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CULTIVO DE HORTALIZAS EN SISTEMAS AGROFORESTALES

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CULTIVO DE HORTALIZAS EN SISTEMAS AGROFORESTALES

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Chapingo, Estado de México, julio de 2020

CONTENIDO

DEDICATORIAS

A mis padres Irene Julieta Colmenares Blanco y Odón Roberto Montes Jarquín

A mis hermanos

A mis abuelos

A todos mis sobrinos

A toda mi familia

A los antiguos mexicanos

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RESUMEN GENERAL

CULTIVO DE HORTALIZAS EN SISTEMAS AGROFORESTALES[1]

La horticultura intensiva en monocultivo a campo abierto ofrece alimentos baratos debido a que no considera en su valor los costos negativos sobre los recursos naturales, además, el cambio climático y el envenenamiento de la población por mal uso de plaguicidas hace suponer que debemos proponer nuevas estrategias para la horticultura. La Agroforestería es una ciencia emergente que se ha desarrollado en los últimos cuarenta años y que propone un tipo de agricultura multifuncional que ofrece productos y beneficios económicos, ecológicos y sociales. El objetivo principal de la presente tesis es proponer los sistemas agroforestales hortícolas como modelos de crecimiento y desarrollo económico sostenible, climáticamente inteligente y resiliente ante el cambio climático en México. La presente tesis está conformada por seis capítulos. El primer y segundo capítulo ofrece a los horticultores mexicanos las mejores opciones de sistemas agroforestales hortícolas, así como las mejores combinaciones de árboles y vegetales para asegurar el éxito de nuevas plantaciones desde una perspectiva climáticamente resiliente y mitigadora del cambio climático. Los artículos presentados en estos capítulos son "*Horticultural agroforestry systems recommended for climatic change adaptation*" y "*Tree used in horticulture based alley cropping".* El tercer capítulo muestra un novedoso sistema agroforestal denominado Horti/Silvi- piscicultura, el cual pretende producir frutas y madera bajo un enfoque sustentable de agua y fertilizantes. El cuarto capítulo ofrece a los horticultores mexicanos la metodología básica para realizar el diagnóstico rápido de diversos parámetros relacionados con la productividad agrícola a través de un análisis de una ortofoto obtenida por un dron. El quinto capítulo muestra la propuesta de una política mexicana de agroforestería de precisión. Y finalmente, debido a que la India es el país con mayor investigación agroforestal, el sexto capítulo muestra algunas posibles intervenciones tecnológicas de la Agroforestería 4.0 en la política agroforestal de la India, esto con el objetivo de promover su adopción tanto en la India como en México. Los sistemas agroforestales hortícolas de precisión pueden suponer una nueva propuesta de horticultura hacia el futuro.

Palabras clave: Agroforestería, Horticultura, Silvoarable, Agricultura de precisión

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[1] Tesis de Doctorado en Ciencias en Horticultura. Universidad Autónoma Chapingo.
Autor: Odón Roberto Montes Colmenares. Director: Dr. Rogelio Castro Brindis.

GENERAL SUMMARY

VEGETABLE CULTIVATION IN AGROFORESTRY SYSTEMS[2]

The open field intensive monoculture horticulture offers affordable food because it does not consider the negative costs of natural resources, in addition, climate change and the poisoning of the population due to the misuse of pesticides suggests that we must propose new horticultural strategies. Agroforestry is an emerging science that has been developed in the last forty years. It proposes a type of multifunctional agriculture that offers products as well as economic, ecological and social benefits. The main objective of this thesis is to propose horticultural agroforestry systems as models of growth and sustainable economic development, climate friendly and resilient to climate change in Mexico. This thesis is made up of six chapters. The first and second chapter offer Mexican horticulturists the best options for horticultural agroforestry systems, as well as the best combinations of trees and vegetables to guarantee the success of new plantations from a climate resilient and climate mitigating perspective. The articles presented in these chapters are "Horticultural agroforestry systems recommended for climatic change adaptation" and "Tree used in horticultural based alley cropping". The third chapter shows a novel agroforestry system called Horti / Silviculture, which aims to produce fruits and wood under a sustainable water and fertilizers approach. The fourth chapter offers Mexican horticulturists the basic methodology to carry out the rapid diagnosis of various parameters related to agricultural productivity through an analysis of an orthophoto obtained by a drone. The fifth chapter shows the proposal for a Mexican precision agroforestry policy. And finally, because India is the country with the most agroforestry research, the sixth chapter shows some possible technological interventions of Agroforestry 4.0 in the agroforestry policy of India, as for the aim of promoting its adoption both in India and Mexico. Precision horticultural agroforestry systems may represent a new horticultural proposal for the future.

Keywords: Agroforestry, Horticulture, Silvoarable, Presicion agriculture

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[2] Thesis, Ph.D. in Horticultural Sciences. Universidad Autónoma Chapingo.
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CAPÍTULO I. INTRODUCCIÓN GENERAL

Los métodos de producción intensivos en monocultivo no han logrado proporcionar alimentos suficientes para la población mundial de manera sostenible y además, han contribuido al aumento de los efectos negativos del cambio climático (Mauricio et al., 2019). La horticultura intensiva en monocultivo a campo abierto ofrece alimentos baratos debido a que no considera en su valor los costos negativos sobre los recursos naturales, además, el cambio climático y el envenenamiento de la población por mal uso de pesticidas hace suponer que debemos proponer nuevas estrategias para la horticultura.

En respuesta y para enfrentar esta problemática, la Agroforestería es una ciencia emergente que se ha desarrollado en los últimos cuarenta años y que propone un tipo de agricultura multifuncional que ofrece productos y beneficios económicos, ecológicos y sociales. El objetivo principal de la presente tesis es proponer los sistemas agroforestales hortícolas como modelos de crecimiento y desarrollo económico sostenible, climáticamente inteligente y resiliente ante el cambio climático en México. A esta luz, a continuación se presentan cinco artículos científicos que brindan un amplio espectro del estado del conocimiento de los sistemas agroforestales hortícolas mundiales.

El primer artículo denominado "*Horticultural agroforestry systems recommended for climatic change adaptation*" publicado en la revista *Agricultural Reviews* ofrece a los horticultores mexicanos diversas opciones agroforestales para manejar su cultivo hortícola preferido desde una perspectiva climáticamente resiliente y mitigadora del cambio climático. Los sistemas agroforestales muestran ventajas climáticas ya que ayudan a los cultivos a través a reducir el estrés por calor, aumentar la humedad del ambiente, reducir de la velocidad del viento (Jose et al., 2004), mantener cierta estabilidad micro-climática y ofrecer un grado de adaptación a climas extremos (Wu et al., 2016). Adicionalmente el potencial de secuestro de carbono de los sistemas agroforestales ha atraído la atención mundial tras su reconocimiento como una importante estrategia de mitigación de gases de efecto invernadero en el Protocolo de Kyoto (Takimoto et al., 2008).

Enseguida el segundo artículo denominado "*Tree used in horticulture based alley cropping"* publicado en la revista *Journal of Applied Horticulture* ofrece a los horticultores mexicanos información sobre las mejores combinaciones de árboles y vegetales anuales para el asegurar éxito de nuevas plantaciones de hortalizas anuales en cultivos de callejones, *Mangifera indica, Psidium guajava, Citrus spp., Leucaena spp., Gliricidia sepium, Cajanus cajan, Populus spp., Eucalyptus, Hevea brasiliensis* son los principales árboles utilizados. Las familias *Fabaceae, Brassicaceae, Solanaceae* y cultivos de tubérculo son las principales vegetales anuales asociadas.

El cultivo en callejones (alley cropping/farming) es el sistema agroforestal mas estudiado, debido a su facilidad de ser mecanizado en comparación con otros sistemas agroforestales, además tiene el potencial de reducir la erosión del suelo, mejorar la eficiencia en el uso de agua y nutrientes, aumentar la biodiversidad, diversificar los ingresos, reducir el riesgo financiero (Wolz et al., 2018), y promover mayores ingresos económicos totales a los agricultores por año (Tiwari et al., 2017). Para asegurar el éxito de la plantación en callejones es determinante una buena selección de la combinación de especies arbóreas y vegetales anuales (Kaushik et al., 2017).

A nivel mundial existen fundamentalmente tres tipos de árboles utilizados asociados a cultivos hortícolas: arboles leguminosos, maderables y frutales. Los árboles frutales tienen un largo período de desarrollo por lo que recibir beneficios económicos (4 y 5 años) es tardado, los espacios intermedios entre los árboles se pueden aprovechar para el cultivo de hortalizas anuales de manera rentable hasta que los arboles desarrollen el dosel (Gunaga, 2017), por su parte los arboles leguminosos en sistema de "arboles de barbecho" ofrecen importantes cantidades de abono orgánico con excelentes cualidades para los suelos hortícolas. Y finalmente los arboles maderables ofrecen la captura de importantes cantidades de carbono, la reducción de erosión, la reducción del viento, material para combustible, entre otros.

El tercer artículo denominado "*Horti/Silvi- pisciculture: agroforestry system for the efficient use of water and fertilizers* publicado en la revista *International Journal of Recent Scientific Research* ofrece a los horticultores mexicanos diversas combinaciones de este sistema agroforestal en donde se cultivan árboles frutales, hortalizas anuales, plantas medicinales, especias, arboles maderables y peces. Los árboles fijan el suelo de las paredes de los estanques o cuerpos de agua, además, mientras que el agua de los peces presenta nutrientes útiles como fertilizantes para los árboles frutales y los cultivos asociados, además algunas hojas de algunos árboles se utilizan como alimento de los peces. La producción de hortalizas es una actividad de altos requerimientos de agua y nutrientes, por lo que generar sistemas de producción con altas eficiencias de estos insumos es muy relevante.

El cuarto articulo denominado "*Fast analysis of plant health, plant count and nitrogen status using drones"* publicado en la revista *Research on Crops* muestra el uso de dos aplicaciones actuales de agricultura de presicion, DroneDeploy y Agremo. En este trabajo se ofrece a los horticultores mexicanos la metodología básica para realizar un vuelo con un dron agrícola y que les permita realizar el diagnostico rápido de diversos parámetros productivos realizando un análisis de la ortofoto. Los recursos naturales limitados, el alto costo de los insumos agrícolas, la degradación ambiental y el envenenamiento de la población por mal uso de pesticidas están promoviendo la agricultura de precisión, por lo que los drones se han vuelto ampliamente disponibles para su uso en la horticultura.

El quinto capítulo muestra la propuesta de una política mexicana de agroforestería de precisión, para promover el crecimiento económico de México a través de una agricultura climáticamente inteligente y una economía resistente para cambio climático. La política incluye cultivos hortícolas mexicanos consolidados y algunos con potencial comercial. Las herramientas y tecnologías de agricultura de precisión son cada vez más útiles en el sector forestal y agroforestal. La agroforestería es una agricultura multifuncional que ha llevado a varios países a desarrollar iniciativas y políticas agroforestales nacionales.

Con la información generada en los primeros artículos, esta política propone el establecimiento de dieciséis sistemas agroforestales hortícolas, las plantaciones serán diagnosticadas con el uso de drones y aplicaciones agrícolas especializadas, con la información recopilada, la aplicación de agro-insumos correspondientes se llevarán a cabo con el uso de un dron pulverizador multirotor modelo DJI AGRAS T16. El gobierno mexicano ofrecerá solo cincuenta especies de árboles y proporcionará asesoramiento técnico agroforestal personal. México es el centro de origen y domesticación de varias especies agrícolas, la implementación de esta política favorecerá su cuidado y preservación.

La intensificación y degradación de la tierra, el uso de energía y los insumos, la gestión ambiental compleja, los problemas sociales que enfrentan las comunidades agrícolas y el cambio climático son solo algunas de las principales preocupaciones de sostenibilidad que amenazan la viabilidad de la agricultura (Fleming et al., 2019). Finalmente, el sexto articulo muestra avances de la Agrofrestería 4.0 en la política nacional agroforestal de la India. Los sistemas agroforestales hortícolas de precisión pueden suponer una nueva propuesta de horticultura hacia el futuro. La horticultura rumbo al futuro debe de adoptar nuevos modelos que sean económicamente rentables, eficientes en el uso de los recursos naturales e insumos sintéticos, protectores de la biodiversidad y agro-biodiversidad, climáticamente resilientes, y que mitiguen el cambio climático.

1.1 Objetivos

General

Proponer los sistemas agroforestales hortícolas como modelos de crecimiento y desarrollo económico sostenible, climáticamente inteligente y resiliente ante el cambio climático en México

Específicos

Seleccionar y ofrecer a los horticultores mexicanos los mejores sistemas agroforestales hortícolas y los mejores árboles compatibles para establecer nuevas plantaciones y mitigar el cambio climático

Seleccionar y ofrecer a los horticultores mexicanos algunas de las combinaciones utilizadas en la Horti/Silvi- piscicultura para promover alta eficiencia en el uso de agua, fertilizantes, contribuir a la adopción de los horticultores y la investigación científica.

Analizar tres parámetros agrícolas utilizando drones y aplicaciones agrícolas especializadas para realizar diagnósticos rápidos que permitan tomar decisiones de manejo en los cultivos hortícolas.

Diseñar una propuesta de política agroforestal mexicana de precisión para desarrollar sosteniblemente la producción de hortalizas en México

1.2 Hipótesis general

Los sistemas agroforestales hortícolas pueden ser modelos de desarrollo en México debido a que son sistemas de producción seminaturales que enlazan una alta producción de hortalizas con la producción de servicios ecosistémicos, la mitigación del cambio climático y mayor eficiencia en el uso de agroquímicos y recursos naturales.

CAPÍTULO II HORTICULTURAL AGROFORESTRY SYSTEMS RECOMMENDED FOR CLIMATIC CHANGE ADAPTATION

RESUMEN

Los altos costos de los insumos, la degradación ambiental y el cambio climático han generado nuevos desafíos en el sector agrícola, hortícola y forestal. El objetivo de este trabajo es identificar los principales sistemas agroforestales hortícolas útiles para la adaptación y mitigación del cambio climático. Agro-horticultura, Horti-olericultura, Silvi-olericultura, Horti-pastura, Horti/ Silvo-medicinal, Horti/Silvo-ornamental, Horti-silvicultura, Horti-entomoforestry y Horti-Pisciculture son sistemas agroforestales hortícolas recomendados. Los sistemas agroforestales en comparación con los sistemas de monocultivo, tienen un mejor uso del agua, el suelo y la luz, pueden ayudar a reducir la aplicación de herbicidas, fungicidas, pesticidas, fertilizantes, aumentar la seguridad alimentaria, la protección de la biodiversidad y la adaptación al cambio climático. Recomendamos políticas nacionales, subsidios, asistencia técnica y créditos para los agricultores mundiales.

Palabras clave: Vegetal anual, Árbol frutal, Cultivo medicinal, Cultivo ornamental

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-medicinal, Horti/Silvo-ornamental, Horti-silviculture, 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.

Keywords: Annual vegetable, Fruit tree, Medicinal crop, Ornamental crop

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-medicinal, Horti/Silvo-ornamental, Horti-silviculture, Horti-entomoforestry* and *Horti-Piscicultue* 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).

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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 Pande *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 on going climate change problem for better well-being of mankind. The recommendation is to use well-adapted tree-crop combinations, thereby limiting competition for resources and maximizing synergies Pardon *et al*. (2018), to optimize plant density, the seeding rate of each crop on the mixture is adjusted below the full rate to reduce competition from overcrowding Ouma *et al.* (2010). All the different components of agroforestry systems are continuously interacting. Their interactions are determined by the management of the system, including the selection of species and their functional characteristics, planting density, stratification and fertilization regime Niether *et al.* (2019).

At the present day, the climate change mitigation and food security are two of the main challenges of human society Feliciano *et al*. (2018), the promotion of agroforestry as a mitigation practice requires an understanding of the economic benefits and its acceptability to farmers De Giusti *et al.* (2019), so it is recommended that farmers can recognize the agroforestry effect combining ecological services and diversified production, it is more stable and resilient over time than monocultures with respect to climate change and price volatility of agricultural products Vaast *et al.* (2016).

Finally, the climate change is affecting all economic sectors and ecosystems (Raj, 2017), Agroforestry land use has the real potential to contribute to food security, climate change mitigation and adaptation while preserving and strengthening the environmental resource base of rural landscapes Mbow *et al.* (2014), Agroforestry should be a major climate-smart agriculture option as it combines sustainable production with adaptation and mitigation of climate change Vaast *et al.* (2016), so that, the main objective of this paper was to identify the main horticultural agroforestry systems useful for climate change mitigation and adaptation.

The search for scientific papers was performed between January and September 2019, at Universidad Autónoma Chapingo Mexico, considering publications on agroforestry systems with a horticultural component, using SCOPUS, Web of Science and SciELO databases.

HORTICULTURE BASED AGROFORESTRY SYSTEMS

Agri-horticulture

Agroforestry system where fruit trees and annual crops are intercropped Bhardwaj *et al.* (2017), fruit trees and field crops can be grown together in many variations Lallianthanga *et al.* (2014). *Mangifera indica* Das *et al.* (2017)*, Psidium guajava* (Swain, 2016)*, Citrus spp.* Dubey *et al.* (2016)*, Prunus spp.* Bellow *et al.* (2008)*, Malus spp.* Hong *et al.* (2017)*, Annona squamosa* Raj *et al.* (2019)*, Pyrus sp.* Song *et al*. (2010) *and Cocos nucifera* Maheswarappa *et al.* (2010) are mainly intercropped with *Zea mays, Triticum spp*., *Sesamum indicum and Sorghum spp.*

Horti-olericulture

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* Iijima *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, *Stylosanthus hamata, Cenchrus ciliaris*, *Panicum máximum*, *Dicanthium annulatum and* natural grasses are compatible forage crops. Other horti-pasture systems are Silvo-oleri-pasture (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 callothyrsus* 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 *Arecha 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-medicinal

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.,* *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* + *Hellianthus annuus* Bhoyar *et al.* (2016), *Prunus domestica* + *Hellianthus 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, Gliricidia 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. melongena* o *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 Dagar *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 Dhyani (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), *Syzygum cumini* Karshie *et al.* (2017), *Coffea spp.* Boreux *et al.* (2013), *Ribes spp*. Sereke *et al.* (2014) y *Citrus spp.* Grajales *et al.* (2013), *Zea mays*, *Sesamun 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 myllitte*, *Phelosamia 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 foliar 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 (Toppo 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 (CO_2) 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* and *Dicanthium annulatum* are compatible grasses. We recommended national politics, subsidies, technical support and credits for global farmers.

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CAPÍTULO III TREE USED IN HORTICULTURE BASED ALLEY CROPPING

RESUMEN

El objetivo principal de este trabajo es la selección de la combinación de árboles y vegetales para el éxito en nuevas plantaciones de cultivos de callejones basados en horticultura, frutas, leguminosas y árboles de madera se integran en varias asociaciones con vegetales anuales, *Mangifera indica, Psidium guajava, Citrus spp., Leucaena spp. , Gliricidia sepium, Cajanus cajan, Populus spp., Eucalyptus, Hevea brasiliensis* son los principales árboles utilizados. Las familias *Fabaceae, Brassicaceae, Solanaceae* y tubérculos son los principales cultivos vegetales asociados. Este sistema se puede adaptar a agricultores, regiones y países específicos para los requisitos de verduras, frutas y madera. Los créditos y subsidios específicos pueden aumentar el capital natural, económico y social del mundo.

Palabras clave: Agroforestería, árbol frutal, árbol de leguminosas, árbol de madera, vegetales anuales, sistema silvoarable.

