Horticultural Agroforestry Systems Recommended for Climate Change Adaptation: A Review

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ABSTRACT

High input costs, environmental degradation and climate change have generated new challenges in the agriculture, horticulture and forestry sector. The objective of this paper is to identify the main horticultural agroforestry systems useful for climate change adaptation and mitigation. Agri-horticulture, Horti-olericulture, Silvi-olericulture, Horti-pasture, Horti/Silvo-medical, Horti/Silvo-ornamental, Horti-silvculture, Horti-entomoforestry and Horti-Pisciculture are horticultural agroforestry systems recommended. Agroforestry systems in comparison with monoculture systems, have better use of water, soil and light, can help reduce the application of herbicides, fungicides, pesticides, fertilizers, increasing food security, biodiversity protection and climatic change adaptation. We recommended national politics, subsidies, technical support and credits for global farmers.

Key words: Annual vegetable, Fruit tree, Medicinal crop, Ornamental crop.

Growing consensus in the scientific community indicates from climate change resulting that higher temperature and changing precipitation levels (such as erratic rainfall, floods and droughts), consequently, changes in water availability and land cover, altered nitrogen availability and nutrient cycling Alemu et al. (2019), moreover, the intensification of agriculture has contributed to an increase in the negative effects of climate change Mauricio et al. (2019), affecting agricultural production, where its impacts on economic growth, in general, are still issues in debate Kimaro et al. (2019). Mono cropping systems offer low-cost food for consumers with significant negative environmental costs or externalities (water pollution, soil degradation and greenhouse gas), generally externalities not considered in market value Jalón et al. (2018), so that, need to reduce agricultural inputs without significant productivity loss may require a fundamental re-design of cropping systems Jamar et al. (2016).

The dramatic increases in crop productivity in modern agriculture have been accompanied in many instances by environmental degradation and social problems Altieri et al. (2018), agroforestry systems can contribute to feeding a growing population in a sustainable way Groeneweg et al. (2018), world population will reach 9.7 billion by 2050 (United Nations 2015), sufficient food production for an increasing global population while conserving natural capital is a major challenge to humanity Barrios et al. (2017). In response, Agroforestry interventions were successful in combatting food insecurity, by responding to challenges and opportunities related to climate change Tsuji et al. (2019), moreover, has attracted considerable attention in recent years because of its potential to reduce poverty, reduce land degradation and mitigate climate change Buyinza et al. (2019).

The multilayered structures of agroforestry can maintain the stability of internal microclimates which are strong assets for extreme weather adaptions Wu et al. (2016), trees cause important changes in microclimate (immediately under and adjacent to trees), mesoclimate (tens to hundreds of square meters away from the trees) and macroclimate (at a landscape scale of tens to hundreds of square meters), moreover, trees at wide spacing also helps them to develop more stable root systems to resist damage from storms and regular pruning of lower branches helps to avoid wind throw Santos et al. (2019). Trees play a significant role in reducing the amount of rainfall reaching the soil due to canopy interception and in moisture conservation, having the potential to increase infiltration rate of rainwater and check the runoff Chaturvedi et al. (2018), additionally, agroforestry systems increase water quality Pandey et al. (2018), better water use dynamics Paut et al. (2018) and better water use efficiency Abul-Soud et al. (2014).

Horticulture based agroforestry has played a multifarious role in agricultural production and protection of the environment through carbon sequestration to mitigate...
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Hortic-o-lericulture
Agroforestry system where fruit trees and annual vegetables are intercropped (Singh and Dwivedi, 2018), Citrus spp. Blair et al. (2016), Prunus spp. Bhutia et al. (2015), Psidium guajava (Krishnan, 2016), Artocarpus heterophyllus (Gogoi, 2015), Musa spp. Nedunchezhiyan et al. (2012), Mangifera indica Mirjha et al. (2016), Pyrus spp. Nerlich et al. (2013) Morus alba Asati et al. (2007) Zizyphus mauritiana Sereke et al. (2014), Coffea arabica lijima et al. (2003) and Carica papaya Aiyelaagbe et al. (1992) are mainly intercropped with Fabaceae, Solanaceae, Brassicaceae and Euphorbiaceae crops.

