International Journal of Environment and Climate Change

Volume 12, Issue 12, Page 1053-1069, 2022; Article no.IJECC.95292
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Agroforestry Assisted Natural Farming in India: Challenges and Implications for Diversification and Restoration of Agroecosystem

S. Dinesha [a], Abhishek Raj [a], M. R. Bhanusree [b], Wagmare Balraju [c], S. Rakesh [d], W. Goutham Raj [e], Ramesh Kumar Jha [a], Neeraj [a] and Krishna Kumar [a*]

[a] PDUCHF (Dr. Rajendra Prasad Central Agricultural University), Piprakothi-845 429, Bihar, India.
[b] Agricultural College, Jagtial-505 529, PJTSAU, Hyderabad, Telangana, India.
[c] Mizoram University, Aizawl-796 004, Mizoram, India.
[d] Uttar Banga Krishi Viswavidyalaya, Pundibari-736 165, West Bengal, India.
[e] Institute of Forest Biodiversity, Dulapally-500 100, Hyderabad, Telangana, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors substantially contributed to research design, analysis and interpretation of data, drafting the paper, revising it critically. All the authors approved the submitted version of the manuscript.

Article Information

DOI: 10.9734/IJECC/2022/v12i121544

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/95292

Review Article

Received: 21/10/2022
Accepted: 26/12/2022
Published: 28/12/2022

ABSTRACT

The Government of India is promoting natural farming (NF) which is evolved from our ancient heritage and traditional cultivation practices. Though NF has many advantages, it is facing several challenges like low yield in initial years, expecting high outputs from low cost of cultivation, lack of local cultivars and livestock, less availability of tree based diverse inputs, dependency on purchase

---

**Corresponding author: E-mail: kkpath@gmail.com;*

or exchange inputs from other farm hold and dispute in farming type and crop composition. On these backdrops, sustainable and/or resilient agroforestry (AF) systems can be synergized by using principles and practices of AF with NF. This AF assisted NF hybrid model is helpful in diversification and restoration of agroecosystem. AF includes at least one livestock components along with perennial trees and agricultural crops. Trees and livestock based NF is the foremost nature based solution (NBS) for climate change mitigation, food security and land degradation neutrality. In NF, to prepare various plant protection formulations neem, pongamia and various perennial species byproducts are essential which can be substituted by tree components in AF. It also provides continues supply of inputs for jeevamrut and beejamrut preparations along with continuous biomass mulching through nitrogen fixing trees. In addition, AF assisted NF practices reduce methane emission from ruminating livestock by reducing heat stress and increasing the feed quality. Some studies on NF have indicated that yield levels were drastically reduced in several cropping systems. Instead of integrating tree and animal components, these studies focused solely on the multi-location evaluation of various cropping systems. Therefore, it would be premature to recommend its wide-spread adaption or adoption prior to scientific validation of this NF. This review provides detail information and implications of AF assistance in NF and recommends preferentially, climate resilient, economical, native and naturalized trees and livestock incorporation, along with amalgamation of traditional and improved AF practices.

Keywords: Agro biodiversity; climate mitigation; food security; nature farming; soil health.

1. INTRODUCTION

In ancient Indian times, natural resource based traditional cultivation was practiced in collaboration with indigenous knowledge and experience of the practitioners, which upheld the nation of less population with food security and ecological balance. On the other hand, burgeoning population impacted ancient agriculture to suffer to sustain, then Green revolution came into the picture in mid-60s to fulfill the changing demands. Although it has incurred a marked influence on agricultural sector by initial boosting up of crop productivity, from late-90s onwards it has begun to lose its hope due to stagnation in yield, and deteriorated soil quality [1] and environment [2]. Non-judicious management of chemical fertilizers, pesticides and many other synthetic substances have deliberately led India to sacrifice its ecological balance and environmental safety [2]. Furthermore, introduction of exotics, hybrids and genetically modified (GM) crops forced to extinct of indigenous traditional landraces.

Globally, India is well recognized for its agrarian economy depended by large population. Despite of high agricultural production, India is always under immense pressure to feed its ever increasing population and suffers with hunger, malnutrition and poverty. Various studies showed that India still fails to address its complete food and nutritional security in spite of being backboned by agriculture [2,3]. In addition, yield of many crops in India such as rice, wheat, pulses etc., are lesser than the yields obtained in the soils of developed countries [3]. Indian soils have been extensively used over many years for growing crops without being replenished. Other reasons for the low yield with high negative side-effects are poor inputs and infrastructure, fragmentation of land, green revolution, inefficient farming techniques, land degradation, population [4], urbanization and other anthropogenic activities results farmers' reluctance to farming [2].