ABSTRACT

Main objective of this paper is selection of tree and vegetable combination for success in new horticulture based alley cropping plantations, fruit, legume and wood tree are integrated in several associations with annual vegetable, *Mangifera indica, Psidium guajava, Citrus spp., Leucaena spp., Gliricidia sepium, Cajanus cajan, Populus spp., Eucalyptus, Hevea brasiliensis* are the main tree used. *Fabaceae, Brassicaceae, Solanaceae* families and tuber crops are the main associated vegetable crops. This system can be adapted for specific farmers, regions, and countries for vegetable, fruit and wood requirements. The specific credits and subsidies can increase natural, economic, social capital of the world.

Keywords: Agroforestry, fruit tree, legume tree, wood tree, annual vegetable, silvoarable system

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Tree used in horticulture based alley cropping

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Abstract

Main objective of this paper is selection of tree and vegetable combination for success in new horticulture based alley cropping plantations, fruit, legume and wood tree are integrated in several associations whit annual vegetable, *Mangifera indica, Psidium guajava, Citrus spp., Leucaena spp., Gliricidia sepium, Cajanus cajan, Populus spp., Eucalyptus, Hevea brasiliensis* are main tree used. *Fabaceae, Brassicaceae, Solanaceae* families and tuber crops are main vegetable crops associated. This system can have adapted for specific farmers, regions, and countries for vegetable, fruit and wood requirements. The specific credits and subsidies can increase natural, economic, social capital of the world.

Key words: Agroforestry, fruit tree, legume tree, wood tree, annual vegetable, silvoarable system

Introduction

The horticulture associated with trees is not new, several combinations and arrangements have been developed in different parts of the world to domesticate, produce and improve some vegetable and fruit tree species. Actually, the horticulture based alley cropping systems (agroforestry) combined perennial woody crops and non-woody crops (Martin *et al*., 2019), the vegetables are arranged spatially for farmers in order to achieve both the economic and environmental benefits of the farming system (Mercado *et al*., 2008), and the choice of crops is also determined by the technical factors like agro-climatic and edaphic conditions, with crops with different rooting systems, a different pattern of water and nutrient demands and a different above ground habits (Pandey *et al*., 2017).

Vegetable crops in alley cropping recommended are short durational and shade loving crops with high efficiency of photosynthesis and biological fixation (Singh *et al*., 2018). Some criteria for selecting of horticultural intercrops are: 1. early maturing. 2. shade tolerance. 3. should not compete with the perennial companion crop. 4. should not be more susceptible than the main crop to diseases they have common (Dhakar *et al*., 2013). Theoretically, C3 plants planted under shade should be able to perform better than C4 plants and could be better suited for agroforestry practices (Jose *et al*., 2004), and, the crop variety, management of crops and trees, seasonal climate variability (Bellow *et al*., 2008), and socio-economic suitability contribute to system performance (Dhakar *et al*., 2013).

The tree component election is very important for the success of agroforestry plantation, depending of species, trees checking erosion also ameliorate soil in terms of increasing organic matter, fixing nitrogen, and nutrient uptake and recycling through litter fall (Pande *et al*., 2018), for example the fast-growing wood tree species in combination with horticultural crop may increase the employment generation for the nursery growers, local labors and small scale wood industries (Shukla *et al*., 2018), and legume tree for "fallow system" (Kang *et al.*, 1985) provides nitrogen through biological fixation, and help in solubilizing insoluble P in soil, improving the soil physical environment, increasing soil microbial activity, restoring organic matter, and also has smothering effect on weed (Ghosh *et al*., 2007).

In another hand, horticulture becoming problematic as the drainage effluent contains drained nutrients, salts and residues of agro-chemicals and affects the health of reservoirs, rivers and inland seas into which it is discharged (Fanish and Priya, 2013), in response agroforestry is being viewed as a restoration agent, rehabilitation process, bio remediation (Asati *et al*., 2007), ameliorate soil health (Dhewa and Daniel, 2017), and the biodrainage plantations purify our environment by absorbing greenhouse gases (Fanish and Priya, 2013). So that, agroforestry systems are a biodiversity-friendly alternative to food and wood production (Oliveira *et al*., 2019).

Finally, alley cropping system is one of the most common agroforestry practices around the world (Wolz and DeLucia, 2018), vegetables provides regular income to the farmers during the early stages of tree establishment (Kaushik *et al*., 2017), and is an economically feasible way to protect crop plants from extremes in microclimate and soil moisture and should be considered a potential adaptive strategy for farmers in areas that will suffer from extremes in climate (Lin, 2007), the main objective of this paper is selection of tree and vegetable combination for success in new horticulture based alley cropping plantations.

Legume tree

The advantages of legume tree in vegetable production based agroforestry systems include: nitrogen fixation, insect pest reduction, disease prevention (Blair *et al*., 2016; Majumdar, 2011), increase water infiltration (Chaturvedi *et al*., 2018), promote soil health, increase nutrient availability, reduce fertilizer requirement, and soil erosion control (Palada *et al*., 1992) and others. Legume tree, mainly use for "fallow system", and the amount of nutrients provided by pruning's are determined by the production rate and nutrient concentrations, both depending on climate, soil type, tree species, plant part, tree density and tree pruning regime (Palm, 1995), the asynchrony of nutrient release (mulch application) from alley cropping pruning's and nutrient demand from the crops is often the main cause for low crop N use efficiency and yield (Seiter and Horwath, 1999), right away are the main leguminous trees used and scientifically validated for use in this type of plantations.

***Leucaena leucocephala*:** *Leucaena leucocephala* is native to Central America (Nehdi *et al*., 2014), diversified uses such as cattle and human food, firewood, timber, shade, green manure, soil erosion control, soil health enrichment, windbreaks, fire break, etc. (Harun-Ur *et al*., 2018). Tree requires warm temperatures for optimal growth, and is drought-tolerant (4m x 0.5m usually recommended), the tree can repeat harvest of the foliage (7-10 month after established) up to 10 times a year (Honda *et al*., 2019), usually, application of pruning's resulted in higher soil moisture retention, organic matter, exchangeable K, Ca, Mg, and also nitrate levels in the soil solution (Kang *et al*., 1985). This is a tree more used in horticulture based alley cropping. *Vigna sp., Manihot esculenta,* and *Ipomoea batatas* are some annual vegetables cultivated in *Leucaena* alley cropping.

Palada *et al.* (1992) concluded that pruning's provide significant amounts of N, P, K and Ca, and four vegetables in alley cropping can reduce fertilizer requirement, Insaidoo and Quarshie (2007) concluded that with adequate water, the half rate fertilizer can be efficient particularly when combined with pruning's, so that this system could reduce *Solanum melongena* fertilizer requirement, moreover with lack of significant change of pH, K and Mg levels in the soil. Zaki *et al.* (2017) concluded that moderate nitrogen fertilization produced higher total growth parameters of *Pisum sativum in Leucaena* alley cropping. While, *Abelmoschus esculentus* cultivars were higher yield in the alley than the non-alley field, moreover suggesting that *L. leucocephala* planted as alley crops have the potential to suppress nematode populations (Adekunle, 2009). Table 1 shows another vegetables crops and fruit tree in *L. leucocephala* alley cropping.

Cajanus cajan: *Cajanus cajan* is a multipurpose tree (Zu et al., 2006), it is an important food legume crop in the semi-arid regions of the world (Varshney *et al*., 2010), moreover tree grows well in the P-deficient soils of the tropical environment (Fujita *et al*., 2004), and combines high tolerance to environmental stresses, and provides high biomass productivity (Odeny, 2007), additionally tree improve soil fertility, fodder and firewood, and mulching has provided an alternative for this reliance on inorganic fertilizers and provides the much needed organic material to maintain soil productivity (Abugre and Twum, 2011), *Manihot esculenta, Ipomoea batatas,* and *Vigna spp.* are annual vegetables cultivated in *Cajanus cajan* alley cropping.

Alves *et al*. (2004) concluded that biomass incorporation a high positive N-balance was found, uptake of P increased significantly after biomass incorporation in *Beta vulgaris* and *Daucus carota* crops. In another hand, *Solanum lycopersicum* highest yield (9.35 tons/ha) was obtained at the highest rate of mulch/fertilizer interaction (15 tons/ha and 150 kg N/ha), and mulch would reduce the dependence on inorganic fertilizers (Abugre and Twum, 2011). Table 1 shows another vegetables crops and fruit tree in *Cajanus cajan* alley cropping and another legume tree.

Gliricidia sepium: *Gliricidia sepium* is a medium size tree*,* is native to tropical zone of Central America (Montero *et al*., 2017), it is integrated into farming practices for poles, firewood, hedges, forage, green manure and soil stabilization, pruning's cutting interval of 6-12 weeks is usually recommended (Suttie, 2015), leaves release máximum nitrogen within 15 days (Kumar *et al*., 2016). Tree grows best in tropical, seasonally dry climates (4-6m x 0.5m usually recommended) (Adekunle, 2009). It is widely used to provide crop shade for coffee, cacao and other shade loving crops and other shade loving crops (Marak and Wani, 2018). *Manihot esculenta, Vigna spp.,* and *Brassica oleracea* are some annual vegetables cultivated in *Gliricidia* alley cropping.

Kuntashula *et al*. (2004) concluded the highest cabbage and onion yields were obtained from manure + half rate fertilizer application. Olasantan (2000) concluded that pruning's applied (mulch) with application of 30 kg ha^{-1} gave more economical in *Abelmoschus esculentus* and *Solanum lycopersicum* yield than application of 60 kg ha^{-1}. Paulino *et al*. (2011) concluding that the quantity of N added to the orchard with *Gliricidia* pruning's was higher than the recommended fertilization for *Mangifera indica* and soursop tree plots, quantities of P and K added to the orchard were not enough to supply the fertilization demanded for both cultures. Table 1 shows another vegetables crops and fruit tree in *Gliricidia* alley cropping.

Wood tree

Vegetable based alley cropping offer synergic fulfil the demand of vegetable crops and timber to human and industry (Bhusara *et al*., 2018), many farmers are inclined to intercrop young timber trees with well-fertilized annuals to confer nutrient and weeding benefits to the trees while gaining a short-term return on the land (Nissen *et al*., 2001) usually the rows are planted in a North-south orientation (Newman *et al*., 1997), for to derive optimal benefits from intercropping timber, farmers should make important initial decisions on tree species and planting density with a good understanding of their tradeoffs (Nissen and Midmore, 2002).

Tectona grandis: Teak (*Tectona grandis*) is an specie of tropical regions and is native to India, and can grow under a wide range of climatic and edaphic conditions (Singh *et al*., 2017), it is one of the most valuable tropical hardwood species in the international timber market (Deb *et al*., 2017), teak alley cropping involving high-value crops for example, banana, pineapple, fruit trees, coffee, etc. (Pachas *et al*., 2019) and others, depending of crop intercropped, 3m x 2m recommended (Patel *et al*., 2018). *Capsicum spp., Solanum tuberosum,* and *Solanum melongena* are some annual vegetables cultivated in *Tectona grandis* alley cropping. *Solanum melongena* L. increase in various growth as well as yield parameters under teak system as compared to monocrop, number of fruits per plant, fruit circumference, fruit length, average fruit weight and yield (Sondarva *et al*., 2018), similarly various cucurbitaceous crops under teak can provide additional income to the teak farmers recommended (Patel *et al*., 2018). Table 2 shows another vegetables crops and fruit tree in *Tectona grandis* alley cropping.

Hevea brasiliensis: *Hevea brasiliensis* is a tree belonging to the *Euphorbiaceae* family, indigenous to the tropical forests of the Amazon basin (Wadeesirisak *et al*., 2017), and is the worldwide main commercial source of natural rubber (Zhang *et al*., 2019), it is susceptible to low temperatures (Chen *et al*., 2019). The intercropping system generally adopted in rubber cultivation in

Table 1. Legume tree + annual vegetable and fruit tree

Legume tree	Annual vegetable and fruit tree	Reference
Leucaena leucocephala *Leucaena* spp.	(1) *Vigna sp.,* (2) *Manihot esculenta,* (3) *Ananas comosus,* (4) *Dioscorea spp.,* (5) *Solanum melongena,* (6) *Solanum tuberosum,* (7) *Coriandum sativum,* (8) *Solanum lycopersicum,* (9) *Capsicum annuum,* (10) *Brassica oleracea,* (11) *Curcuma longa,* (12) *Abelmoschus esculentus,* (13) *Pisum sativum,* (14) *Ipomoea batatas,* (15) *Allium cepa, (*16) *Cucurbita sp.,* (17) *Tagetes minuta,* (18) *Ocimum basilicum,* (19) vegetables.	(1) (Akinnifesi *et al*., 1998; Atta-Krah, 1990; Chaturvedi et al., 2001; Duguma *et al*., 1988; Ghosh *et al*., 2007; Hulugalle and Kang, 1990; Jha and Chaturdevi, 1995; Kang *et al*., 1985; Lal, 1989; Lawson and Kang, 1990; Mittal and Singh, 1989; Ngambeki, 1985; Paningbatan, 1986; Schroth, 1995; Singh and Van den Beldt, 1989; Ssekabembe, 1985; Vanlauwe *et al*., 1998; Vinaya and Suresh, 1988), (2) (Atayese *et al*., 1993; Barreto and Fernandes, 2001; Bayard *et al*., 2007; Dhakar *et al*., 2013; Ernst, 1994; Fagbola *et al*., 1998; Hy *et al*., 2002; Leihner *et al*., 1996; Liasu *et al*., 2006; Moura *et al*., 2017; Osonubi *et al*., 1995; Oyetunji and Osonubi, 2007; Oyetunji *et al*., 2003; Schroth, 1995; Singh, 1987; Tonye, 1989; Tonye *et al*., 1994), (3) (Adinya *et al*., 2010; Asati *et al*., 2007; Firoz *et al*., 2012; Gogoi, 2015), (4) (Budelman, 1990; Dhakar *et al*., 2013; Schroth, 1995), (5) (Insaidoo and Quarshie, 2007), (6) (Brook, 1992; Yamoah *et al*., 1989), (7) (Schroth *et al*., 2000), (8) (Palada *et al*., 1992), (9) (Soreng and Kerketta, 2017), (10) (Mappaona *et al*., 1994), (11) *(Adekunle, 2009; Narain et al.*, 1997), (12) (Palada *et al*., 1992), (13) (Zaki *et al*., 2016), (14) (Balasubramanian and Sekayange, 1991), (15) (Kuntashula *et al*., 2004), (16) (Sampaio *et al*., 2015), (17) (Thakur *et al*., 2005), (18) (Verma *et al*., 2017), (19) (Upadhyay and Yadava, 2009).
	(1) *Theobroma grandiflorum* and *T. cacao,* (2) *Musa spp*., (3) *Citrus aurantium,* (4) *Citrus reticulata,* (5) *Coffea spp.,* (6) *Cocos nucifera,* (7) *Citrus aurantifolia,* (8) *Carica papaya,* (9) fruit tree.	(1) (Oelbermann *et al*., 2004; Sampaio *et al*., 2015; Schroth *et al*., 2000; Singh, 1987), (2) (Schroth and Sinclair, 2003; Singh, 1987; Wilson and Swennen, 1989), (3) (Abd-allah *et al.*, 1999), (4) (Abd-allah *et al*., 1999), (5) (Schroth *et al*., 2000), (6) (Schroth and Sinclair, 2003), (7) (Dyal *et al*., 1996), (8) (Hymavathi *et al*., 2010), (9) (Hymavathi *et al*., 2010).
Cajanus cajan	(1) *Manihot esculenta,* (2) *Ipomoea batatas,* (3) *Vigna spp.,* (4) *Dacus carota,* (5) *Ananas comosus,* (6) *Capsicum annuum,* (7) *Beta vulgaris,* (8) *Phaseolus spp.,* (9) *Dioscorea spp.,* (10) *Solanum lycopersicum.*	(1) (Akondé *et al*., 1997; Atayese *et al*., 1993; Ernst, 1994; Leihner *et al*., 1996; Lose *et al*., 2003; Murray and Bannister, 2004; Salami *et al*., 2005), (2) (Brook, 1992; Isaac *et al*., 2003; Kang, 1993; Murray and Bannister, 2004; Nedunchezhiyan *et al*., 2012), (3) (Blair *et al*., 2016; Kang, 1993; Kang *et al*., 1985; Singh, 2016), (4) (Alves *et al*., 2004; Isaac *et al*., 2003), (5) (Firoz *et al*., 2012; Murray and Bannister, 2004), (6) (Palada *et al*., 1992), (7) *(Alves et al*., 2004), (8) (Alves *et al*., 2004; Isaac *et al*., 2003), (9) (Murray and Bannister, 2004), (10) (Abugre and Twum, 2011).
	(1) *Prunus sp.,* (2) *Mussa sp*., (3) *Citrifolia sinensis,* (4) *Santalum yasi,* (5) *Carica papaya,* (6) *Psidium guajava*, (7) *Annona squamosa*, (8) *Acharus sapota*, (9) *Tamarindus indica.*	(1) (Alves *et al*., 2004; Murray and Bannister, 2004), (2) (Sangwan *et al*., 2015), (3) (Harrison and Harrison, 2016), (4) (Harrison and Harrison, 2016), (5) (Jakhar *et al*., 2010), (6) (Pareek and Awasthi, 2008), (7) (Pareek and Awasthi, 2008), (8) (Pareek and Awasthi, 2008), (9) (Pareek and Awasthi, 2008).
Gliricidia sepiumG. maculata	(1) *Manihot esculenta,* (2) *Vigna spp.,* (3) *Dioscorea spp.,* (4) *Brassica oleracea,* (5) *Abelmoschus esculentum,* (6) *Capsicum frutescens,* (7) *Solanum melongena,* (8) *Solanum lycopersicum,* (9) *Allium cepa,* (10) *Ipomoea batatas,* (11) vegetables.	(1) (Amara *et al*., 1996; Barreto and Fernandes, 2001; Böhringer and Leihner, 1996; Evensen *et al*., 1995; Ghuman *et al*., 1991; Kass *et al*., 1992; Lose *et al*., 2003; Moura *et al*., 2017; Oelbermann *et al*., 2004; Okon, 2011; Osonubi *et al*., 1995; Kass 1987.; Salami and Osonubi, 2003; Tonye *et al*., 1994; Wilson *et al*., 1986), (2) (Budelman, 1990; Budelman and Pinners, 1987; Duguma *et al*., 1988; Evensen *et al*., 1995; Hulugalle and Kang, 1990; Lawson and Kang, 1990; Paningbatan, 1986), (3) (Schroth, 1995), (4) (Kuntashula *et al*., 2004; Mafongoya and Jiri, 2016; Ribeiro *et al*., 2018), (5) (Adekunle, 2009; Olasantan, 2000; Schroth *et al*., 1995), (6) (Iijima *et al*., 2003), (7) (Mafongoya and Jiri, 2016; Palada *et al*., 1992), (8) (Olasantan, 2000; Wilson *et al*., 1986), (9) (Mafongoya and Jiri, 2016), (10) (Brook, 1992), (11) (Upadhyay and Yadava, 2009).
	(1) *Theobroma cacao,* (2) *Carica papaya,* (3) *Musa sp.,* (4) *Mangifera sp.,* (5) *Anona muricata., (6) Cocos nucifera*	(1) (Lasco *et al*., 2001; Schroth *et al*., 2000), (2) (Jakhar *et al*., 2010; Ribeiro *et al*., 2018), (3) (de Paula *et al.*, 2015), (4) (Paulino *et al*., 2011), (5) (Paulino et al., 2011), (6) (Kaba *et al*., 2019).
Acacia auriculiformis *A. lenticularis,* *A. stenophylla,* *A. tortills,* *A. indica*	(1) *Capsicum annuum,* (2) *Ipomoea batatas,* (3) *Vigna radiata,* (4) *Manihot esculenta,* (5) *Pisum sativum,* (6) *Vicia faba,* (7) *Dacus carota,* (8) *Solanum tuberosum,* (9) *Cicer arientinum,* (10) *Allium sativum,* (11) *Pachyrhizus erosus,* (12) *Solanum lycopersicum,* (13) *Cucumis sativum,* (14) *Raphanus raphanistrum*, (15) *Ananas comosus.*	(1) (Chaturvedi *et al*., 2001; Shapo and Adam, 2008), (2) (Brook, 1992; Chaturvedi *et al*., 2001), (3) (Chaturvedi *et al*., 2001), (4) (Chaturvedi *et al*., 2001), (5) (Schroth *et al*., 2000), (6) (Shapo and Adam, 2008), (7) (Shapo and Adam, 2008), (8) (Chaturvedi *et al*., 2001), (9) (Hymavathi *et al*., 2010), (10) (Chaturvedi *et al*., 2001), (11) (Chaturvedi *et al*., 2001), (12) (Hanada, 1990), (13) (Hanada, 1990), (14) (Hanada, 1990), (15) (Bhatt *et al*., 2006).
	(1) *Mangifera indica.*	(1) (Escaño and Tababa, 1998).
Prosopis cineraria	(1) *Vigna aconitifolius,* (2) *Cyamopsis tetragonoloba,* (3) *Brassica tourneforti,* (4) *Euruca sativa,* (5) *Capsicum sp.*	(1) (Dhakar *et al*., 2013; Handa and Newaj, 2017; Kaushik *et al*., 2003; Singh, 2009), (2) (Dhakar *et al*., 2013; Kaushik *et al*., 2003), (3) (Kaushik *et al.*, 2003), (4) (Kaushik *et al*., 2003), (5) (Ranashinghe and Newman, 1993).
	(1) *Psidium guajava,* (2) *Zizyphus mauritiana.*	(1) (Dalal *et al*., 2015; Nedunchezhiyan *et al*., 2012), (2) (Singh and Singh, 2015).
C. callothyrsus *C. houstoniana*	(1) *Manihot esculenta,* (2) *Vigna spp.,* (3) *Colocasia esculenta,* (4) *Solanum tuberosum,* (5) *Ipomoea batatas,* (6) *Allium ascalonicum.*	(1) (Evensen *et al*., 1995; Nolte *et al*., 2005; Tonye *et al*., 1994), (2) (Gichuru and Kang, 1989; Matthews et al., 1992), (3) (Rosecrance *et al*., 1992), (4) (Yamoah *et al*., 1989), (5) (Balasubramanian and Sekayange, 1991), (6) (McDonald *et al*., 2003), (6) (McDonald *et al*., 2003).