Horti-pastures
Agroforestry system where fruit trees and forage crops are intercropped, this system is ideal for the population living in rainy areas Kumar et al. (2016). Psidium guajava Korwar et al. (2005), Annona spp. (Rakhi, 2015), Prunus spp. Nerlich et al. (2013), Zizyphus spp. Toppo et al. (2018) and Punica granatum Pareek et al. (2008) are compatible fruit trees, Stylosanthes hamata, Cenchrus ciliaris, Panicum maximum, Dicancium annulatum and natural grasses are compatible forage crops. Other horti-pasture systems are Silvo-olericulture (timber trees + annual vegetables + pastures) Saha et al. (2012), Agri-Horti-Silvi-pasture (timber trees + fruit trees + annual crops, + forage crops) (Gogoi, 2015), Agri-hortipasture (fruit trees + fodder crop + annual crop) Pareek et al. (2008).

Silvi-olericulture
Agroforestry system where mainly legume, timber, oleaginous tree and trees annual vegetables are intercropped (Handa and Dhyani, 2015). Cajanus cajan Salami et al. (2005), Gliricidia sepium (Acquaah 2009), Calliandra calothyrsus Nolte et al. (2005), Tectona grandis (Handa and Newaj, 2017), Eucalyptus spp. Dhyani et al. (2013), Poplar spp. Dhillon et al. (2012), Hevea brasiliensis He et al. (2012), Grewia optiva Verma et al. (2010) and Bambusa spp. Behera et al. (2016). Some oleaginous trees examples are Areca catechu + Ananas comosus Bhatt et al. (2006), Moringa sp. + Solanum lycopersicum Asati et al. (2007), Juglans regia + Lactuca sativa Wang et al. (2014), Elaeis guineensis + Ananas comosus Ashraf et al. (2018) and Ricinus communis + Vigna spp. y Capsicum spp. Singh et al. (2014).

Horti/Silvo-medical
Agroforestry system where fruit, wood, legume, oleaginous tree and medicinal crops are intercropped Suvera et al. (2015). Eucalyptus spp., Hevea brasiliensis, Pinus spp., Paulownia tomentosa, Bambusa spp., Cunninghamia lanceolata, Cedrus deodara, Abies spp., Acacia auriculiformis, Populus spp., Albizia lebbeck, Eucalyptus tereticornis, Gmelina arborea, Leucaena leucocephala and Areca catechu are compatible Rao et al. (2004). Coffea spp.,
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*Cocos nucifera, Musa spp., Malus spp., Mangifera indica and Theobroma spp.* are compatible fruit trees Thakur et al. (2005).

**Horti/Silvo-ornamental**

Agroforestry system where fruit, wood, legume, oleaginous tree and ornamental crops are intercropped. Fruit tree agroforestry orchards include *Psidium guajava* + *Helianthus annuus* Bhoyar et al. (2016), *Prunus domestica* + *Helianthus annuus* Nerlich et al. (2013), *Prunus domestica* + *Gladiolus sp.* Juárez et al. (2014), *Malus sylvestris* + flowers Sereke et al. (2014), *Vaccinium corymbosum* + ornamentals Workman et al. (2003) and *Diospyros virginiana* + cut flowers Workman et al. (2003).

**Horti-silviculture**

Agroforestry system where leguminous, timber and oleaginous trees are fruit trees, are intercropped. *Leucaena leucocephala, Cajanus cajan, Gliciridia sepium, Acacia spp., Tectona grandis, Eucalyptus spp., Populus spp., Hevea brasiliensis, Mangifera indica, Theobroma cacao, Musa spp., Psidium guajava* and *Citrus spp.*, are recommended. Another example is oleaginous tree species, such as *Elaeis guineensis* + *Theobroma cacao* Ashraf et al. (2018).

**Silvi-Horti-Agri/olericulture**

Agroforestry system where leguminous, timber and oleaginous trees are fruit trees, vegetables or annual crops are intercropped Rani et al. (2016), the timber tree is established in the high stratum, the fruit tree in the medium stratum and the vegetable or the annual crop in the low stratum. Some examples of this system are: *T. grandis + M. indica* + *S. longengoa* + *Abelmoschus esculentus* (Gunaga, 2017), *C. serrata + M. indica* + *Grewia sp.* + *Triticum aestivum* (Rajput, 2016) and *Trema orientalis* + *Musa spp.* + *Zea mays* or *Phaseolus spp.* or root crops Dagur et al. (2016).

**Horti-pisciculture**

Agroforestry system where leguminous, timber and oleaginous trees are fruit trees, vegetables, annual crops herbs are management synergistically along ponds in which fish is cultivated Bhardwaj et al. (2017), Handa and Dhyan (2015) report culture of *Azolla spp.*, *Oryza sativa*, annual vegetables, fruit trees, *Paulownia spp.*, *Salix spp.*, *Populus spp.*, *Tectona grandis* will can be included, data indicate that using water from fish cultures on vegetables, rice and mulberry may eliminate the need for commercial fertilizers Chang et al. (1997).