Natural Farming (NF) is a chemical-free, diversified and nature based traditional farming method which incorporates crops, livestock and trees with well-designed biodiversity. NF is facing some challenges like low yield, lack of local cultivars and livestock, dependency on purchase or exchange inputs from other farms, focusing more on cutting cost of cultivation than productivity, etc., [5,6]. These challenges can be tackled by using principles and practices of AF in NF. This review provides detail information and implications for need of AF assistance in NF to overcome many challenges.

1.1 Natural Farming: History and Foreword

A Japanese farmer and philosopher, Masanobu Fukuoka presented NF as an ecological farming approach in his book 'The One-Straw Revolution' in 1975 (Table 1). Masanobu Fukuoka and Mokichi Okada developed NF is also referred as "do-nothing farming" or "the farming approach that imitates the way of nature". Nature is responsible for the maintenance of vegetation including natural forests through nutrient and water cycling and protection them from infections and pests (Table 1). NF is a method in which agricultural practices are guided by natural laws and allows the complexity of both flora and fauna that creates sustainable agro ecological unit. Later, Yoshikazu Kawaguchi who inspired from the work of Masanobu Fukuoka developed own methods and quoted NF is a way of approaching nature with awareness and respect [7]. Kawaguchi's NF method states the four core values i.e., do not plough the fields, there is no need to add fertilizers, weeds and insects are farmers' friends and promoted locally grown climate beneficial food (Table 1). With these four core values, he recommended to grow food in most parts of the world without off-farm inputs [7].

The most commonly followed NF in India is ZBNF model. This model is natural and spiritual farming system which was developed by Subhash Palekar. It is also known as Subhash Palekar NF [8]. The term "Zero Budget" denotes zero external financing, dramatic cut in the cost of production and non usage of any purchased inputs like fertilizer, pesticide and other synthetic chemicals [9]. ZBNF movement started in Karnataka during 2002 and shortly spread in South Indian states through various demonstrations, promotional activities and trainings. Recently, from the farmers' success stories especially from Andhra Pradesh [10] and Karnataka [11], many other state governments are encouraging ZBNF with the assistance of central government, progressive farmers, private and public organizations [8,10]. Many studies have reported the capability of ZBNF to achieve higher yields, resource use efficiency, and soil health and agro biodiversity as compared to conventional practices [2,8,9]. This cost-effective and sustainable farming practice provides food and livelihood security, and improves socio-economic status of the dependent farming community [9].

1.2 Types of NF

There are several successful NF types exist in various regions of the world with different names [10]. Some of the important NF practices are *Fertility farming*, Native American farming, Nature farming, Rhishi kheti, Low external input sustainable agriculture (LEISA) and ZBNF (Fig. 1). *Fertility farming* is a system featuring the use of a cover crop, no tillage, no chemical fertilizers and pesticides, no composting and weeding. This farming system was developed by Turner who is British commercial farmer shared principles in accordance with Fukuoka's system of NF [12]. Recent study in the field of traditional ecological knowledge found that ancient American tribes worked the land in strikingly similar ways to today's NF [13]. According to contemporary Native Americans, the *Native American NF* is only through interaction and relationships with native plants that mutual respect is established. The concept of *Nature farming* or no fertilizer farming system was developed by Japanese farmer Okada in the 1930s that predated Fukuoka. NF and nature farming both are used interchangeably. However, as compared to natural farming, '*Nature farming*' is a correct literal translation of the Japanese term [14].

In India, Rishi Kheti is a form of NF which includes cow products like buttermilk, milk, curd and its waste urine for preparing growth promoters [10]. It is considered to be non-violent (Ahimsa) farming without any usage of synthetic fertilizer and pesticides. It is still practiced in a small number of farmers in Andhra Pradesh, Maharashtra, Madhya Pradesh, Punjab and Tamil Nadu. The Low external input sustainable agriculture (LEISA) is a form of NF where all the inputs are locally (on farm) available and output of one farming system is mostly used as input in other farming system. It can be a promising option to small scale resource-poor farmers under uncertainty of locality factors such as climatic, edaphic, topographic and biotic factors [15]. Minimizing the use of external inputs, optimizing the use of locally available resources and achieving a synergetic effect among the various components of the farming system enable higher income and sustainability. LEISA system has significantly contributed in improvement of farmer's income and sustainability in different agro-ecological zones of many Asian countries [15].