Table 2. Wood tree + annual vegetable and fruit tree

Wood tree	Annual vegetable and fruit tree	Reference
Tectona grandis	(1) *Capsicum spp.,* (2) *Solanum tuberosum,* (3) *Solanum melongena,* (4) *Vigna spp.* (5) *Ocimum spp.,* (6) *Manihot esculenta,* (7) *Curcuma longa,* (8) *Piper nigrum,* (9) *Ananas comosus,* (10) *Abelmoschus esculentus,* (11) *Cicer arietinum,* (12) *Cucumis sativus,* (13) vegetables.	(1) (Handa and Newaj, 2017; Weersum, 1982), (2) (Singh, 1987; Weersum, 1982), (3) (Bhoyar *et al*., 2016; Bhusara, 2014; Gunaga, 2017), (4) (Bhoyar *et al*., 2016; Chaturvedi *et al*., 2001), (5) (Kumar *et al*., 2017, 2015), (6) (Weersum, 1982), (7) (Singh, 1987), (8) (Singh, 1987), (9) (Dhewa and Daniel, 2017; Singh, 1987), (10) (Gunaga, 2017), (11) (Bhoyar *et al*., 2016), (12) (Patel *et al*., 2018), (13) (Hymavathi *et al*., 2010).
	(1) *Mangifera indica,* (2) *Carica papaya,* (3) *Cocos nucifera,* (4) *Theobroma cacao,* (5) *Psidium guajava,* (6) *Pyrus pyrifolia* (7) *Musa sp.,* (8) fruit trees.	(1) (Gunaga, 2017; Sureshbhai *et al*., 2017; Toppo *et al*., 2016), (2) (Handa and Newaj, 2017; Verma *et al*., 2017), (3) (Singh, 1987), (4) (Singh, 1987), (5) (Anand *et al*., 2016), (6) (Rani *et al*., 2016), (7) (Bhusara, 2014), (8) (Hymavathi *et al*., 2010).
Hevea brasiliensis	(1) *Ananas comosus,* (2) *Manihot esculenta, (*3) *Dioscorea floribunda,* (4) *Amomum villosum,* (5) *Passiflora edulis,* (6) *Piper nigrum.*	(1) (He *et al*., 2012; Kumar *et al*., 2012; Malézieux *et al*., 2009; Rajasekharan and Veeraputhran, 2002), (2) (Rajasekharan and Veeraputhran, 2002), (3) (Rao *et al*., 2004), (4) (Rao *et al*., 2004), (5) (Newman, 1985), (6) (Newman, 1985).
	(1) *Musa spp.,* (2) *Coffea sp*., (3) *Carica papaya*, (4) *Cocos nucifera,* (5) *Citrus reticulata.*	(1) (Newman, 1985; Rajasekharan and Veeraputhran, 2002; Ranashinghe and Newman, 1993; Rani *et al*., 2016), (2) (Newman, 1985; Ranashinghe and Newman, 1993), (3) (Newman, 1985; Ranashinghe and Newman, 1993), (4) (Kumar *et al*., 2012; Newman, 1985), (5) (Khaunkuab *et al*., 2008).
Poplar sp.	(1) *Brassica juncea,* (2) *Solanum tuberosum,* (3) *Allium cepa,* (4) *Capsicum sp.,* (5) *Solanum melongena,* (6) *Solanum lycopersicum,* (7) *Zea mays* (sweet corn), (8) *vegetables*	(1) (Ghimire, 2010), (2) (Devender *et al*., 2012), (3) (Yadav, 2006), (4) (Yadav, 2006), (5) (Yadav, 2006), (6) (Yadav, 2006), (7) (Bhushan and Khare, 2018), (8) (Jose *et al*., 2008).
	(1) *Prunus spp.,* (2) *Psidium guajava,* (3) *Mangifera indica,* (4) *Citrus spp.,* (5) *Pyrus communis.*	(1) (Dhillon *et al*., 2012, 2010; Sangwan *et al*., 2015), (2) (Dhillon *et al*., 2012, 2010; Sangwan *et al*., 2015), (3) (Handa and Newaj, 2017; Verma *et al*., 2017), (4) (Dhillon *et al*., 2012, 2010; Sangwan *et al*., 2015; Verma *et al*., 2017), (5) (Dhillon *et al*., 2012).
Eucalyptus	(1) *Manihot esculenta,* (2) *Vigna spp.,* (3) *Capsicum sp.,* (4) *Brassica oleracea, B. chinensis* (5) *Coriandrum sativum,* (6) *Solanum melongena,* (7) *Cicer arentinum,* (8) *Solanum tuberosum,* (9) *Solanum lycopersicum*, (10) vegetables.	(1) (Dhyani *et al*., 2013; Singh, 1989), (2) (Asati *et al*., 2007; Nissen and Midmore, 2002), (3) (Schroth, 1995), (4) (Vinaya and Suresh, 1988), (5) (Sureshbhai *et al*., 2017), (6) (Sureshbhai *et al*., 2017), (7) (Asati *et al*., 2007), (8) (Asati *et al*., 2007), (9) (Asati *et al*., 2007), (10) (Upadhyay and Yadava, 2009).
	(1) *Mangifera indica,* (2) *Theobroma cacao,* (3) *Litchi chinensis,* (4) *Pouteria sapota,* (5) *Citrus lemon,* (6) *Pyrus pyrifolia*	(1) (Verma *et al*., 2017), (2) (Handa and Newaj, 2017; Lakaria *et al*., 2012; Verma *et al*., 2017), (3) (Upadhyay and Yadava, 2009), (4) (Sureshbhai *et al*., 2017), (5) (Sureshbhai *et al*., 2017), (6) (Rani *et al*., 2016).
Populus tomentosa, P. euramericana, P. deltoides, P. nigra	(1) *Brassica alba, B. nigra*, *B. oleracea*, (2) *Citrullus lanatus* (3) *Cicer arietinum,* (4) *Cucurbita pepo,* (5) *Dacus carota,* (6) *Vicia faba,* (7) *Pisum sativum,* (8) *Vigna sp.,* (9) *Solanum tuberosum,* (10) *Solanum lycopersicum*, (11) *Capsicum sp.*	(1) (Asati *et al*., 2007; Burgess *et al*., 2005; Sangwan, 2014; Singh, 1989), (2) (Jiang and Qin, 2007; Tolunay *et al*., 2007), (3) (Asati *et al*., 2007; Tolunay *et al*., 2007), (4) (Akbulut *et al*., 2003), (5) (Tolunay *et al*., 2007), (6) (Burgess *et al*., 2005), (7) (Burgess *et al*., 2005), (8) (Chauhan *et al*., 2013), (9) (Asati *et al*., 2007; Chaturvedi *et al*., 2001), (10) (Asati *et al*., 2007), (11) (Asati *et al*., 2007).
	(1) *Coffea spp.,* (2) *Malus spp.,* (3) *Pyrus pyrifolia*	(1) (Kumar *et al*., 2012), (2) (Dhakar *et al*., 2013; Kumar *et al*., 2012), (3) (Rani *et al*., 2016).
Grewia optiva	(1) *Withania somnífera,* (2) *Cicer arietinum,* (3) *Solanum tuberosum,* (4) *Brassica oleracea,* (5) *Solanum lycopersicum,* (6) *Capsicum sp.*	(1) (Verma and Thakur, 2010), (2) (Asati *et al*., 2007), (3) (Asati *et al*., 2007), (4) (Asati *et al*., 2007), (5) (Asati *et al*., 2007), (6) (Asati *et al*., 2007).
	(1) *Prunus spp.,* (2) *Coffea sp.,* (3) *Malus domestica,* (4) *Mangifera indica*	(1) (Bijalwan, 2012; Verma and Thakur, 2010), (2) (Dhyani *et al*., 2013) (3) (Bijalwan, 2012), (4) (Verma and Thakur, 2010).
Bambusa spp.	(1) *Vigna unguiculata, Vigna umbellata,* (2) *Cucumis sativus, (3) Lablab purpureus,* (4) *Solanum nigrum,* (5) *Ocimum basilicum,* (6) *Momordica charantea,* (7) *Capsicum frutescens,* (8) *Manihot esculenta*	(1) (Behera *et al*., 2016), (2) (Christanty *et al*., 1997), (3) (Christanty *et al*., 1997), (4) (Christanty *et al*., 1997), (5) (Christanty *et al*., 1997), (6) (Christanty *et al*., 1997), (7) (Christanty *et al*., 1997), (8) (Christanty *et al*., 1997).
	(1) *Psidium guajava,* (2) *Mangifera indica*	(1) (Hymavathi *et al*., 2010), (2) (Christanty *et al*., 1997).
Alnus japonicum A. nepalensis A. rubra	(1) *Zea mays*, (2) *Amomum subulatum* (3) *Vigna radiata,* (4) *Solanum tuberosum,* (5) *Capsicum sp.* (6) *Colocasia spp.,* (7) *Ananas comosus,* (8) *Phaseolus multiflorus*	(1) (Seiter and Horwath, 1999; Stelen, 1997), (2) (Ranashinghe and Newman, 1993; Singh, 1989), (3) (Paningbatan, 1986), (4) (Handa and Newaj, 2017), (5) (Handa and Newaj, 2017), (6) (Handa and Newaj, 2017), (7) (Chauhan *et al*., 1993), (8) (Dhakar *et al*., 2013).

India (6.7 x 3.4 m) allows intercropping with a variety of crops during the initial three years, integration of other crops with rubber is not commonly practiced in older plantations due to the limited light availability and concerns of negative effect on the performance of rubber (Jessy *et al*., 2017). *Ananas comosus, Manihot esculenta,* and *Piper nigrum* are some annual vegetables cultivated in *Hevea brasiliensis* alley cropping.

Glomus deserticola significantly increased *Manihot esculenta* biomass accumulation and nutrient yield of alley cropped. Root tuber nutrient yield for nitrogen, potassium and phosphorus was significantly increased by *Glomus deserticola* inoculation (Okon, 2011). The results showed that, under this pattern, the pineapple were able to grow and develop normally, and the fruit quality of Tainong NO. 16 pineapple slightly declined, without a significant difference. On the other hand, there was not any negative effect for the rubber's growth and development (He *et al*., 2012). Table 2 shows another vegetables crops and fruit tree in *Hevea brasiliensis* alley cropping.

Populus deltoides: Poplar (*Populus deltoides*) is a fast growing, deciduous, and tall tree (Thakur *et al*., 2012), and is rated among the most promising species for the energy generation because of its minimum fertilizer requirement and its ability to grow on unfertile marginal lands (Rawat *et al*., 2013), it is a very suitable for horti-agro-forestry system (Devender *et al*., 2012), which permits enough sunlight for cultivation of horticultural crops, intercropping results in increased growth rate of poplar on the other due to frequent irrigation. Chauhan *et al.* (2013) concluded that *Curcuma longa* and *Vigna radiata* showed initially better performance under partial shade in yield and yield contributing parameters, and decreased as poplar canopy advanced in age of tree.

Akbulut *et al.* (2003) concluded that *Cucurbita pepo* in *Populus euramericana* alley cropping may contribute to increasing beneficial arthropod diversity compared with monocrops. Dhillon *et al.* (2012) concluded growth increment of poplar was significantly higher when planted with fruit crops (*Psidium guajava*, *Citrus reticulata*, *Pyrus communis*, *Prunus persica*, *Prunus americana*) as compared to sole poplar planting. Table 2 shows another vegetables crops and fruit tree in *Populus deltoides* alley cropping, and another wood tree.

Fruit tree

The production of horticultural trees as intercrops was found to be more effective for improvement in soil fertility and productivity (Verma *et al*., 2017), fruit trees have a long gestation period (4-5 years) to provide income; the interspaces can be used for cultivation of crops profitably till they develop canopy (Gunaga, 2017), 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), helps in strengthening the farmers economy (Gupta and Arora, 2015), the outcomes of various intercropping practices confirm that vegetable crops are economically and ecologically most suitable and viable intercrops for fruit plantation at early phase of growth, however, is need of synchronization of cultural practices adapted for intercrops with the requirements of fruit trees (Singh *et al*., 2018).

Mangifera indica: Mango (*Mangifera indica* L.) belongs to *Anacardaceae* family (Lieb *et al*., 2019), tree takes 10 - 12 years to grow and attain its full production potential (Kumar *et al.*, 2008), it can be intercropped with vegetables crops (Musvoto and Campbell, 1995) to efficiently utilize resources as water, and light (Swain *et al*., 2012), intercropping, besides providing income to the grower, suppresses weed growth, improves soil fertility and prevents leaching of nutrients and erosion of soil, achieves higher gross return per unit area (Kumari *et al*., 2016). The light intensity below the mango trees decreased with the increasing tree age, the decrease was more pronounced at a distance of 3 m distance from the trunk, 5 x 5m (Ali *et al*., 2018) to 10 × 10 m recommended (Swain, 2014), the changing light profile within the orchard due to the growing plant canopy influence the choice of intercrop to be grown at different ages (Das *et al*., 2017).

Depending of intercrops, recommended for adoption with selective up to 8-10 years (Negi, 2000), or up to 15 years of age of mango plantation (Swain, 2014). *Solanum melongena* L. is a common intercrop (Singh *et al*., 2011). In another hand, leguminous intercrops was due to improved availability of soil nutrients probably caused by nitrogen fixation, reduction in soil and nutrients erosion, and incorporation and decomposition of intercrop residues in soil of the orchard (Pradhan *et al.*, 2018). Table 3 shows another vegetables crops and fruit tree in *Mangifera indica* alley cropping.

Psidium guajava: Guava (*Psidium guajava)* is an important fruit in tropical regions (Etemadipoor *et al.*, 2019), belongs to the family *Myrtaceae*, it grows on different soils and in both humid and dry climates (Hiwale, 2015), and is a small tree (Hoseinifar *et al*., 2019), the inter row space in guava orchards remains underutilized in the early growing period may be grown as intercrops (Singh *et al*., 2016), intercropping with vegetables can fetch better returns besides generating more employment (Mitra, 2005). The plant start bearing 3 years after planting and reach their maximum bearing capacity within 6-7 years after planting (5 x 5 planted recommended) (Bhatt *et al*., 2016). The light intensity below the guava plants, maturity orchard shade at a distance of 2 m from the trunk (Ali *et al.*, 2018).

Selection of suitable intercrops in the guava orchard to improve the soil fertility status mainly depends upon the agro-climatic condition of the area where the crop is grown, guava plants have responded well to especially tuber (Singh *et al*., 2016), selection of suitable intercrops in the guava orchard to improve the soil fertility status mainly depends upon the agro-climatic condition of the area where the crop is grown (Swain, 2016). Table 3 shows another vegetables crops and fruit tree in *Psidium guajava* alley cropping.

Citrus spp.: *Citrus* is a large genus that includes several major cultivated species, including *C. sinensis* (sweet orange), *Citrus reticulata* (tangerine and mandarin), *Citrus limon* (lemon), *Citrus grandis* (pummelo) and *Citrus paradisi* (grapefruit) (Xu *et al*., 2013). The intercropping of perennial lemon with vegetables has enhanced the profitability in the irrigated areas (Dubey *et al*., 2016), intercropping of legumes in citrus orchards is beneficial for the citrus production. Intercrop improves fruit production of the orchard as compared to non-intercropped orchard (Gill *et al*., 2018), as intercrop citrus 4 x 4 planted recommended (Vijaykumar *et al*., 2018), income to the growers, controls weed population, check soil erosion, conserve soil moisture and organic matter and protects the soil from leaching of nutrients are some intercrops advantages (Hnamte *et al*., 2013).

Leguminous crops and ginger is beneficial in terms of economic returns (Lachungpa, 2004), other authors recommended *Cucumis melo*, and *Brassica oleracea* (Dubey *et al.*, 2016), *Capsicum spp*., *Curcuma longa Ocimum basilicum*, *Vigna unguiculata, Abelmoschus esculentus* and *Cucumis melo,* to be compatible with citrus intercrop (Aiyelaagbe, 2001). Table 3 shows another vegetables crops and fruit tree in *Citrus* alley cropping.