**Horti-entomoforestry**

Horti-apiculture is an agroforestry system where fruit trees and the production of honey (Singh and Dwivedi, 2018), *Pyrus pashia* Asati et al. (2007), *Litchi chinensis* Upadhyay et al. (2009), *Syzygium cumini* Karshie et al. (2017), *Coffeea spp.* Boreux et al. (2013), *Ribes spp.* Sereke et al. (2014) y *Citrus spp.* Grajales et al. (2013), *Zea mays*, *Sesamum indicum*, *Helianthus annuus*, *Medicago sativa*, *Coriandrum sativum*, *Foeniculum vulgare* and the family *Brassicaceae* are compatible Shanker et al. (2000). Horti-sericulture is an agroforestry system where *Morus spp.* y *Bombyx mori* were cultivated integrally (Singh and Dwivedi, 2018), *Antheraea mylitta*, *Phelosia ricini* and *Antheraea assamensis* are other options to integrate into this system Handa et al. (2016).

**Horticultural Agroforestry Systems for Climate Change**

Agroforestry can be a multifunctional tool for high food production, poverty population reduction, input reduction, water conservation, improved soil quality, biodiversity conservation, climate change mitigation and climate change adaptation Toppo et al. (2018). Four major ecosystem services and environmental benefits: (1) carbon sequestration, (2) biodiversity conservation, (3) soil enrichment and (4) air and water quality for not only the landowners or farmers, but for society at large (Jose 2009). Moreover, agroforestry systems so as to make them better able to handle ever-changing climate conditions and to preserve habitats and ecosystems services Castro et al. (2019).

The increased pollution of ground and surface water have provided an additional impetus for the development and adoption of agroforestry around the world Kumar et al. (2012), from the early twentieth century, with the rise of both the global population and society’s consumerism, agriculture was intensified, having a direct impact the degradation of soils, water, air, natural landscapes and biodiversity Pavlidis et al. (2018). Land intensification and degradation, energy use and inputs, complex environmental management, social issues facing farming communities and climate change are just some of the headline sustainability concerns threatening the viability of farming Fleming et al. (2019), currently the challenge is intensification methods that have not succeeded in providing sufficient food for the world population in a sustainable way and has contributed to an increase in the negative effects of climate change Mauricio et al. (2019).

The modification in microclimate potential for positive interspecific interaction exists Kumar et al. (2018), microclimate variations play a major impact on crop environment Singh et al. (2016), the presence of trees modify site microclimate in terms of temperature, water vapor content, wind speed, temperature reductions and can help reduce heat stress of crops Jose et al. (2004), wood plants also modify the microclimate by reducing evapotranspiration and moderating extremes in soil temperatures and daily photosynthetically active radiation Re et al. (2019), Shade trees modify the interception of radiant energy by the foliage of crops Monteith et al. (1991), that affect the physiology of the undergrown crop Charbonnier et al. (2017), photosynthetically active radiation and temperature are reduced, while the humidity is increased Sangwan et al.
(2017), water use efficiency and carboxylation efficiency is better Sangwan et al. (2015), reducing vulnerability, increasing resilience of farming systems against climate-related risks (NRCAR 2013; Sureshbhai et al. 2017).

The microclimate changes will impact biological processes on insect pests of crops (directly proportional to the temperature of the crops) and the increase of air humidity, can promote the development of fungal diseases like mildews and rusts. Farmers know that these diseases are more frequent near the dense hedgerows Lawson et al. (2018), more efficient management practices and new/innovative agroforestry solutions are required and must incorporate the regional and local abiotic factors of climate, soil, water and nutrient balances as well as the biotic conditions (pests, diseases and dispersal agents) Castro et al. (2019).

Climate change is the most important global environmental challenge which is facing by all living organism including humans and disturb natural ecosystems, agriculture and health. In this situation agroforestry emerge as a robust farming practice addressing food security problem by making feeds to people, mitigate adverse effects of climate change by enhancing environmental quality, sustain economic viability and enhance quality of life (Tope and Raj 2018). Global climate change threatens the sustainability of agriculture and agroforestry worldwide through increased heat, drought, surface evaporation and associated soil drying (Borland et al. 2015).

Climate change and its variability are posing the major challenges influencing the performance of agriculture including annual and perennial horticulture crop, the extreme weather events of hot and cold wave conditions have been reported to cause considerable damage to many fruit crops. The various impacts need to be addressed in a concerted and systematic manner in order to prepare the horticulture sector to face the imminent challenges (Malhotra 2017). Exposure of crops and forests to warmer and drier environments will increase leaf: air water vapor–pressure deficits (VPD) and will result in increased drought susceptibility and reduced productivity, not only in arid regions but also in tropical regions with seasonal dry periods Borland et al. (2015).

