. "Role of Legumes in Nitrogen Economy of Cereals/Cropping systems - The Indian Scenario". In Abrol, Y.P., N. Raghuram, M.S. Sachdev (eds). *Agricultural Nitrogen Use & its Environmental Implications*. International Publishing House Pvt. Ltd. New Delhi, pp. 351-368.

Vilich-Meller, V. 1992. "*Pseudocercosporella herpotrichoides, Fusarium* spp. and *Rhizoctonia cerealis* stem rot in pure stands and interspecific mixtures of cereals". Crop Prot. 11, 45-50.

Waddington, S.R., X. Li, J. Dixon, G. Hyman, C. M. de Vicente, 2010. "Getting the focus right: production constraints for six major food crops in Asian and African farming systems". *Food Security* 2, 27-48.

Zhang, F., L. Li, 2003. "Using competitive and facilitative interactions in intercropping systems enhances crop productivity and nutrient-use efficiency". *Plant and Soil* 248, 305-312.

Zhu, Y., H. Chen, J. Fan, Y. Wang, Y. Li, J. Chen, J. X. Fan, S. Yang, L. Hu, H. Leung, T.W. Mew, P.S. Teng, Z. Wang, C.C. Mundt, 2000. "Genetic diversity and disease control in rice". *Nature* 406, 718-722.