Further studies: Agroforestry seems to be a viable and economically feasible solution for the farmers to meet the

Table 3. Fruit tree and annual vegetable

Fruit tree	Annual vegetable	Reference
Citrus sp., C. sinensis., C. reticulata	(1) *Legumes crops*, (2) *Cicer arietinum*, (3) *Coriandrum sativum, (4) Capsicum annum,* (5) *Fagopyrum esculentum,* (6) vegetables, (7) *Zingiber officinale*, (8) *Colocasia esculenta,* (9) *Manihot esculentam*, (10) *Solanum lycopersicum*, (11) *Solanum tuberosum.*	(1) (Blair *et al*., 2016; Workman *et al*., 2003), (2) (Goswami *et al*., 2014a; Hnamte *et al*., 2013; Jose *et al*., 2008), (3) (Sureshbhai *et al*., 2017), (4) (Bhatt and Misra, 2003; Bhoyar *et al*., 2016; Goswami *et al*., 2014a), (5) (Gogoi, 2015), (6) (García *et al*., 2018; Jalón *et al*., 2018; Verma *et al*., 2017; Workman *et al*., 2003), (7) (Tabin *et al*., 2015), (8) (Goswami *et al*., 2014b; Hnamte *et al*., 2013), (9) (Goswami *et al*., 2014a; Hnamte *et al*., 2013), (10) (Goswami *et al*., 2014a; Hnamte *et al*., 2013), (11) (Goswami *et al*., 2014a).
Mangifera indica	(1) *Capsicum annum, (*3) *Manihot esculenta,* (4) *Vitis spp*., (5) *Coriandrum sativum,* (6) *Brassica oleraceae,* (7) *Ipomea batatas,* (8) *Chrysopongon fulvus,* (9) *Heteropogon contortus,* (10*) Cenchrus spp.,* (11) *Vigna spp.,*	(1) (Bhoyar *et al*., 2016; Bhusara, 2014; Chaturvedi *et al*., 2001), (3) (Harrison and Harrison, 2016), (4) (Kumar *et al*., 2012), (5) (Sureshbhai *et al*., 2017), (6) (Sureshbhai *et al*., 2017), (7) (Chaturvedi *et al*., 2001), (8) (Jha and Chaturdevi, 1995), (9) (Jha and Chaturdevi, 1995), (10) (Jha and Chaturdevi, 1995), (11) (Mirjha and Rana, 2016).
Prunus domestica., P. armeniaca, P. pérsica, P. avium	(1) *Pisum sativum,* (2) *Solanum lycopersicum,* (3) *Fragaria sp*., (4) *Zea mays (sweet corn),* (5) *Cucurbita sp*., (6) *Capsicum sp*., (8) *Vitis vinífera,* (9) vegetables, (10) *Cicer arietinum*, (11) *Brassica napus,* (12) *Vigna sp.*	(1) (Bhutia *et al*., 2015; Jose *et al*., 2008; Williams and Gordon, 1992), (2) (Jose *et al*., 2008; Williams and Gordon, 1992), (3) (Jose *et al*., 2008; Williams and Gordon, 1992), (4) (Blair *et al*., 2016), (5) (Williams and Gordon, 1992), (6) (Juárez and Fragoso, 2014), (8) (Nerlich *et al*., 2013), (9) (Tolunay *et al*., 2007), (10) (Jose *et al*., 2008), (11) (Nerlich *et al*., 2013), (12) (Shah *et al*., 2017) .
Artocarpus heterophyllus, A. altilis	(1) *Ananas comosus,* (2) *Manihot esculenta*, (3) *Ipomoea batatas,* (4) Vegetables	(1) (Gogoi, 2015; Harrison and Harrison, 2016; Hasan *et al*., 2008), (2) (Harrison and Harrison, 2016), (3) (Chaturvedi *et al*., 2001), (4) (Verma *et al*., 2017).
Zizyphus mauritiana	(1) *Cyamopsis tetragonoloba*, (2) *Vigna spp.*, (3) *Manihot esculenta*	(1) (Korwar and Pratibha, 2005; Meghwal and Henry, 2006; Sharma, 1996, 2014), (2) (Korwar and Pratibha, 2005; Sharma, 1996), (3) (Meghwal and Henry, 2006).
Malus spp.	(1) *Legumes crops,* (2) *Rubus spp.,* (3) *Ribes nidigrolaria,* (4) *Fragaria sp.,* (5) (*Zea mays*), (6) *Vigna spp. (7)* (Anjulo, 2009), *Cicer arietinum,* (8) *Solanum lycopersicum*	(1) (Blair *et al*., 2016), (2) (Rivera *et al*., 2004), (3) (Rivera *et al*., 2004), (4) (Sereke *et al*., 2014), (5) (Schroth *et al*., 1995; Tolunay *et al.*, 2007), (6) (Verma *et al*., 2017), (7) (Anjulo, 2009), (8) (Anjulo, 2009).
Sysigium spp.	(1) *Vigna spp.,* (2) *Brassica nigra*	(1) (Chaturvedi *et al*., 2001; Pareek and Awasthi, 2008), (2) (Rizvi *et al*., 2011).
Psidium guajava	(1) *Vigna spp.,* (2) *Capsicum sp.,* (3) *Cyamopsis tetragonoloba*, (4) *Piper nigrum,* (5) *Vigna spp.,* (6) *Curcuma longa,* (7) vegetables	(1) (Das *et al*., 1993; Dhakar *et al*., 2013; Krishnan, 2016; Sharma et al., 2017; Yadav, 2017), (2) (Bhoyar *et al*., 2016; Verma *et al*., 2017), (3) (Meena, 2015), (4) (Gogoi, 2015). , (5) (Pareek and Awasthi, 2008; Sharma, 2011), (6) (Bhatt *et al*., 2006; Hembram, 2014; Jain and Sharma, 2011), (7) *(Verma et al*., 2017)
Musa sp.	(1) *Ipomoea batatas,* (2) *Manihot esculenta,* (3) *Vigna sp., Vigna radiata*, (4) *Colocasia esculenta* (5) *Zingiber officinale,* (6) *Curcuma longa,* (7) *Dolichos lablab,* (8) *Abelmoschus esculentus,* (9) *Ananas comosus,* (10) *Telfairia occidentalis,* (11) vegetables	(1) (Balasubramanian and Egli, 1986; Kanmegne and Degrande, 2002; Nedunchezhiyan *et al*., 2012), (2) (Balasubramanian and Egli, 1986; Kanmegne and Degrande, 2002), (3) (Aiyelaagbe and Kintomo, 2002; Balasubramanian and Egli, 1986), (4) (Balasubramanian and Egli, 1986), (5) (Rahman *et al*., 2012), (6) (Rahman *et al*., 2012), (7) (Rahman et al., 2012), (8) (Rahman *et al*., 2012), (9) (Ranashinghe and Newman, 1993), (10) (Aiyelaagbe and Jolaoso, 1992), (11) (Verma *et al*., 2017).
Pyrus sp., Pyrus silvestris	(1) *Pisum sativum,* (2) legumes, (3) *Vigna spp*., (4) *Manihot esculenta*, (5) *Solanum tuberosum*, (6) *Colocasia esculenta*, (7) *Capsicum annuum*, (8*) Zingiber officinale*, (9) *Solanum lycopersicum*	(1) (Jose *et al*., 2008; Nerlich *et al*., 2013), (2) (Nerlich *et al.*, 2013), (3) (Goswami *et al*., 2014b), (4) (Goswami *et al*., 2014b), (6) (Goswami *et al*., 2014a), (7) (Goswami *et al*., 2014a), (8) (Goswami *et al*., 2014a), (9) (Goswami *et al*., 2014a).
Morus alba	(1) *Cicer arietinum,* (2) *Solanum tuberosum,* (3) *Brassica oleracea,* (4) *Brassica nigra,* (5) *Solanum lycopersicum,* (6) *Capsicum sp.,* (7) *Solanum tuberosum*	(1) (Asati *et al*., 2007), (2) (Asati *et al*., 2007), (3) (Asati *et al*., 2007), (4) (Asati *et al*., 2007), (5) (Asati *et al*., 2007), (6) (Asati *et al*., 2007), (7) (Benavides, 2002).
Cocos nucifera	(1) *Ipomoea batatas,* (2) *Piper nigrum*, (3) tuber crops, (4) *Capsicum sp.,* (5) *Maranta arundinacea,* (6) *Ananas comosus,* (7) *Manihot esculenta*	(1) (Chaturvedi *et al*., 2001; Nedunchezhiyan *et al*., 2012), (2) (Gogoi, 2015; Kumar et al., 2012), (3) (Bavappa, 1990a, 1990b) (4) (Bavappa, 1990a), (5) (Bavappa, 1990a), (6) (Peng *et al*., 1999), (7) (Kumar, 2006)
Coffea arabica L.	(1) *Lycopersicum esculentum,* (2) *Vigna sesquipedalis,* (3) *Capsicum sp.* (4) *Passiflora edulis,* (5) *Ipomoea batatas*	(1) (Iijima *et al*., 2003), (2) (Iijima *et al*., 2003), (3) (Nuberg and Evans, 1993), (4) (Ranashinghe and Newman, 1993), (5) (Nedunchezhiyan *et al*., 2012).
Carica papaya	(1) *Abelmoschus esculentus,* (2) *Citrullus lanatus,* (3) *Ipomoea batatas,* (4) *Solanum gilo,* (5) *Solanum lycopersicum*	(1) (Aiyelaagbe and Jolaoso, 1992), (2) (Aiyelaagbe and Jolaoso, 1992), (3) (Aiyelaagbe and Jolaoso, 1992), (4) (Aiyelaagbe and Jolaoso, 1992). (5) (Kumar *et al*., 2000).

challenges of food, nutrition, energy, employment and environmental security (Verma *et al*., 2017), we recommended further studies should be carried out related to water use efficiency, biofertilizers, weed management, technical support, integration of fruit trees and vegetables of high commercial value, biological control, harvest mechanized, integration of indigenous fruit trees and indigenous vegetables, carbon credits, birds, predators, bees, policies, credits, and subsidies can help increase global food production and conserve the environment are necessary.

Discussion

The legumes tree has great potential for inclusion in horticulture (Zaki *et al.*, 2017) in various ways, for example, fix atmospheric nitrogen, nitrogen green manure, transformed and increase the soil mineral N pool (Del Grosso *et al*., 2006), reduce resilience on mineral forms of N fertilizer (Seran and Brintha, 2010), and reduce the environmental damage trough NO_3 leaching and N_2O emission (Meena *et al*., 2018), it is a natural mini-nitrogen manufacturing factory in the field and can play a vital role in increasing indigenous nitrogen production (Ghosh *et al*., 2007), seven times faster compared to natural forests (Pavlidis and Tsihrintzis, 2018). Legume green manuring improves SOC, nutrient availability, physicochemical and biological properties of soil, and crop productivity (Meena *et al*., 2018), it can help improving the soil physical environment, increasing soil microbial activity, restoring organic matter, and also has smothering effect on weed, and solubilizing insoluble P in soil (Hymavathi *et al*., 2010) for bacterial phytase enzymes activity for release as free phosphorus over time (Blair *et al*., 2016), so nitrogen and phosphorus efficiency is higher (Khan *et al*., 2017).

The excessive application of chemical fertilizers has enormously increased (nitrogen especially), which has been designated as a severe environmental threat especially of air and ground water pollution (Khan *et al*., 2017), among the pollutants, nitrates, and phosphoric compounds from agricultural activities are the most common and hazardous to the environment human health (Pavlidis and Tsihrintzis 2018), in response alley cropping is an interest strategic tool for food and wood production and careful environmental. Legume tree offers advantages to the horticultural crops, and mitigate challenges mainly related to growing population, climate changes and loss of biodiversity (Ribeiro *et al*., 2018).

In another hand, smallholder farmers are inclined to intercrop young timber trees with well-fertilized annuals to confer nutrient and weeding benefits to the trees while gaining a short-term return on the land (Nissen and Midmore, 2002), recommended principles for designing the cropping system based on this approach include: selecting species for complementary functional traits, developing complex trophic levels, and reproducing ecological succession (Lovell *et al.*, 2017; Malézieux, 2012). Agroforestry systems can be significant sink of atmospheric carbon (C) due to their fast growth and high productivity (Tiwari *et al.*, 2017), under the Kyoto Protocol's Article 3.3, A&R (afforestation and reforestation) with agroforestry as a part of it has been recognized as an option for mitigating greenhouse gases (Sureshbhai *et al*., 2017), the potential of C sequestration is dependent on the tree component (Nair *et al*., 2009; Sureshbhai *et al*., 2017).

The selection of fruit and vegetable species must prioritized for regional economic potential and specific interactions between crops (Lovell *et al*., 2017), the success towards ecologically and economically sound agroforestry systems lies in identification of compatible tree-crop units under varying spatial arrangements and limited solar energy available underneath (Thakur *et al*., 2018), satisfactory growth and yields of both woody and crop plants can be achieved in the microenvironment of the agroforestry land-use system that is established, a microenvironment that varies considerably with time (Lin *et al*., 1998).

The modification in microclimate is one of the important features of agroforestry (Kumar *et al*., 2018), AC provides climate change adaptation potential and ecological benefits by buffering alley crops to weather extremes, diversifying income to hedge financial risk, increasing biodiversity, reducing soil erosion, and improving nutrient and water use efficiency (Wolz and DeLucia, 2018), so that, has potential to address the problems of food insecurity especially in developing countries and conservation of natural resources (Gunaga, 2017), reducing vulnerability, increasing resilience of farming systems and buffering households against climate related risk in addition to providing livelihood security (Sureshbhai *et al*., 2017). Tree can maintain the stability of internal microclimates, are strong assets for extreme weather adaption (Wu *et al*., 2016), the presence of trees modifies site microclimate in terms of temperature, water vapor content or partial pressure, and wind speed, among other factors, and, temperature reductions can help reduce heat stress of crops associated (Jose *et al*., 2004), temperature reductions in the alleys can help to reduce heat stress of crops by lowering rates of foliar evapotranspiration and soil evaporation (Jose *et al.*, 2008), in vegetable crops, photosynthetically active radiation and temperature are reduced, while the humidity is increased (Chauhan, 2016; Sangwan *et al.*, 2017), so that, water use efficiency and carboxylation efficiency under shade conditions are important factors (Sangwan *et al.*, 2015).

Appropriate selection of tree and vegetable combination promising success of plantation, *Mangifera indica, Psidium guajava, Citrus spp., Leucaena spp., Gliricidia sepium, Cajanus cajan, Populus spp., Eucalyptus,* and *Hevea brasiliensis,* are the main tree used. *Fabacea, Brassicacea, Solanacea* families and tuber crops are main vegetable crops associated. Climate change and its variability are posing the major challenges influencing the performance of horticulture crops, 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 concerted and systematic manner in order to prepare the horticulture sector to face the imminent challenges (Malhotra, 2017), the AC diversifying nature of this system allows farmers to make the best use of their land, by maximizing the crop yields as well as diversify income, and help in increasing resilience to global threat of climate change (Gunaga, 2017).

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CAPÍTULO IV HORTI/SILVI- PISCICULTURE: AGROFORESTRY SYSTEM FOR THE EFFICIENT USE OF WATER AND FERTILIZERS

RESUMEN

La producción de alimentos es una actividad de alto requerimiento de agua y nutrientes, por lo que generar sistemas de producción con altas eficiencias de estos insumos es muy relevante. Horti / Silvicultura es un sistema agroforestal donde se cultivan sinergísticamente peces, madera, frutas, especies anuales, plantas medicinales y especias. Los árboles tienen varias funciones dentro de este sistema, por ejemplo, la retención y fijación de las paredes u hojas de los estanques se utilizan para alimentar a los peces, mientras que el agua de los peces presenta nutrientes útiles como fertilizantes para los árboles frutales y los cultivos asociados. El objetivo principal de este trabajo es mostrar algunas combinaciones utilizadas en el sistema Horti / Silvicultura para promover la adopción global de los agricultores, el hundimiento nacional y la investigación científica. La agroforestería es una ciencia emergente que ha demostrado tener diferentes contribuciones al bienestar de los humanos y otras especies biológicas.

Palabras clave: Pescado, Madera, Frutas, Especies Anuales, Plantas Medicinales, Especias

ABSTRACT

Food production is a high requirement activity of water and nutrients, so generating production systems with high efficiencies of these inputs are highly relevant. Horti/Silvi- pisciculture is an agroforestry system where fish, wood, fruits, annual species, medicinal plants, and spices are cultivated synergistically. Trees have various functions within this system, for example, retention and fixing of pond walls or leaves are used for feeding fish, while the water of the fish presents useful nutrients as fertilizer for fruit trees and associated crops. The main objective of this work is to show some combinations used in Horti/Silvi- pisciculture system to promote global farmers adoption, national subside, and scientific research. Agroforestry is an emerging science that has been shown to have different contributions to the well-being of humans and other biological species.

Keywords:
Fish, Wood, Fruits, Annual Species, Medicinal Plants, Spices

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Horti/Silvi- pisciculture: agroforestry system for the efficient use of water and fertilizers

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Food production is a high requirement activity of water and nutrients, so generating production systems with high efficiencies of these inputs are highly relevant. Horti/Silvi- pisciculture is an agroforestry system where fish, wood, fruits, annual species, medicinal plants, and spices are cultivated synergistically. Trees have various functions within this system, for example, retention and fixing of pond walls or leaves are used for feeding fish, while the water of the fish presents useful nutrients as fertilizer for fruit trees and associated crops. The main objective of this work is to show some combinations used in Horti/Silvi-pisciculture system to promote global farmers adoption, national subside, and scientific research. Agroforestry is an emerging science that has been shown to have different contributions to the well-being of humans and other biological species.

Keywords: Fish, Wood, Fruits, Annual Species, Medicinal Plants, Spices

INTRODUCTION

Agroforestry systems have demonstrated positive economic, ecological and social effects, in addition to offering important advances in the resilience of global agri-food systems that face a reduction and deterioration of natural resources. The Horti/Silvi- pisciculture is an agroforestry system where the wood tree, fruit tree, annual crop, and fish are cultivated integrated, this system provides better water and fertilizer efficiencies compared to the same separately established crops. Trees have various functions within this system, for example in the retention and fixing of pond walls, for feeding fish or diversifying income. Sometimes in this system, annual crops are added, mainly rice or another crop with a high water requirement, so around the world there are various traditional agroforestry systems that include aquatic components.

In India the rice-fish based integrated farming system is an eco-efficient land management practices with the integration of crop-livestock-agro-forestry system having judicious use of farm resources and waste recycling with lesser dependence of non-renewable resources, this system enhances resilience and reverses soil degradation, providing nitrogen-rich residues and increasing soil organic matter (Adelakun et al. 2014), Wu and Zhu (1997) reported combination of tree-crop-fish which includes paulownias, willow, poplar and fruit trees, along with ponds in which fish is cultivated (Table 1), and Karshie et al. (2017) reported the association of *Carica papaya, Mangifera indica Azadirachta indica*, vegetables, with fish ponds. In this type of system, fruit trees are normally benefited due to good and constant levels of humidity in the soil and some concentrated nutrients in the water of the fish production. The main objective of this work is to show some combinations used in Horti/Silvi-pisciculture system to promote global farmers adoption, national subside, and scientific research.

Agroforestry and pisciculture

In Agroforestry the presence of trees in agroforestry offers better water use dynamics (Paut et al. 2018), around the world, there are various traditional agroforestry systems that include aquatic components, for example, Mangrove in Madagascar where wood is used extensively for making the fishing traps and the canoes, for processing the prawn and fish catch, and for domestic use including fencing, housing, and fuel for cooking (Rasolofo 1997), the Chinanpas in Mexico are artificial islands created by the accumulation of sediments and litters (Embarcadero et al. 2015), or rice-fish-fruit tree system in India (Adelakun et al. 2014), at present these systems have been taking relevance due to the reduction of natural resources and the high costs of fertilizers, Agricultural water, and fertilizer requirements are increasingly unviable economically, ecologically, and socially, therefore, viable technological alternatives compatible with agricultural producers must be sought. Table 1 shows some Horti/Silvi- pisciculture systems.

Another important interaction between the components of these systems is the feeding of the fish with leaves of various tree species (normally dehydrated, sifted or in pellets), legumes standing out for their high protein content, some of the leguminous trees of which their leaves are used in feeding fish are used are *Cajanus cajan* (Ogunji et al. 2008; Hammed et al. 2013)**,** *Gliricidia spp.* (Seijas et al. 1994; Nnaji et al. 2010)**,** *Sesbania grandiflora* (Dorothy et al. 2018), *Leucaeana leucocephala* (Amisah et al. 2010), however, some research has also recently been carried out the contribution of compounds that can improve the health of fish, for example, *Mangifera indica* (Amisah et al. 2010).

However, various factors must be considered; one of the most important is the presence of antinutritional compounds that can reduce the health and development of fish cultures. For example mimosine in *Leucaena leucocephala* leaf meal as an ingredient for Nile tilapia (*Oreochromis niloticus*) where contributed to low growth of fish (Wee and Wang 1987). To solve this problem, the use of probiotics inoculated in leaf-based food has been proposed, Bairagi et al. (2004) used *Leucaena leucocephala* leaf meal at 20%, 30% and 40% levels replacing other ingredients partially, this food was inoculated with fish intestinal bacteria *Bacillus subtilis* (isolated from *Cyprinus carpio*) and *B. circulans* (isolated from *Oreochromis mossambicus*). The results showed that it is possible to incorporate *Leucaena* leaf meal inoculated with enzyme-producing fish intestinal bacteria in carp diets up to a 40% level of inclusion (Amisah et al. 2010).