Several evaluations have documented that agroforestry systems seem to be a viable and economically viable solution for the farmer to meet the challenges of food, nutrition, energy, employment and environmental security Verma et al. (2017), especially in developing countries Pande et al. (2018). The adoption of agroforestry technologies depends on the edaphic-climatic, socio-economic status and needs of farmers Gunaga et al. (2007), normally, management is influenced by physical, demographic and, institutional factors Bayard et al. (2007).

One of the main motivations for farmers to grow simultaneously a variety of vegetables and fruits is to reduce the overall risk on production through a diversification effect Paut et al. (2018). Farmers are interested in growing annual plants among young timber trees to receive the benefits of annual fertilization and weed management. however, to obtain optimal benefits, farmers must make important initial decisions about tree species, plant density and a good understanding of their advantages and disadvantages Nissen et al. (2002). While fruit trees have a long gestation period (4-5 years) to provide income; the interspaces can be used for the cultivation of agricultural crops profitably until they develop canopy (Gunaga 2017).

However, several characteristics of the trees like slow growth, long term effects, on their surroundings, long life, area over which the influence of trees extends, etc., complicating the issue of assessment and adoption Hymavathi et al. (2010). This paper can be used in the design of policies, credits, subsidies and technical support that can help increase global adoption of horticultural agroforestry systems in farmer, urban and peri-urban zones, for increasing global food production, conserve the environment, water resources protection Pavlidis et al. (2018).

Agroforestry systems are a possible solution to restore some of the damages from farming to improve the ecosystem services associated with soil and water Udawatta et al. (2017), the primary agroforestry objective of soil conservation is to improve or maintain soil fertility aboveground and soil C stocks to mitigate climate changes Tiwari et al. (2017). The increase the number of trees planted in agricultural systems, or agroforestry can improve the productivity and sustainability of future rural agricultural landscapes Fleming et al. (2019), tree presence increase C sequestration per unit of land due to the C sequestered by the tree itself Sureshbhai et al. (2017), the potential of C sequestration is dependent on the tree component Nair et al. (2009).

According to Kyoto protocol, agroforestry is recognized as an afforestation activity that, in addition to sequestering carbon dioxide (CO₂) to soil, conserves biodiversity, protects cropland, works as a windbreak and provides food and feed to human and livestock, pollen for honey bees, wood for fuel and timber for shelters construction, so that, Agroforestry is more attractive as a land use practice for the farming community worldwide instead of cropland and forestland management systems (Abbas et al. 2017). Agroforestry also has implications for emissions of other greenhouse gases, like nitrous oxide and methane and provides opportunities for the adaptation of crop production to climate change, maintain agricultural production and enhance carbon sequestration Lawson et al. (2018).

Finally, climate change poses a great threat to agriculture and food security (Lasco et al. 2016), the increasing land-use conflicts call for the development of land-use systems that reconcile agricultural production with the provisioning of multiple ecosystem services, including
climate change mitigation. Agroforestry has been suggested as a global solution to increase land-use efficiency while reducing environmental impacts and economic risks for farmers (Paul et al. 2017). This article offers a great diversity of horticultural agroforestry systems that can be adopted by farmers in different countries around the world, these systems must be adapted according to the internal requirements of each country and synergistically promote mitigation and adaptation to global climate change.

CONCLUSION
Agri-horticulture, Horti-olericulture, Silvi-olericulture, Horti-pasture, Horti/Silvi-medicinal, Horti/Silvi-ornamental, Horti-silviculture, Horti-entomoforestry and Horti-Pisciculture are agroforestry systems recommended for climatic change mitigation and adaptation. Horticulture based agroforestry systems area possible multifunctional solution for global food security, environmental protection and mitigate and climatic change adaptation. In comparison with monoculture systems, they have better use of water, soil and light and can help reduce the application of herbicides, pesticides and fertilizers. Leucaena leucocephala, Cajanus cajan, Gliricidia sepium, Tectona grandis, Poplar spp., Hevea brasiliensis, Mangifera indica, Psidium guajava, Prunus persica, Citrus spp. and Annona squamosa are compatible tree. Fabaceae, Solanaceae, Euphorbiaceae and Brassicaceae are compatible annual vegetable. Zea mays, Triticum spp. and Sesamum indicum are compatible annual crops and Cenchrus ciliaris, Cynodon dactylon, Dicanthium annulatum are compatible grasses. We recommended national politics, subsidies, technical support and credits for global farmers.

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