Other tree species investigated for their value as fish food are T*erculia setigera* (Adelakun et al. 2014), *Samanea saman* (Rath et al. 2014), *Albizia julibrissin* (Kirecci et al. 2014), *Moringa olerifera* (Afuang et al. 2003; Richter et al. 2003), *Jatropha curcas* (Kumar et al. 2010), *Morus alba, Carica papaya* (Dorothy et al. 2018), and *Juglans spp.* (Avant 2016). Rain tree leaf (*Samanea saman*) pod is identified as a good source of protein (25.2%) and energy for carp feed (Rath et al. 2014), Silk Tree (*Albizia julibrissin*) seed can be used up to %20 of diet as protein source in diets of koi carp (*Cyprinus carpio*) without any adverse effects(Kirecci et al. 2014), the solvent-extracted moringa leaf meal could replace about 30% of fishmeal from Nile tilapia diets(Afuang et al. 2003), and finally, *Mangifera indica* kernel stimulates the immunity and makes *Labeo rohita* more resistant to *A. hydrophila* infection (Sahu et al. 2007).

The world population is projected at 9.7 billion for 2050 (United Nations 2015; Chouchane et al. 2018), human civilization is mostly dependent upon food, fodder, and fuelwood, the development, and progress of human civilization lie with the sustainability of the environment (Jhariya et al. 2019), many foods are needed, 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). Agroforestry practices show great potential as biodiversity interventions contributing to an ecological intensification of agriculture. The Horti/Silvi- pisciculture system can be a powerful tool for multiple productions of goods and services, in addition to providing better water and fertilizer efficiencies. This system must be integrated into the development policies of the countries in search of economically resilient economies and food security.

Table 1: Horti/Silvi- pisculture system

Fruit tree	Vegetable	Aquatic component	Tree	Other crop	Reference
Mangifera indica, Carica papaya	Vegetables	Fish	*Azadirachta indica*		(Karshie et al. 2017).
Mangifera indica Artocarpus integrifolia		Fish	Timber trees	*Oryza sativa*	(Wangpakapattanawong et al. 2017).
Fruit tres	Vegetables	Fish	*Paulownia sp., Salix sp., Poplar sp.*	Herbs, wheat, oil crops	(Wu and Zhu 1997).
Fruit trees		Fish and Ducks	Fodder trees	*Brachiaria mutica, , Pennisetum glaucum, Megathyrsus maximus*	(Sheriff 1998).
C. nucifera, Musa sp., P. guajava, Citrus sp., M. indica, C. papaya, P. granatum		Fish and Ducks	*Tectona grandis*, Fodder tree		(Sheriff 1998).
Morus alba	Vegetables	Fish		*Oryza sativa*	(D'Silva and Maughan 1994).
Prunus pérsica	*Brassica juncia*	*Labeo spp., Catla catla, H. molitrix, C. idella* and *Puntius japonicus*			(Tornar and Bhatt 2005).
Cocos nucifera		Fish			(Dagar and Tewari 2016).
Morus alba	Aquatic plants	Fish			(Krishnan et al. 2016).
Musa sp. Carica papaya	*Ananas comosus*	Fish and Ducks			(Upadhyay and Yadava 2009).
P. guajava, C. nucifera, E. officinalis, M. indica, Citrus spp., Litchi chinensis		Fish	*Aquilaria malaccensis, Terminalia cebula, Sesbania grandiflora*		(Gogoi 2015).

CONFLICT OF INTEREST

The authors declared that present study was performed in absence of any conflict of interest.

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Add acknowledgements here

AUTHOR CONTRIBUTIONS

Add contribution of each author (with abbreviated name) here. For example WEP designed and performleed the experiments and also wrote the manuscript. EW, OA, and IDJ performed animal treatments, flow cytometry experiments, tissue collection, and data analysis. AS and MR designed experiments and reviewed the manuscript. All authors read and approved the final version.

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CAPÍTULO V FAST ANALYSIS OF PLANT HEALTH, PLANT COUNT AND NITROGEN STATUS USING DRONES

RESUMEN

Los recursos naturales limitados, el alto costo de los insumos agrícolas y la degradación ambiental están promoviendo la agricultura de precisión, los drones se han vuelto ampliamente disponibles para su uso en imágenes aéreas de campos agrícolas, estos pueden analizar datos de mapas de drones para comprender la salud de los cultivos. El objetivo de este trabajo fue el análisis rápido de la salud de las plantas, el estado del nitrógeno y el conteo de plantas en cultivos de maíz utilizando drones. En nuestro campo, la salud de las plantas es mejor en áreas bajas. El área total con deficiencia de nitrógeno es el 14% del campo, localizada en áreas altas, por lo que se recomiendan acciones de manejo en áreas identificadas. El análisis de conteo de plantas reporta 20,964 plantas. La información rápida obtenida para drones y software puede tomar medidas rápidamente para remediar algunos problemas agrícolas comunes.

Palabras clave: Software Agremo, software DroneDeploy, ortomosaico, agricultura de precisión

ABSTRACT

The limited natural resources, high cost of agro-inputs and environmental degradation are promoting precision agriculture, the drones have become widely available for use in agriculture aerial imagery of fields, these can be analyzing drone map data to understand the health of crops. The objective of this paper was the fast analysis of plant health, nitrogen status, and plant count in maize crops using drones. In our field, plant health is better in low areas. The total area with nitrogen deficiency is 14% of the field, spot in high areas, so that management actions on identified areas are recommended. Plant count analysis reports 20,964 plants. The fast information obtained for drones and software can take action quickly to remedy some agricultural common issues.

Keywords: Agremo software, DroneDeploy software, orthomosaic, precision agriculture

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Fast analysis of plant health, plant count and nitrogen status using drones

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Key words : Agremo software, DroneDeploy software, orthomosaic, precision agriculture

INTRODUCTION

In the present era, there are too many developments in precision agriculture (PA) for increasing the crop productivity (Mogili and Deepak, 2018), precision agriculture aims at optimizing and improving agricultural processes to ensure maximum productivity and requires fast, reliable, distributed measurements in order to give growers a more detailed overview of the ongoing situation in their cultivation area, and/or coordinates the automated machinery in such a way that optimizes energy consumption, water use and the use of chemicals for pest control and plant growth Tzounis *et al.* (2017). The PA using unmanned aerial vehicles can help optimize agriculture and crop production (Nansen, 2014).

Low-cost Unmanned Aerial Vehicles (UAVs), also known as drones, are increasingly gaining interest for enabling novel commercial (Koubâa *et al.,* 2019), and have become widely available for use in a broad range of disciples, in agriculture, drones make it possible to capture on-demand aerial imagery of fields. This means the user can analyze drone map data to understand the health of crops, spot problem areas, and take action quickly to remedy any issues before they spread (Skobelev *et al.,* 2018).

Drones are high-end reliable instruments flying in the sky and can be used by farmers to inspect the farm condition at the beginning of any crop year, drones generate 3-D maps for soil analysis which is useful for farmers to take care during seed plowing. Soil and field analysis via drones also provides data useful for irrigation and managing the nitrogen level of fields for better crop growth. With drones, crop health imaging can be done using Infrared, NVDI and multispectral sensors making the farmers better track the health of the crop, transpiration rates, and sunlight absorption rates, etc. (Puri *et al.,* 2017).

The DroneDeploy (www.Dronedeploy.com) is a drone mapping software platform that captures aerial data as images and processes those images generate high-resolution maps and 3D models, so that designed for drone flight planning provides a simple interface for data capture and automated flights that allows you to explore and share high-quality interactive maps directly from our mobile device (Marín *et al.,* 2018).

In another hand, Agremo is agriculture

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specialized platform to analyze maps from DroneDeploy with powerful algorithms and obtain results, the reports are comprehensive and easy to understand for managing fields (www.Agremo.com), the success and popularity of these platforms have significantly decreased their market cost, and have driven technological developments of the platforms themselves, their sensors and software systems (Madjid *et al.,* 2018).

A wide breadth of countries, ranging from Uruguay, Argentina, Brazil, to Australia are also using drones in agriculture to track cattle, survey crop health, detect harvest readiness, and as a tool for surveying the damage from drought, flooding, weeds, and pests (Green, 2013; Freeman and Freeland, 2014), Japan is the only nation that has implemented drones applications in farming on a large scale (Freeman and Freeland, 2015). The development of such systems of automatic control of drone groups will allow timely receiving detailed information on crops, reduce the costs of plant protection and increase yields (Skobelev *et al.,* 2018).

Finally, traditional methods used by farmers aren't sufficient enough to serve the increasing demand and so they have to hamper the soil by using harmful pesticides in an intensified manner, this affects the agricultural practice a lot and in the end, the land remains barren with no fertility (Jha *et al.,* 2019). In the past decade, the latest technologies are included in precision agriculture to improve the productivity of the crop. These technologies are useful where human interventions are not possible for spraying of chemicals on crops and scarcity of the labour, it also helps the spraying job easy and faster (Mogili and Deepak, 2018). The objective of this paper was the fast analysis of plant health, nitrogen status, and plant count in maize crops using drones.

MATERIALS AND METHODS

Study Area

Our study was carried out on 11 October of 2019 in final maize crop at the protected area of Comision de Recursos Naturales (CORENA) in Teutli Volcano at coordinates 19.2350, -99.0278, at 2542 m altitude, the experimental field is included in the "Altepetl" government program. 16610 postal code was used in Drone Deploy software (Drone Deploy, San Francisco, USA) for the search area to create a new project.

Drone and Flight Planner

For aerial imaging, a DJI Phantom 4 Pro (DJI, Shenzhen, Guangdong, China) was used with autopilot (DroneDeploy, San Francisco, USA) in a tablet (Fig. 1a). The drone was configured for autonomous flights, was programmed to fly at 40 m altitude, the overlaps between the images were fixed (75% side-lap and 70% front-lap) (Fig. 1b, c). Pilot flights were conducted between 12 : 30 a. m. and 1 : 00 p. m. on 11 of October 2019 in polygon selected.

Orthomosaic

A free trial version of DroneDeploy, an online platform was used to process the generated data that consisted of 155 geo-tagged images captured from the flight. The resulting geo-referenced 2D quality map was 1,1 cm/ pix resolution. The exported output was the final visual format on orthomosaic (Fig. 1d) and was obtained in DroneDeploy.

Agremo Software

Four steps for using Agremo software (Fig. 2a) : (1) *Collect aerial data and images :* Any kind of drone (UAV), (2) *Generate maps :* 2D maps from collected areal data, (3) *Analyze images* : With powerful algorithms (Fig. 2b) and (4) *Manage fields :* Requirements show in the analysis. This work followed the first three steps.

RESULTS AND DISCUSSION

Orthomosaic and Elevation

The UAV data allowed precise mapping of maize field, the orthomosaic obtained shown in Fig. 3 (a) and 1.1 cm/pixel resolution are sufficient resolution for plant, health, nitrogen status, plant count analysis, however, not for pest, weed and disease as requirement is 2.5 cm/pixel resolution. The elevation map obtained shown in Fig. 3 (b), orthomosaic and mapping tools in next procedure in Agremo software offered better field management.

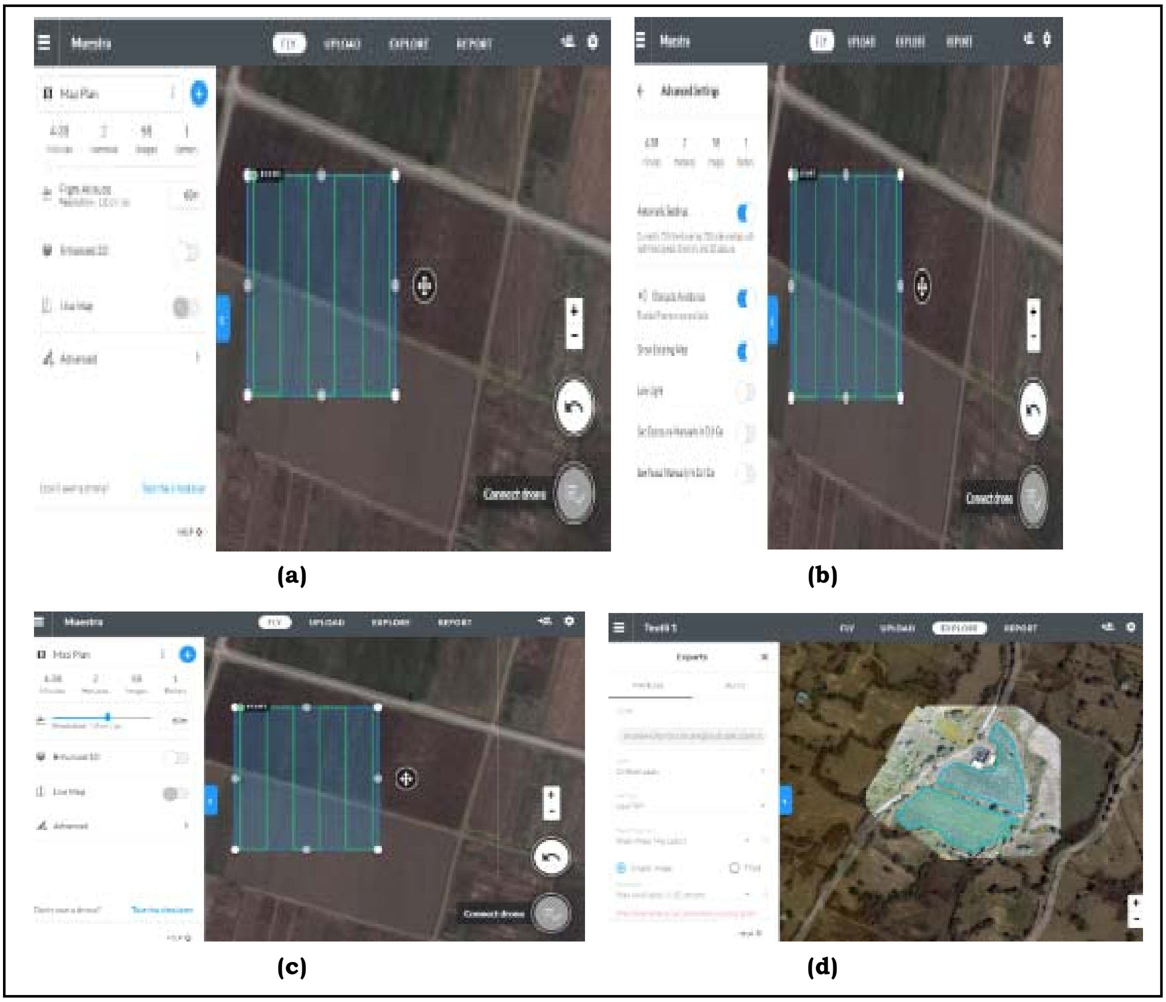

Fig. 1. (a) Map plan, (b) Advanced settings, (c) Altitude configuration and (d) Exports.

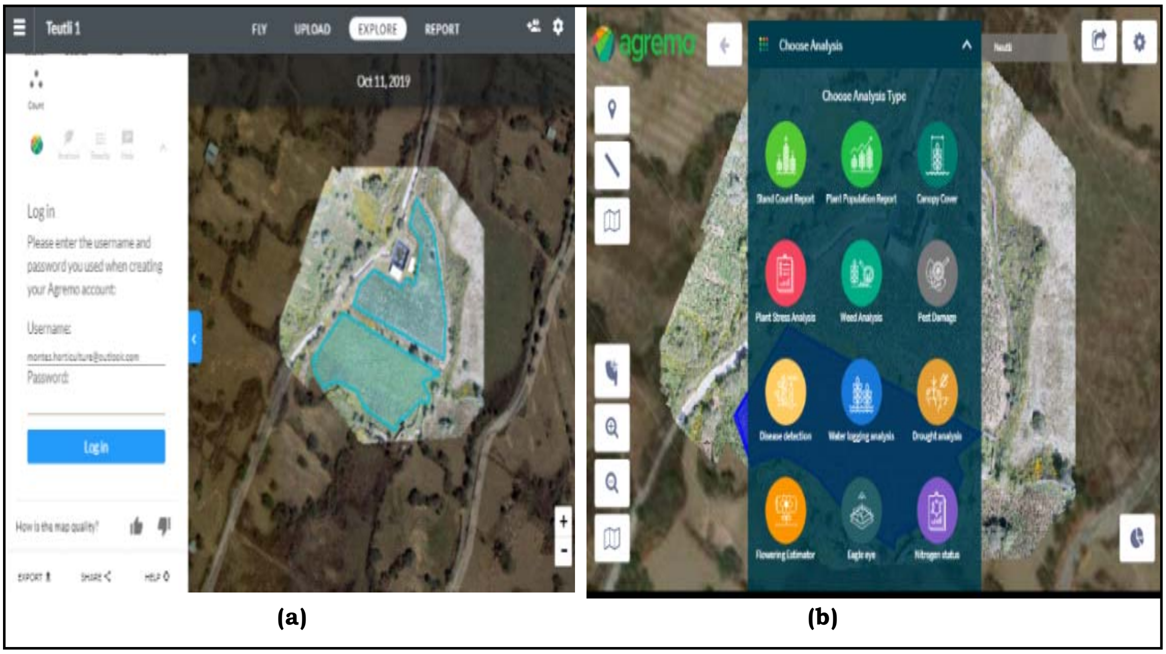

Fig. 2. (a) Agremo log in and (b) Agremo analysis.

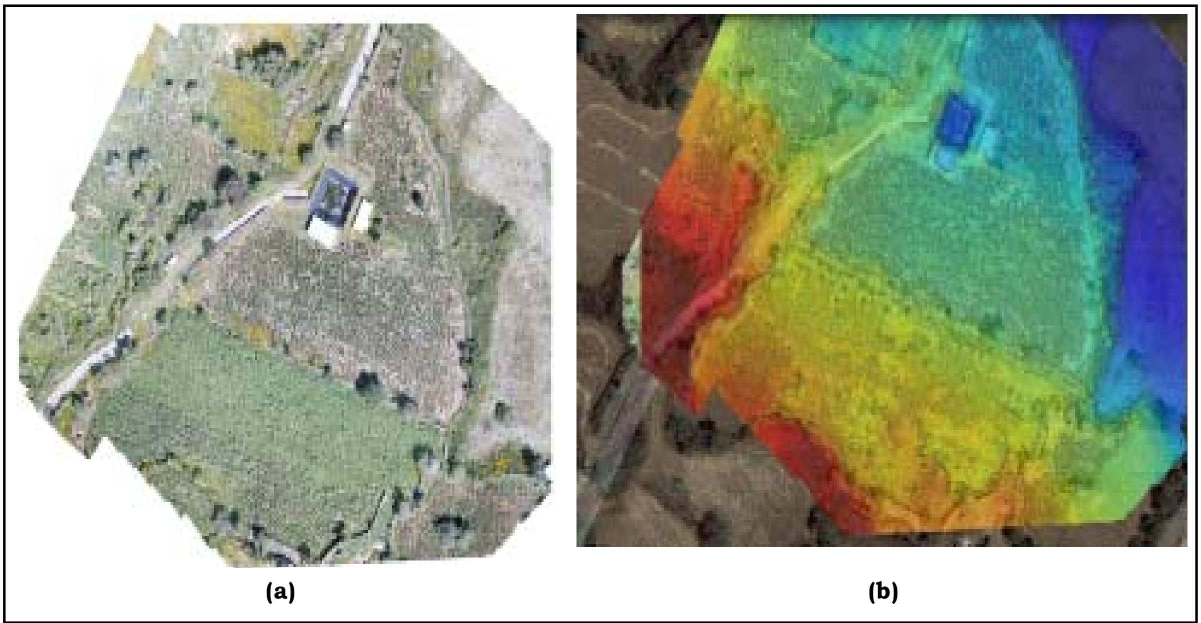

Fig. 3. (a) Orthomosaic of maize field and (b) elevation.

Plant Health and Plant Count

Plant health was better in low areas in Drone Deploy and Agremo analysis (Fig. 4 a, b), software applied use of reflectance data in crop management was based on important assumptions about relationships between "crop status" and the way crops absorb/reflect sunlight (Nansen, 2014), in our field manifest spot problem in high areas, so that management actions on identified areas. On another hand, polygon used plant count analysis (Fig. 4c) reported 20,964 plants (Fig. 4d). Drone Deploy and Agremo coupled with their relatively low cost enhanced the further potential for farmers use, drones made it possible to capture on-demand aerial imagery of fields, this means the user can analyze drone map data to understand the health of crops, spot problem areas, and take action quickly to remedy any issues before they spread (Skobelev *et al.*, 2018).

Nitrogen Status

The total area with nitrogen deficiency was 14% of the field, the high zone was a problematic area (Figs. 5 and 6), the nitrate in cropland runoff was mainly derived from soil, fertilizer and precipitation (Sui *et al.*, 2019), so that recommended levelling of field, and nitrogen fertilization in problematic areas. Excess use of nitrogen fertilizers in agriculture often led to accumulation of nitrate in the unsaturated zone and to groundwater pollution (Weissman *et al.*, 2018), agricultural practices raised the level of nutrients reaching aquifers (especially for nitrogen and phosphorus) (Aguilar *et al.,* 2019), nitrate was extremely water-soluble making it move freely in the soil solution (Daw *et al.,* 2018), so that, the nitrate in groundwater was reported as a major problem all over the world (Rodriguez *et al.,* 2018).

CONCLUSION

The flight at 40 m generates 1.1 cm/ pixel orthomosaic resolution, this is sufficient to generate an analysis of the maize crop health, nitrogen status and plant count. In our field plant health is better in low areas. The total area with nitrogen deficiency is 14% of the field, spot in high areas, so that management actions on identified areas are recommended. The plant count analysis reported 20,964 plants. The drones can optimize fertilizer use, water and chemicals for pest control. The drones and software fast information obtained can help take action quickly to remedy some common issues. The fast information obtained for drones and software can take action quickly to remedy some agricultural common issues.

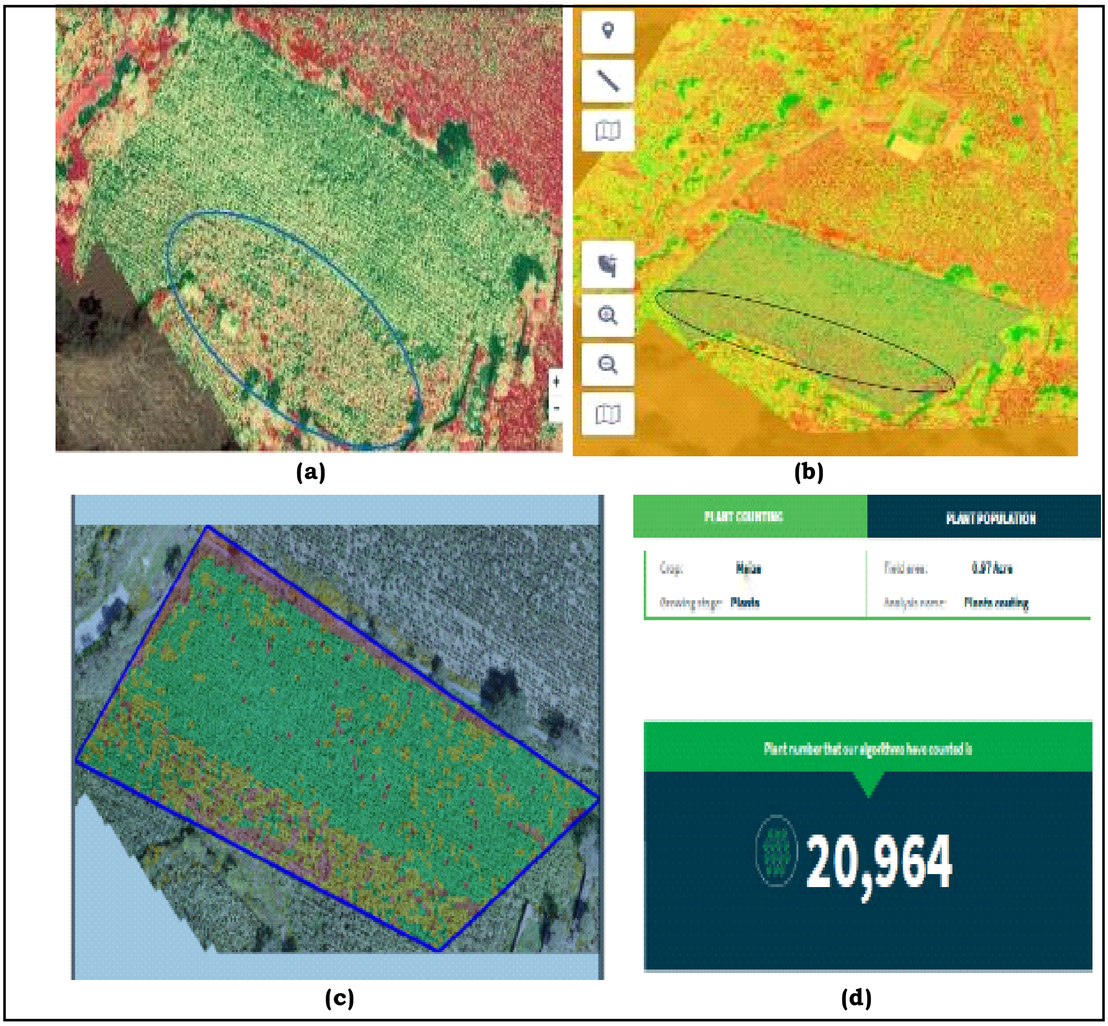

Fig. 4. (a) Plant health map from DroneDeploy analysis, (b) Plant health map from Agremo analysis, (c) Polygon used for plant count analysis and (d) Results of plant population analysis.

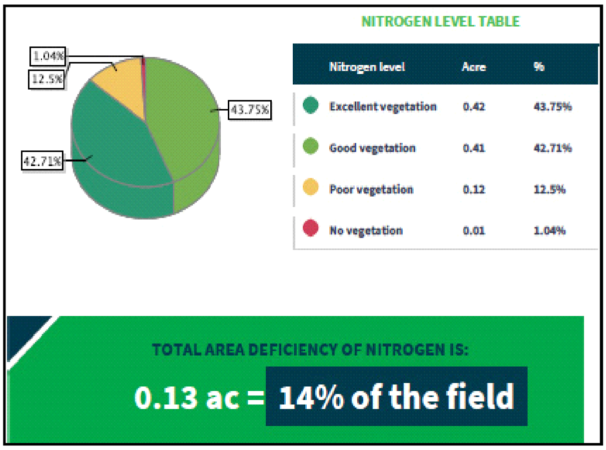

Fig. 5. Nitrogen analysis report.

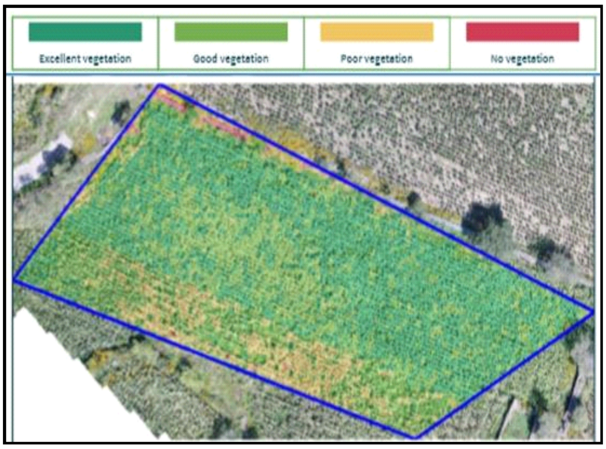

Fig. 6. Nitrogen analysis report.

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CAPÍTULO VI MEXICAN PRECISION AGROFORESTRY POLICY

RESUMEN

Los recursos naturales limitados, el alto costo de los insumos agrícolas y la degradación ambiental están promoviendo la agricultura de precisión, los drones se han vuelto ampliamente disponibles para su uso en imágenes aéreas de campos agrícolas, estos pueden analizar datos de mapas de drones para comprender la salud de los cultivos. El objetivo de este trabajo fue el análisis rápido de la salud de las plantas, el estado del nitrógeno y el conteo de plantas en cultivos de maíz utilizando drones. En nuestro campo, la salud de las plantas es mejor en áreas bajas. El área total con deficiencia de nitrógeno es el 14% del campo, localizada en áreas altas, por lo que se recomiendan acciones de manejo en áreas identificadas. El análisis de conteo de plantas reporta 20,964 plantas. La información rápida obtenida para drones y software puede tomar medidas rápidamente para remediar algunos problemas agrícolas comunes.

Palabras clave: Insumos agronómicos, Drone, Recursos fitogenéticos, Agricultura de precisión.

ABSTRACT

The limited natural resources, high cost of agro-inputs and environmental degradation are promoting precision agriculture, the drones have become widely available for use in agriculture aerial imagery of fields, these can be analyzing drone map data to understand the health of crops. The objective of this paper was the fast analysis of plant health, nitrogen status, and plant count in maize crops using drones. In our field, plant health is better in low areas. The total area with nitrogen deficiency is 14% of the field, spot in high areas, so that management actions on identified areas are recommended. Plant count analysis reports 20,964 plants. The fast information obtained for drones and software can take action quickly to remedy some agricultural common issues.

Keywords: Agronomic inputs, Drone, Fitogenetic resources, Precision agriculture

Mexican precision agroforestry policy

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ABSTRACT

The precision agriculture tools and technologies are becoming more and more useful in forestry and agroforestry sector. Agroforestry is multifunctional agriculture, and smart climatically that combines high food productivity with environmental protection according to the local sociocultural context, these advantages have prompted several countries have developed national agroforestry initiatives and policies. The main objective of this short communication is the proposal of a Mexican precision agroforestry policy for promoting economic growth through climatic smart agriculture and a resilient economy to climate change. This policy includes the establishment of sixteen agroforestry systems, the plantations will be diagnosed with the use of drones and specialized agricultural applications, with the information collected, the application of the corresponding agro-input will be carried out with the use of a multirotor sprayer drone. The Mexican government will offer only fifty species of trees and will provide personal agroforestry technical advice. Mexico is the center of origin and domestication of several agricultural species, the implementation of this policy will favor its care and preservation.

Keywords: *Agronomic inputs, Drone, Fitogenetic resources, Precision agriculture*

1. Introduction

Several agroforestry policies and initiatives have been developed around the world, in 2014 India became the first country to adopt a national agroforestry policy (Singh et al., 2016), other areas with national agroforestry initiatives are North America (Cutter et al., 1999), Europe (Carvalho et al., 2002; Herzog, 2018; Mouysset et al., 2019), Asia (Barua and Wilson, 2005; Cedamon et al., 2018; Simelton et al., 2017), South America (Alfaro, 1994; Figueroa, 1994; Jordan, 2012), and Africa (Birhane, 2014; Divine, 2013; Graefe et al., 2017; Kengoum, 2015; Sanginga et al., 2004; Stainback, 2011).

Precision agriculture (PA) has had a strong development in the last two decades (Thompson et al., 2019) for monitoring and assessing crops, orchards, and forests (Barbedo, 2019), PA can be very useful for Agroforestry (Sun et al., 2018), for example with UAVs, can add low-cost precision images can fast detection important information about crop status, weeds, pests, diseases infestations, and other abnormalities (Pádua et al., 2017), and immediately information collected will be processed with specialized applications for farmers can make an accurate application (with a multirotor sprayer drone) of agro-inputs (Khanal et al., 2017). Multirotor sprayer drone applications improve the performance, efficiency and success of the spraying operation, avoid the application of chemicals in areas non-priority, the reduction of human contact with chemicals (Faiçal et al., 2016), low-cost choice (Xiongkui et al., 2017), and reduce environmental damage (Partel et al., 2019).

Finally, climate change is affecting agricultural production and ecosystems worldwide (Thayer et al., 2020), and it can severely reduce the economic development of a country (Yalew et al., 2017), in response to this problem, agroforestry is a development model that can at the same time mitigate climate change, improve food security and increase the local economy (FAO, 2015; Waldén et al., 2020), and in different regions (Abbasi Surki et al., 2020), so that this type of agriculture has recently caught the attention of researchers around the world (Ahmad et al., 2017). The main objective of this short communication is the proposal of a Mexican precision agroforestry policy for promoting economic growth through climatic smart agriculture and a resilient economy to climate change.

2. Agroforestry system authorized

2.1 Authorized tree

This policy authorizes only fifty tree species (Table 1) will be used in sixteen agroforestry systems, because tree species with high interest for the productivity of the country, both to meet internal and international market requirements.

2.2 Alley farming, Intensive Silvopastoral System and Apiforestry

In *Gramineae* in alley cropping (Xu et al., 2019) farmers shall select at least one arboreal component and an annual component (Table 2). In Intensive silvopastoral system (Mauricio et al., 2019) farmers shall select at least one forage tree and two forage grasses (Table 2), fruit or wood tree can or not included. In Horti-olericulture system (Singh et al., 2018) farmers shall select at least a fruit tree and an annual vegetable component (Table 2). In Medicinal crops in alley cropping (Thakur et al., 2017) farmers shall select at least a fruit or wood tree (Table 2). In Ornamental crops in alley cropping farmers shall select at least a fruit or wood tree (Table 2). Finally, in apiforestry *Prosopis leavigata*, *Coffea spp.*, *Malus spp.*, *Prunus spp.*, *Mangifera indica*, *Cocos nucifera*, *Musa spp.*, and *Robinia pseudoacacia* are species prioritized.

Table 1. Fifty authorized trees

Fruit tree	Wood tree	Legume tree	Forage tree	Other tree
Crataegus mexicana, Melicoccus bijugatus, Prunus salicifolia, Theobroma spp., Spondias purpurea, Carica papaya, Prunus capulí, Persea spp., Manilkara zapota, Citrus spp., Mangifera indica, Psidium guajava, Prunus domestica, Pyrus spp., Cocos nucifera, Malus spp., Annona spp., Coffea spp., Diospyros spp., Opuntia ficus-indica, Byrsonima crassifolia, Opuntia joconostle, Prunus armeniaca, Polaskia chichipe, Polaskia chende, Escontria chiotilla, Myrtillocactus chenckii	*Tectona grandis, Hevea brasiliensis, Populus spp., Pinus spp., Poplar spp., Cedrella odorata, Swietenia mahagoni, Quercus spp., Cordia spp.*	*Leucaena spp., Gliricidia sepium, Cajanus cajan, Calliandra calothyrsus, Erytrinia spp., Inga spp., Prosopis spp., Robinia pseudoacacia*	*Guazuma ulmifolia* *Tithonia diversifolia*	*Salix bomplandiana* *Agave spp.* *Yucca spp.* *Licaria arborea*

Table 2. Authorized combinations

Agroforestry system	Tree component	Herbaceous component
Gramineae in alley cropping	Any fruit, wood and legume tree authorized	*Zea mays, Sorghum spp., Triticum spp., Avena sativa, Secale cereal,* and *Hordeum vulgare*
Intensive silvopastoral system	*Leucaena spp., Guazuma ulmifolia, Tithonia diversifolia, Citrus spp., Cocos nucifera*	*Panicum maximum* cv. *Tanzania, Cynodon plectostachyus,* and Natural grasses
Horti-olericulture	Any fruit tree authorized	*Physalis ixocarpa, Curcubita spp., Capsicum spp., Ananas comosus, Pisum sativum, Solanum tuberosum, Solanum lycopersicum, Fragaria spp., Cicer arietinum, Ipomea batatas, Manihot esculenta, Solanum melogena, Cucumis sativus, Dysphania ambrosioides, Porophyllum ruderale, Portulaca oleracea, Coriandrum sativum, Petroselinum crispum, Beta vulgaris, Raphanus sativum, Brassica oleracea, Pachyrhizus erosus,* and *Fabaceae, Solanaceae, Brasicaceae* crops
Horti/Silvi-medicinal	Any fruit and wood tree authorized	*Ocimum basilicum, Ruta chalepensis, Matricaria recutita, Artemisia vulgaris, Mentha spp., Pluchea symphytifolia, Ocimum micranthum, Salvia rosmarinus,* and medicinal crops
Horti/Silvi-ornamental	Any fruit and wood tree authorized	*Tagetes spp., Tigridia spp., Cosmos spp., Dahlia spp., Euphorbia spp., Anthurium spp., Begonia spp., Helianthus spp., Ipomoea spp., Laelia spp., Rossioglossum spp., Salivia spp.,* and *Tithonia spp.*
Apiforestry	Any fruit and wood tree	

2.3 Mexican traditional agroforestry systems

The teen Mexican agroforestry systems considered is Chinampas with ahuejotes tree (*Salix bomplandiana*) (Merlín et al., 2013), Metepantle with *Agave spp.*, *Opuntia spp*., *Buddleja americana, Quercus castanea, Pinus leiophylla, Crataegus mexicana, Prunus capuli, Prunus persica, Prunus armeniaca, Eysenhardtia polystachya* and *Senecio salignus* (Moreno et al., 2013). Chichipera with *Polaskia chichipe* and *Polaskia chende*-maize intercrop (Moreno *et al*., 2012), Jiotillal with *Escontria chiotilla*- maize intercrop (Moreno et al., 2010), Garambullal with *Myrtillocactus schenckii*- maize intercrop (Moreno et al., 2010), Mezquitales with *Prosopis spp*.- maize intercrop (Moreno et al., 2013), Palmerales with *Yucca spp*.- maize intercrop (Moreno et al., 2013), *Inga shade/ Erythrina spp.*-organic coffee (Soto et al., 2010), *Theobroma cacao* with *Cedrella odorata-Cordia spp.* (Brito et al., 2018), and *Cacaotales* with *Licaria arborea* and *Theobroma cacao* (Moreno et al., 2013).

3. Precision agriculture for Mexican agroforestry policy

To capture the images of the agroforestry plantations, the DJI MATRICE 200 is a UAV model will be used, because too easy to transport, mount, launch, easy operate, and cheap prices (Pádua et al., 2017), the drone allows farmers to observe their fields from the sky, and images can reveal diverse issues on the orchard, as irrigation related problems, soil variations, fungal and pest infestations (Yinka and Ajayi, 2019), with this information allows the farmer to establish the most appropriate earlier management. In this policy DroneDeploy mapping software platform will be used for captures images and processes those images into maps and 3D models (Ezat et al., 2018), and then Agremo software is proposed for agricultural analysis, for example, nitrogen status in crops, weed analysis, pest analysis, plant disease analysis, plant stress analysis, waterlogging analysis, drought analysis, stand count, plant population, flowering estimator and canopy analysis (Agremo, 2020).

To aerial spraying of the agroforestry plantations, the DJI AGRAS T16 is a multirotor UAV model that will be used. Precision pest control systems, such as distributors of natural enemies and pesticide spray rigs, can provide localized solutions (Filho et al., 2020), and precision weed control systems can be providing localized solutions in weed-infested areas (Casa et al., 2019). Diverse studies have reported the Mexican people's health damage for exposure to pesticides (Rodríguez et al., 2018; Sierra et al., 2019), and the national level, hypoxia is another prevalent problem in the Gulf of Mexico (Hudson et al., 2005), so it is necessary the application of environmental laws, as they are important factors that contribute to these complex problem for the human health and the environment conservation (Rodríguez et al., 2018). The government will assign trees, agroforestry technical support, and drone analysis. The SADER, CORENA, and Universidad Autónoma Chapingo will carry out the corresponding agroforestry technical support and Mesmis evaluation (Lopez et al., 2002).

4. Precision agriculture for agroforestry farmers

The precision agriculture tools and technologies are becoming more and more useful in forestry and agroforestry production, so it is necessary to continue carrying out specialized research in the adaptation and management of these technologies in already consolidated agroforestry systems, such as alley cropping, silvopastures, taungya system, etc. By their nature, agroforestry systems are very diverse; this condition will require the adaptation and elaboration of specific methodologies for the analysis of each specific agricultural parameter, especially some trees have particular characteristics (eg canopy size, natural architecture, leaves type, etc.).

For agroforestry proposes the most available sensors are RGB sensors, NIR sensors, Infrared sensors, Multispectral sensors, and Hyperspectral sensors (Milics, 2019). The hyperspectral sensors are more precise in plant nutrient status, identifying plant disease, water quality assessment, and surface chemical composition. The thermal sensors identifying any heat stress, water stress, and plant metabolism from their canopy temperature, while LiDAR sensors use a laser beam to create 3D models of crops to identify drought stress and to measure the vegetation level (Gautam and Sarkar, 2020). These tools and technologies can help agroforestry professionals in short, medium, and long-term operations, due to the possibility of identifying problems faster and, consequently, react quickly, reducing losses, monitored reacting to different agronomic treatments, avoid unnecessary economic expenses, and more effective use of resources (Pádua et al., 2017), thus contributing to the rural economy, employment, poverty alleviation, and environmental protection at a local, regional, and national level (Alavalapati et al., 2004).

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CAPÍTULO VII AGROFORESTRY 4.0 FOR INDIAN AGROFORESTRY POLICY

RESUMEN

La Política Agroforestal Nacional de la India tiene un gran potencial para la adopción de la tecnología Agroforestry 4.0. Agroforestry 4.0 supone el uso de robots, herramientas, tecnologías y plataformas de agricultura de precisión. En la actualidad, la tecnología de Internet de las cosas (IoT) y Big Data juegan un papel importante en la producción de alimentos. El objetivo principal de este documento de la conferencia es proponer algunas intervenciones de tecnología Agroforestry 4.0 para la política agroforestal india. La aplicación móvil Indian Agroforestry permitirá a los agricultores solicitar App Services en gestión agroforestal: riego inteligente, análisis de sanidad vegetal, análisis de sequía, recuento de plantas, análisis de anegamiento, pulverización aérea inteligente de herbicidas, pulverización aérea inteligente de fertilizantes, pulverización aérea inteligente de insecticida , fumigación aérea inteligente de fungicidas, fertilización con vehículos terrestres no tripulados y análisis de dosel. El papel de la tecnología de vehículos aéreos no tripulados en Agroforestry 4.0 incluye riego, fertilización, uso de pesticidas, manejo de malezas, monitoreo del crecimiento de las plantas y manejo de enfermedades de los cultivos. Además, la aplicación móvil ofrece información sobre el clima, asistente técnico, cápsula técnica de video, nueva investigación agroforestal, descuentos en insumos agroforestales, oferta de productos agroforestales y entrega a domicilio. La tecnología de teléfonos inteligentes y las aplicaciones móviles son prometedoras para el desarrollo futuro de la agroforestería 4.0. Palabras clave: agricultura inteligente, aplicación móvil, vehículo terrestre no tripulado, vehículos aéreos no tripulados.

Palabras clave: Agricultura inteligente, aplicación móvil, vehículo terrestre no tripulado, vehículos aéreos no tripulados

ABSTRACT

India's National Agroforestry Policy has great potential for the adoption of Agroforestry 4.0 technology. Agroforestry 4.0 supposes the use of robots, tools, technologies, and platforms of precision agriculture. At the present day, the Internet of Things (IoT) technology and Big Data play an important role in food production. The main objective of this conference paper is to propose some Agroforestry 4.0 technology interventions for Indian agroforestry policy. The Indian Agroforestry mobile app will permit to farmers ask for App Services in Agroforestry management: smart irrigation, plant health analysis, drought analysis, plant count, waterlogging analysis, smart aerial spraying of herbicide, smart aerial spraying of fertilizers, smart aerial spraying of insecticide, smart aerial spraying of fungicide, fertilization using Unmanned Ground Vehicle, and canopy analysis. The role of Unmanned Aerial Vehicles technology in Agroforestry 4.0 includes irrigation, fertilization, use of pesticides, weed management, monitoring of plant growth, and management of crop diseases. Moreover, the mobile app offers Information on weather, technical assistant, video technical-capsule, new agroforestry research, agroforestry input discounts, agroforestry products offer, and home delivery. Smartphone technology and mobile applications hold promise for the future development of agroforestry 4.0. Keywords: smart agriculture, mobile application, Unmanned Ground Vehicle, Unmanned Aerial Vehicles

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Short communication

Agroforestry 4.0 Interventions for Indian Agroforestry Policy

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ABSTRACT

India's National Agroforestry Policy has great potential for the adoption of Agroforestry 4.0 technology. Agroforestry 4.0 supposes the use of robots, tools, technologies, and platforms of precision agriculture. At the present day, the Internet of Things (IoT) technology and Big Data play an important role in food production. The main objective of this conference paper is to propose some Agroforestry 4.0 technology interventions for Indian agroforestry policy. The Indian Agroforestry mobile app will permit to farmers ask for App Services in Agroforestry management: smart irrigation, plant health analysis, drought analysis, plant count, waterlogging analysis, smart aerial spraying of herbicide, smart aerial spraying of fertilizers, smart aerial spraying of insecticide, smart aerial spraying of fungicide, fertilization using Unmanned Ground Vehicle, and canopy analysis. The role of Unmanned Aerial Vehicles technology in Agroforestry 4.0 includes irrigation, fertilization, use of pesticides, weed management, monitoring of plant growth, and management of crop diseases. Moreover, the mobile app offers Information on weather, technical assistant, video technical-capsule, new agroforestry research, agroforestry input discounts, agroforestry products offer, and home delivery. Smartphone technology and mobile applications hold promise for the future development of agroforestry 4.0.

Keywords- Smart Agriculture, Mobile Application, Unmanned Ground Vehicle, Unmanned Aerial Vehicles

INTRODUCTION

Technological innovations are changing mechanization in agriculture Kernecker *et al*. (2020). In recent years, the world assists in the Fourth Industrial Revolution, also called Industry 4.0, which leads to a higher level of connectivity, automation, and efficiency Corallo *et al.* (2020). The term "Agri-Food 4.0" is an analogy to the term "Industry 4.0", coming from the concept "agriculture 4.0" Lezoche *et al.* (2020)**,** Agriculture 4.0, as the fourth evolution in the farming technology, puts forward four essential requirements: increasing productivity, allocating resources reasonably, adapting to climate change, and avoiding food waste Zhai *et al*. (2020). Agriculture 4.0 refers to systems that employ drones, robotics, Internet of Things (IoT), vertical farms, artificial intelligence, and solar energy. Through the integration of digital technology into farming practices, companies are able to increase yields, reduce costs, experience less crop damage, and minimize water, fuel, and fertilizer usage. For the consumer, this equals cheaper and better quality food (Yahya, 2018).

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The agricultural sector also benefits greatly from what Industry 4.0 brings. IoT (Internet of Things), AI (Artificial Intelligence), Remote Sensing & ImP (Remote Sensing and Image Processing) techniques have been integrated with GIS (Geographic Information Systems) and have been actively used in agriculture in recent years Wolfert *et al.* (2017). Monitoring agriculture from remote sensing is a vast subject that has been widely addressed from multiple viewpoints, sometimes based on specific applications (e.g. precision farming, yield prediction, irrigation, weed detection), on specific remote sensing platforms or sensors or specific locations and climatic contexts (e.g. country or continent, wetlands or drylands) Weiss *et al*. (2020).

The soil characteristic and meteorological data collected by sensors, high-resolution multi-band images taken from satellite systems and unmanned aerial vehicles are transferred to decision support platforms and artificial intelligence support can be used to determine the stress factors of crops and propose instant solution alternatives Wolfert *et al.* (2017), so that, Precision Agriculture offers the opportunity for a farmer to apply the right amount of treatment at the right time and at the right location in the farm Raj *et al.* (2020). Precision Agriculture supposes they use robots, tools, technologies, and platforms. Two types of robots employed in agriculture applications are typically used: unmanned ground vehicles (UGV) and unmanned aerial vehicles (UAV) Zecha *et al.* (2013). Autonomous, robotic vehicles have been developed for farming purposes, such as mechanical weeding, application of fertilizer, or harvesting of fruits Walter *et al.* (2017).

Agriculture automation has several methods of getting data from vegetable crops like sensors for environmental measurement. Therefore, we developed a portable measurement technology including a soil moisture sensor, air humidity sensor, and air temperature sensor. Moreover, an irrigation system using wireless sensor networks has installed these sensors, with the purpose of collecting the environment data and controlling the irrigation system via smartphone Kaewmard *et al.* (2014). Emerging Internet of Things (IoT) technologies, such as IoT devices (e.g., wireless sensor networks, network-connected weather stations, cameras, and smartphones) can be used to collate vast amount of environmental and crop performance data, ranging from time-series data from sensors to spatial data from cameras, to human observations collected and recorded via mobile smartphone applications Jayaraman *et al*. (2016). Smartphone technology is promising for the future development of agriculture, as it can facilitate and improve many operational procedures and can also be combined with precision agriculture technologies Michels *et al.* (l2020). Mobile apps increasingly constitute complete ecosystems to support businesses such as farming Braun *et al.* (2016).

Industrial Revolution 4.0 has been discussed and debated all around the world. Every country is preparing their strategies to address the Industrial Revolution 4.0 Awang *et al*. (2020). Agriculture is undergoing a new technology revolution supported by policy-makers around the world Rose *et al*. (2018). In another hand, the South and Southeast Asian region are often described as the cradle of agroforestry in recognition of its long history of the practice of an array of systems under diverse agro-ecological conditions Kumar *et al.* (2012), Since ages agroforestry has been known as a traditional land-use system in India Chavan *et al*. (2015). India launched National Agroforestry Policy on 10th February 2014 which has the potential to substantially reduce poverty in rural India and revive the wood-based industry, besides integrating food production with environmental services Dhyani *et al.* (2017). The analysis of land potentiality in India for agroforestry suitability reveals 32.8% as highly suitable (S1), 40.4% moderately suitable (S2), 11.7% marginally suitable (S3), and 9.1% not suitable (NS) Ahmad *et al*. (2019).

Agriculture is one of the major backbones of the Indian economy where around 60% of people are depending directly or indirectly upon agriculture Kale *et al.* (2019), and Agroforestry system has the enormous capacity to achieve social, economic, and environmental goals by optimizing land productivity Ahmad *et al.* (2019). Advances in Smart Farming and

Big Data applications have the potential to help agricultural industries meet productivity and sustainability challenges Jakku *et al.* (2019). As agriculture meets digital technologies, a new frontier of innovation is emerging and creating multiple pathways to a smart farming future Relf-Eckstein *et al.* (2019). The main objective of this conference paper is to propose some Agroforestry 4.0 technology interventions for Indian agroforestry policy.

DATA ACQUISITION TECHNOLOGIES

Precision Agriculture is a cyclic optimization process where data have to be collected from the field, analyzed and evaluated and finally used for decision making for site-specific management of the field Balafoutis *et al.* (2017). Sensors, drones, weather satellites and robots are examples of technologies that make farming 'smart' van der Burg *et al.* (2019). Data acquisition technologies include GNSS technologies, mapping technologies, data acquisition of environmental properties and machines and their properties. Data analysis and evaluation technologies comprise the delineation of management zones, decision support systems and farm management information systems. Finally, precision application technologies embrace variable-rate application technologies, precision irrigation and weeding and machine guidance Balafoutis et al. (2017).

Wireless Sensor Networks: Wireless Sensor Networks establish the foundation for a revolution in precision agriculture. As an integral part of smart farming systems, they can collect detailed information about crop health, air, and soil conditions, and other relevant parameters to support agriculturists in their decision-making Huchtkoetter *et al. (*2018). Wireless sensor networks (WSN) can be defined as a group of spatially and dedicated sensors for monitoring the physical conditions of the environment, temporarily storing the collected data, and transmitting the gathered information at a central location *Dargie et al*. (2011).

Satellite-based remote sensing: Geographic information system (GIS) and remote sensing are fundamental techniques for precision agriculture, providing different types of information: plantation layouts, crop health, and plant growth stages; these tools can provide information to farmers quickly Avtar *et al.* (2020). Remote sensing appears as an essential tool to respond to the above-mentioned requirements since it offers a non-destructive means of providing recurrent information from the local to the global scale in a systematic way, thereby enabling the characterization of the spatio temporal variability within a given area. Remote sensing has the capacity to assist the adaptive evolution of agricultural practices in order to face this major challenge, by providing repetitive in-formation on crop status throughout the season at different scales and for different actors Weiss *et al.* (2020).

UAVs-based remote sensing: The use of drones in agriculture is becoming more and more popular Tripicchio *et al.* (2015). Unmanned aerial vehicles (UAVs) or drones in smart farming applications offer the potential to monitor farmland on a per-plant basis, which in turn can reduce the amount of herbicides and pesticides that must be applied Lottes *et al.* (2017). With recent advances in sensor technology, several sensors are being extensively used to continuously monitor agriculture areas to have a better yield. These sensors, which include Red, Green, Blue(RGB) cameras, thermal cameras, infrared radiation (IR) cameras, multispectral sensors, and hyperspectral sensors are either ground-based sensors or unmanned aerial vehicle (UAV) based sensors (Aggarwal, 2020).

Drone-based sensors are PAR and IR imagers and sensors (400–2500 nm) RGB camera Multispectral camera/red-edge camera Hyperspectral imager (400–2500 nm) Snapshot imager Line scanner imager Thermal camera (3000–12,000 nm) LiDAR sensor Aerobiological sampling Spraying of pesticides through drone (Raj et al., 2020). UAVs equipped with cameras using both the RGB portion of the visible light spectrum and the near-infrared portion of the electromagnetic spectrum (780–2500 nm) take Blue Normalized Difference Vegetation Index (BNDVI: the blue band is the near-infrared portion in this research) images (Matsumura, 2020). Hyperspectral imaging is a powerful tool for remote sensing of vegetation and the environment, especially in precision agriculture and forest management Kurihara *et al*. (2020).

Multispectral data collected from a UAV is very util in the agroforestry system with a low value of normalized difference vegetation index (NDVI) Avtar *et al.* (2020). Three-dimensional models of forestry from Structure Motion and Multi-View Stereo (SfM-MVS) system have been developed using 2D imagery data captured by UAVs. Such models are useful in the estimation tree height in forestry which is required for several applications of remote sensing. UAV-based SfM measurements allow easy creation of high-resolution ortho-mosaic images and topographic maps Obanawa *et al.* (2020).

DATA COMMUNICATION AND DATA PROCESS TECHNOLOGIES

Internet of Things (IoT): Internet of Things (IoT) technology has a substantial role to play in promoting sustainable agriculture and food production (Khan, 2020). Internet of Things (IoT) plays a crucial role in smart agriculture. Smart farming is an emerging concept because of IoT sensors capable of providing information about their agriculture fields Prathibha *et al.* (2017). "Internet of Things" (IoT) is a technology that permits things to communicate and connect with each other. This is helpful in changing the patterns and processes in both industry and agriculture towards higher efficiency (Anushree, 2018). The emerging Internet of Things (IoT) along with Wireless Sensor Networks (WSNs) with their low-cost sensors and actors enable novel applications and new opportunities for a more precise, site-specific, and sustainable agriculture in the context of Smart Farming Bauer *et al.* (2018).

Internet of Things (IoT) and Unmanned Aerial Vehicles (UAVs) are two hot technologies utilized in cultivation fields, which transform traditional farming practices into a new era of precision agriculture, IoT links the information generated in soil water content sensor, soil moisture content sensor, soil electrical conductivity sensor, ph sensor, weed seeker sensor, temperature sensor, and wind speed sensor. Internet of Things adopts various enabling techniques, such as wireless sensor networks, cloud computing, big data, embedded systems, security protocols, and architectures, communication protocols, and web services Boursianis *et al.* (2020). Moreover, Agriculture is taking advantage of the Internet of Things paradigm and of the use of autonomous vehicles. The 21st-century farm will be run by interconnected vehicles: an enormous potential can be provided by the integration of different technologies to achieve automated operations requiring minimum supervision Bacco *et al.* (2018).

Big Data: Big data technology used to collect, store, and analyze real-time Benjelloun *et al*. (2015). Big data are being used to provide predictive insights in farming operations, drive real-time operational decisions, and redesign business processes for game-changing business models Wolfert *et al.* (2017). Big Data represents a revolution for the agricultural sector, that can change the ways farmers farm, farm workers work, agri-food supply chains operate, and scientists think. Big data are used in many arenas of economic and social life, changing the way business is done and reshaping the style through which decisions are made by companies, organizations, and governments Lioutas *et al.* (2020). Advances in granular and cloud computing offer ample opportunities to extract knowledge from these data, to uncover and understand hidden patterns, and to easily share the results of big data analysis Chen *et al.* (2014).

New technologies have the potential to transform agriculture and to reduce environmental impact through a green revolution. Internet of Things (IoT)-based application development platforms have the potential to run farm management tools capable of monitoring real-time events when integrated into interactive innovation models for fertirrigation. Their capabilities must extend to flexible reconfiguration of programmed actions. IoT platforms require complex smart decision-making systems based on data-analysis and data mining of big data sets Baseca *et al.* (2019).

Artificial Intelligence: Every day, farms produce thousands of information points on temperature, soil, usage of water, atmospheric phenomenon, etc. With the assistance of computer science and machine learning models, this data is leveraged in real-time for obtaining useful insights like choosing the correct time to plant seeds, determining the crop choices, hybrid seed choices, etc. Ramachandran *et al.* (2020). The field of artificial intelligence (AI) involves the development of theory and computer systems capable of performing tasks normally requiring human intelligence, such as sensorial perception and decision making. AI acts on external information sourced from IoT and other big data sources, uses knowledge -based rules (provided by developers), or identifies the underlying rules and patterns using machine learning, to drive the systems towards set objectives. A truly intelligent system can learn, generalize, accumulate knowledge, set objectives and priorities, and minimize risks for decision-making processes Misra *et al.* (2020).

New and developing artificial intelligence (AI) based tools can leverage site-based science and big data to help farmers and land managers make site-specific decisions. These tools are improving information about soils and vegetation that forms the basis for investments in management actions, provides early warning of pest and disease outbreaks, and facilitates the selection of sustainable cropland management practices Bestelmeyer *et al*. (2020). AI-based technological solutions have enabled the farmers to produce more output with less input and even improved the quality of output, also ensuring faster go-to-market for the yielded crops. The robots are performing various agricultural operations autonomously such as weeding, irrigation, guarding the farms for delivering effective reports, ensuring that the adverse environmental conditions do not affect the production, increase precision, and manage individual plants in various unfamiliar ways Talaviya *et al.* (2020).

ENABLED AGRICULTURAL REMOTE MANAGEMENT TECHNOLOGIES

Smart farming: Smart Farming represents a new approach based on the management of observation, measurement, and response to internal and external variations in crops Lasso *et al.* (2018). Smart Farming analyzing the massive amounts of data can be done by accessing and connecting various devices with the help of the Internet of Things (IoT) Alipio *et al.* (2017). Smart Farming is driven by the emergence of precise positioning systems and Internet of Things technologies which have already enabled site-specific applications, sustainable resource management, and interconnected machinery Bothe *et al.* (2019). Smart farming (SF) involves the incorporation of information and communication technologies into machinery, equipment, and sensors for use in agricultural production systems. New technologies such as the internet of things and cloud computing are expected to advance this development, introducing more robots and artificial intelligence into farming Pivoto *et al*. (2018).

Smart farming (also referred to as digital farming, digital agriculture, and precision agriculture) has largely been productivity and efficiency aims Eastwood *et al.* (2019), and have a real potential to deliver more productive and sustainable agricultural production Caffaro *et al.* (2019), so, that, smart farming is seen to be the future of agriculture as it produces a higher quality of crops by making farms more intelligent in sensing its controlling parameters Alipio *et al.* (2017). Increased use of data from smart farming technologies presents an opportunity for farmers to better understand their farm systems, and thereby improve outcomes for productivity, sustainability, and animal care Eastwood *et al.* (2019).

Precision agriculture: Precision Agriculture (PA), as the integration of information, communication, and control technologies in agriculture, is growing day by day Zamora *et al*. (2019). In precision agriculture more and more robots are being used to perform tasks that may include some farming activities, such as pruning, inspection or spraying, assigned to the robot as a result of a previous analysis activity or autonomously identified by the machine itself Fotio *et al.* (2020). Precision agriculture (PA) strongly relies on spatially differentiated sensor information Erler *et al.* (2020).
Agriculture is highly climate dependent and with global warming and rapidly changing weather it has become necessary to closely monitor the environment of growing crops for maximizing output as well as increasing food security while minimizing resource usage Subashini *et al*. (2018). Precision agriculture is starting to play a key role in the new generation of the modern agricultural revolution. It is a modern way of growing crops that allows the farmer to keep direct real-time control of the quality parameters of their fields. Precision agriculture implies the use of advanced cameras and sensors that normally are implemented in satellites, different types of aerial vehicles, and, nowadays, even terrestrial vehicles Caballero *et al*. (2020).

Robotics (UAV and TAV):While smart technologies, such as Artificial Intelligence, robotics, and the Internet of Things, could play an important role in achieving enhanced productivity and greater eco-efficiency, critics have suggested that the consideration of social implications is being side-lined Rose *et al.* (2018). Since human beings transitioned to an agrarian lifestyle, technological advancements have enabled evolutions in agriculture, resulting in greater varieties and yields of crops. However, as society faces the effects of climate change and the resulting social challenges, agriculture is at a unique point in its history. Recent advancements in a number of key technologies have placed agriculture at the precipice of another evolution that could not only affect the variety and yield of crops but also climatological and social outcomes as well. Specifically, advancements with the Internet of Things, artificial intelligence, and robotics among others have enabled data-driven and automated agriculture Charania *et al*. (2020).

UAV (Unmanned Aerial Vehicles): The role of UAV technology in smart agriculture, by analyzing the applications of UAVs in various scenarios, including irrigation, fertilization, use of pesticides, weed management, plant growth monitoring, crop disease management, and field-level phenotyping Boursianis *et al.* (2020). Drone high-resolution images can give detailed information about the soil and crop condition, which can be used for farm management purposes. Leaf area index, normalized difference vegetation index, photochemical reflectance index, crop water stress index, and other such vegetation indices can provide important information on crop health. Through UAV-based PA, stressed areas can be identified in real-time, and some corrective measures can also be carried out (e.g., fertilizer and pesticide spraying) Raj *et al*. (2020).

Drones can be particularly useful in spot-spraying situations over a massive landscape. In drones and other UAVs, the poisoning of people who spray is drastically reduced Kestur *et al.* (2020). A remote-controlled UAV (Unmanned Aerial Vehicle) is used to spray the Pesticide as well as fertilizer Meivel *et al*. (2016). The drone can be useful for spraying pesticides and crop protection. this can be done by the single person standing at a safe distance and by controlling the UAV. This helps the farmer in reducing the time taken and also provide safety to the farmer Teli *et al.* (2019).

UGV (Unmanned Ground Vehicle): Increasing the use of unmanned ground vehicles in precision agriculture has gained significant attention from farmers and industries to minimize human workload to perform tasks such as land preparation, seeding, fertilizing, plant health monitoring, and harvesting. Normally, first, image acquisition is performed over a vineyard to generate an orthomosaic and a digital surface model, which are then used to identify the vine rows and inter-row terrain. This information is then used by the algorithm to generate a path plan for UGV Zoto *et al.* (2020). The tractor has been the central vehicle for executing most of the work required in a crop field. Equipped with the proper accessories, this machine can till, plant, fertilize, spray, haul, mow, and even harvest. Their adaptability to dissimilar tasks makes tractors a prime target for automation, which would enable productivity increases, improve safety, and reduce operational costs Gonzalez *et al*. (2020).

Smart irrigation: Automatic Irrigation System based on Artificial Intelligence and the Internet of Things, which can autonomously irrigate fields using soil moisture data. The system is based on prediction algorithms which make use of historic weather data to identify and predict rainfall patterns and climate changes; thereby creating an intelligent system which irrigates the crop fields selectively only when required as per the weather and real-time soil moisture conditions Choudhary *et al*. (2019). The plant evapotranspiration which was dependent on various atmospheric parameters such as humidity, the wind speed, solar radiations and even the crop factors such as the stage of growth, plant density, the soil properties, and pest was taken into consideration while implementing autonomous irrigation machines Talaviya *et al.* (2020).

Smart Farming has become the main trend in the agriculture sector. Industrial investments are increasing from day to day to achieve integration of IoT solutions in their smart farming products to cut down the overall cost, increase the quality and quantity of the harvesting. Advancements in communication technologies such as GSM and GPRS have enabled remote control of irrigation systems Pooja *et al.* (2018). The tremendously growing population of our country has positioned a tremendous strain on the farming quarter. Nowadays water shortage is the main difficulty for agriculture. In this stage, the synthetic irrigation comes into the situation Shilpa *et al*. (2019).

INDIAN AGROFORESTRY MOBILE APP

Smart farming practices are of utmost importance for any economy to foster its growth and development and tackle problems like hunger and food insecurity and ensure the well-being of its citizens Agrawal *et al.* (2016), various applications of Artificial intelligence in agriculture such as for irrigation, weeding, spraying with the help of sensors and other means embedded in robots and drones. These technologies save the excess use of water, pesticides, herbicides, maintains the fertility of the soil, also helps in the efficient use of manpower and elevate the productivity and improve the quality Talaviya *et al.* (2020). Apps have an open format for geospatial information, provides a gateway to bridge agricultural geographic information and mobile devices such as smartphones and tablets Zhang *et al.* (2016), moreover, can realize remote monitoring and control of a field sprayer (Koc, 2013). Figure 1. Shows a proposal of the agroforestry app for the National Indian Agroforestry Policy.

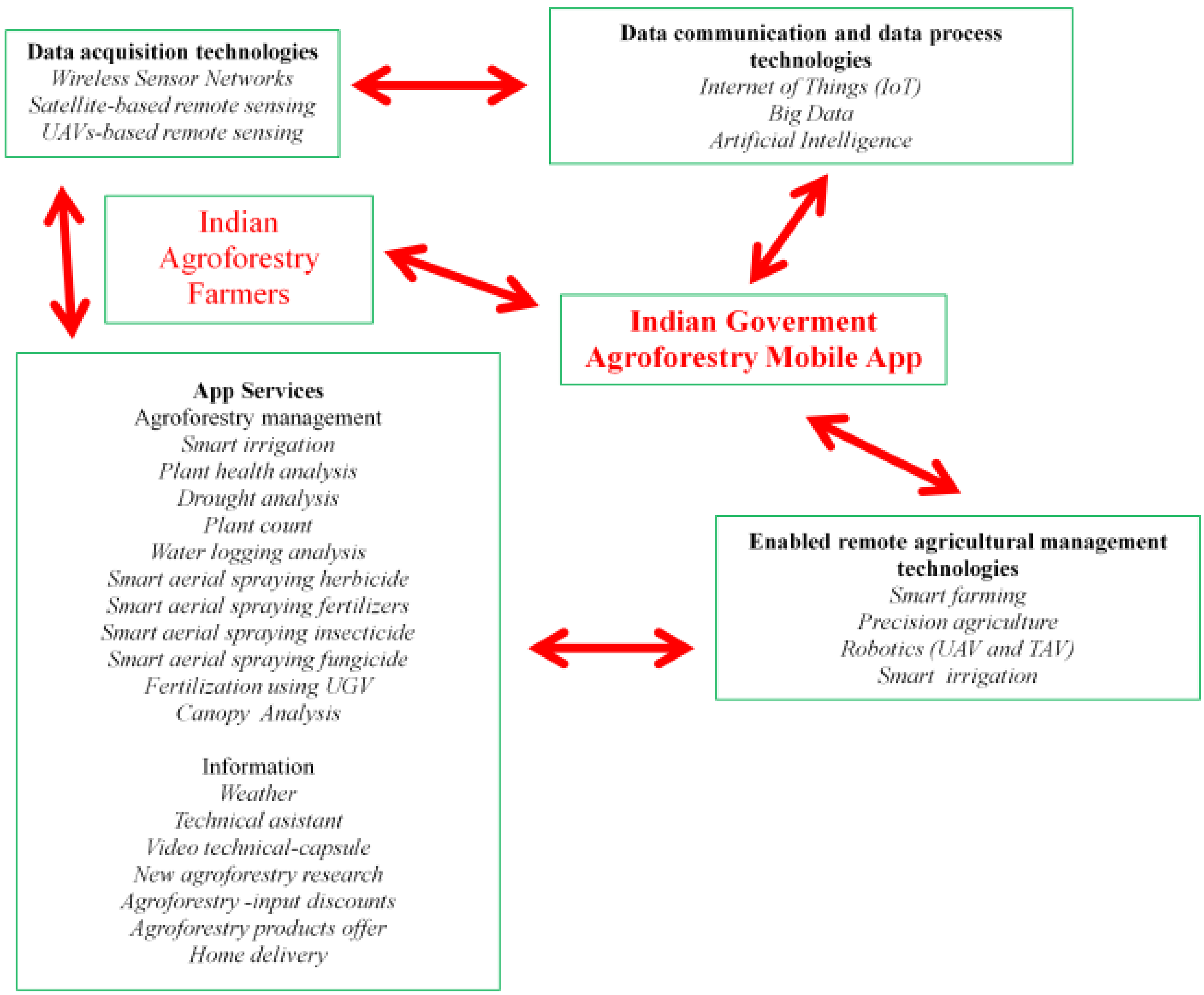

Figure 1. Agroforestry app for Indian Agroforestry Policy

DISCUSSION

The depletion of natural resources makes the improvement of agricultural production more important but also more difficult than ever. This is the reason that although the demand is constantly growing, Information and Communication Technology (ICT) offers to producers the adoption of sustainability and improvement of their daily living conditions El Bilali *et al.* (2020). The growing need for food worldwide requires the development of a high-performance, high-productivity, and sustainable agriculture, which implies the introduction of new technologies into monitoring activities related to control and decision-making Popescu *et al.* (2020). All agricultural machinery incorporates electronic controls and has entered the digital age, enhancing their current performance. In addition, electronics, using sensors and drones, support the data collection of several agriculture key aspects, such as weather, geographical spatialization, animals and crops behaviors, as well as the entire farm life cycle Lezoche *et al*. (2020).

Over the past four decades, advances in Information and Communication Technology (ICT) have resulted in unprecedented opportunity and innovation for improving farming outcomes. Ongoing innovations such as mobile, social media, agricultural drones, Internet of Things (IoT), Big Data, and cloud computing present new challenges and opportunities for agribusinesses to redefine and rethink the role of ICT towards achieving better farming outcomes Xin *et al.* (2016). Advances in smart-farming technologies such as Remote Sensing (RS), Internet of Things (IoT), Big Data/Data Analytics, and Geographic Information Systems (GIS), bring a great opportunity to contribute to such synergy. These technologies allow not only to collect and analyze data directly from the crops in real-time Cadavid *et al*. (2018).

Data acquisition via sensors, control, and task management, and data analysis are considered in the development of the model and system design. In this system, we propose a solution to help farmers facing problems of task management and planning, environment factors measurements, and information distribution Suakanto *et al.* (2017). Undoubtedly, high demands for food from the world-wide growing population are impacting the environment and putting many pressures on agricultural productivity. As advanced information systems and Internet technologies are adopted in Agriculture 4.0, enormous farming data, such as meteorological information, soil conditions, marketing demands, and land uses, can be collected, analyzed, and processed for assisting farmers in making appropriate decisions and obtaining higher profits Zhai *et al*. (2020).

Internet of things (IoT) results in massive amounts of streaming data, often referred to as "big data", which brings new opportunities to monitor agricultural and food processes. IoT is essentially the means of generating and transmitting large amounts of data with information on practical use embedded in it Misra *et al.* (2020). Such data can then be analyzed to filter out invalid data and compute personalized crop recommendations for any specific farm. Improving farm productivity is essential for increasing farm profitability and meeting the rapidly growing demand for food that is fuelled by rapid population growth across the world Jayaraman *et al.* (2016), so that, Smart Farming Technologies raise ethical issues associated with the increased corporatization and industrialization of the agricultural sector Blok *et al.* (2018).

Industrial Revolution 4.0 is assessed to have a strong impact on all aspects of life, economy, and society, not just at the scale of factories and enterprises Vu Anh *et al*. (2019). Agriculture 4.0 is comprised of different already operational or developing technologies such as robotics, nanotechnology, synthetic protein, cellular agriculture, gene-editing technology, artificial intelligence, blockchain, and machine learning, which may have pervasive effects on the future agriculture and food systems and major transformative potential. These technologies underpin concepts such as vertical farming and food systems, digital agriculture, bioeconomy, circular agriculture, aquaponics Klerkx *et al.* (2020), and agroforestry systems.

India is an agricultural country and 70% of the people directly or indirectly depend on agriculture for their living. Nowadays, water scarcity is one of the main challenges faced by farmers Prabha *et al.* (2018). Agroforestry is an intensive land management system that integrates trees into land already used for crop and animal farming. This provides a diverse range of ecosystem services by bridging the gaps between agriculture, forestry, and animal husbandry. It is an important approach to improve the environmental, economic, and social benefits so that, several countries have enacted agroforestry-related policies Shin *et al*. (2020).

CONCLUSIONS

Agroforestry 4.0 supposes the use of tools and technologies of the Industrial Revolution 4.0, and has four essential requirements: increase productivity, the precise use of resources, avoid food waste, and climate change. Precision Agroforestry involves the use of robots, tools, technologies, and platforms. India's National Agroforestry Policy has great potential for the adoption of Agroforestry 4.0 technology. Today, the Internet of Things (IoT) technology and Big Data play an important role in food production. The role of UAV technology in Agroforestry 4.0 includes irrigation, fertilization, use of pesticides, weed management, monitoring of plant growth, and management of crop diseases. Smartphone technology and mobile applications hold promise for the future development of agroforestry 4.0.

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CAPÍTULO VIII. CONCLUSIONES GENERALES

Los sistemas agroforestales hortícolas mas recomendados para la mitigación y adaptación al cambio climático son los sistemas de Agri-horticultura, Horti-olericultura, Silvi-olericultura, Horti-pastura, Horti/Silvi-medicinal, Horti/Silvi-ornamental, Horti-silvicultura, Horti-entomoforestería y Horti-Piscicultura. Los sistemas agroforestales hortícolas son una posible solución multifuncional para la seguridad alimentaria mundial, la protección del medio ambiente y la mitigación y adaptación al cambio climático. Los sistemas agroforestales hortícolas en comparación con los sistemas de monocultivo, tienen un uso más eficiente del agua, el suelo y la luz y pueden ayudar a reducir la aplicación de herbicidas, pesticidas y fertilizantes.

A nivel mundial los árboles mas compatibles en los sistemas agroforestales hortícolas son *Leucaena leucocephala, Cajanus cajan, Gliricidia sepium, Tectona grandis, Poplar spp., Hevea brasiliensis, Mangifera indica, Psidium guajava, Prunus persica, Citrus spp.* y *Annona squamosa*. Mientras que *Fabaceae, Solanaceae, Euphorbiaceae* y *Brassicaceae* son las familias de plantas herbáceas anuales más compatibles. *Zea mays, Triticum spp.* y *Sesamum indicum* son cultivos anuales más compatibles y *Cenchrus ciliaris, Cynodon dactylon* y *Dicanthium annulatum* son pastos forrajeros mas compatibles.

A nivel mundial los principales arboles utilizados en cultivos en callejones con hortalizas son: *Mangifera indica, Psidium guajava, Citrus spp., Leucaena spp., Gliricidia sepium, Cajanus cajan, Populus spp., Eucalyptus* y *Hevea brasiliensis*. Mientras que las familias *Fabaceae, Brassicaceae, Solanaceae* y tubérculos son los principales cultivos vegetales asociados. Realizar una buena elección de los componentes y selección de las compatibilidades del sistema agroforestal puede asegurar el éxito de la plantación.

México es el centro de origen y domesticación de varias especies agrícolas, la presente tesis propone la implementación de una política agroforestal que busca proteger y preservar esta agrobiodiversidad. La política propuesta incluye solo 50 árboles y 16 sistemas agroforestales, el diagnostico y aplicación de agro-insumos con drones. Las herramientas y tecnologías de la agricultura de precisión cada día están más presentes en el sector forestal y agroforestal. Los sistemas agroforestales hortícolas con el uso de herramientas y tecnologías de la agricultura de precisión pueden suponer una nueva propuesta de horticultura hacia el futuro.

El crecimiento de la población, el cambio climático, la reducción y la degradación de los recursos naturales involucrados en la horticultura suponen nuevos desafíos. Los sistemas agroforestales en comparación con los sistemas de monocultivo, tienen un mejor uso del agua, el suelo y la luz, pueden ayudar a reducir la aplicación de herbicidas, fungicidas, pesticidas, fertilizantes, aumentar la seguridad alimentaria, la protección de la biodiversidad y la adaptación al cambio climático.

CAPÍTULO IX. LITERATURA CITADA

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CAPÍTULO X. ANEXOS

ANEXO 1. Cita de artículo “Horticultural agroforestry systems recommended for climatic change adaptation” y datos generales de la revista.

CITA:

Montes-Colmenares., O., Castro-Brindis B., R., Villanueva-Verduzco V., C., Pérez-Grajales G., M., and Uribe-Gómez, M. (2020). Horticultural agroforestry systems recommended for climatic change adaptation. *Agricultural Reviews*, 41(1): 14-24. DOI: 10.18805/ag.R-133. Disponible en: https://arccjournals.com/journal/agricultural-reviews/R-133

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ANEXO 2. Cita de artículo "*Tree used in horticulture-based alley cropping*" y datos generales de la revista.

CITA:
Montes-Colmenares., O., Castro-Brindis B., R., Villanueva-Verduzco V., C., Pérez-Grajales G., M., and Uribe-Gómez, M. (2019). Tree used in horticulture based alley cropping. *Journal of Applied Horticulture*, 21(2): 87-100. DOI: 10.37855/jah.2019.v21i02.16. Disponible en: http://horticultureresearch.net/title.php?a=752

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ANEXO 3. Cita de artículo “Horti/Silvi- pisciculture: agroforestry system for the efficient use of water and fertilizers” y datos generales de la revista.

CITA:
Montes-Colmenares., O. (2020). Horti/Silvi- pisciculture: agroforestry system for the efficient use of water and fertilizers. *Bioscience Research.*

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https://www.isisn.org/Bioscience_Research.htm

ANEXO 4. Cita de artículo "Fast analysis of plant health, plant count and nitrogen status using drones" y datos generales de la revista.

CITA:

Montes-Colmenares., O., Castro-Brindis B., R., Villanueva-Verduzco V., C., Pérez-Grajales G., M., Uribe-Gómez, M. and Jiménez C., C. (2020). Fast analysis of plant health, plant count and nitrogen status using drones. *Research on Crops*, 21(1): 82-87. DOI: 10.31830/2348-7542.2020.013. Disponible en: http://www.indianjournals.com/ijor.aspx?target=ijor:rcr&volume=21&issue=1&article=013

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