The ZBNF model developed in the 1980s by agricultural scientist and extension agent Subhash Palekar, it is natural and spiritual farming system and most commonly followed in India [8]. He established ZBNF after a period of self-study of the Vedas, Upanishad and other ancient scriptures, organic farming and conventional agricultural science along with his own farm experiments [10]. It is already successful in some states of India such as Andhra Pradesh, Karnataka, Maharashtra and Tamil Nadu. The government mandate of ZBNF is our ancient heritage and traditional cultivation practice which was gaining momentum nowadays. It is a natural way of farming which helps to rejuvenate the soil, moisture and crop health through its own practices mainly Jivamrita, Bijamrita, mulching, soil aeration, intercropping, crop diversification, crop rotation, bunds, bio-pesticides and many more utilized in a holistic approach [9] (Fig. 2).

Table 1. Four farms of NF principles developed by different philosophers

Masanobu Fukuoka	Yoshikazu Kawaguchi	Mokichi Okada	Subhash Palekar
Presented NF as an ecological farming approach in his book “The One-Straw Revolution”	He quoted NF is a way of approaching nature with awareness and respect	NF is also known as Nature farming	“Zero Budget” denotes non usage of any credit, purchased inputs or off-farm resources
No tillage	Do not plow the fields	Farming is guided by natural laws	Jevamrut, beejamrut and vapasa used
No fertilizer	There is no need to add fertilizers	Nature maintains the plant life through nutrient and water cycling	Leguminous trees and crops with crop rotation, diversification and intercropping are followed
No herbicides, pesticides and weeding	Weeds and insects are not your enemies	Nature protects vegetation from infections and pests	Plant protection measures used like bramhastra and neemastra,
No pruning	Adjust the foods you grow based on your local climate and conditions	"Do-nothing farming" that mimics the way of nature	Uses or exchange machinery and seeds of other farms and preferred indigenous livestock and perennials

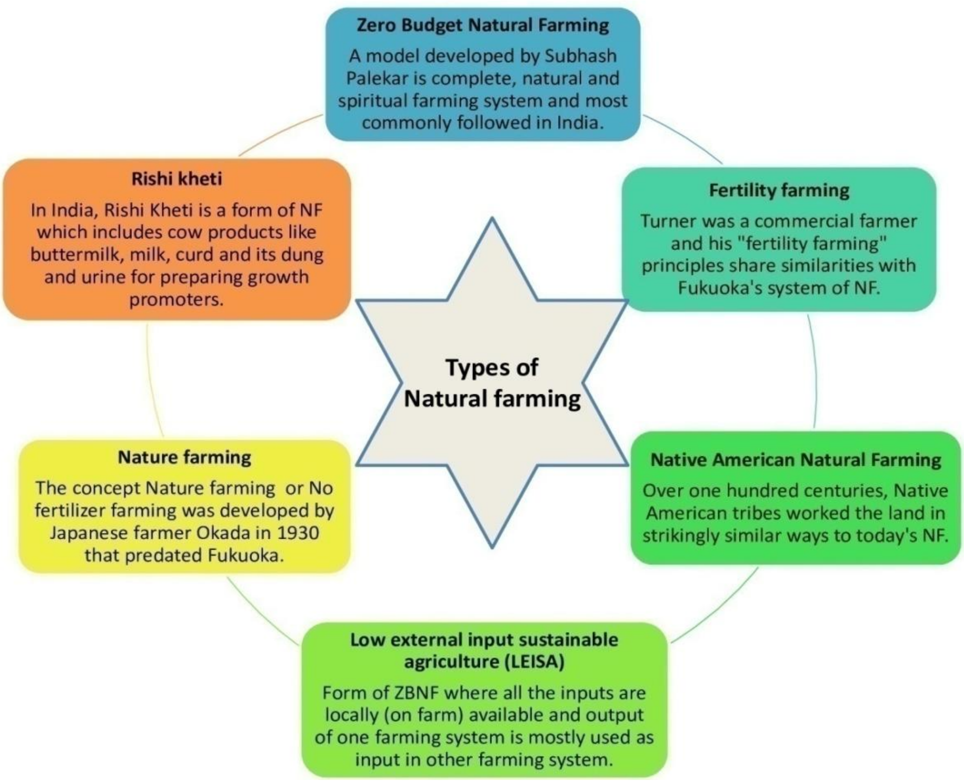

Fig. 1. Types of natural farming prevalent in different parts of world

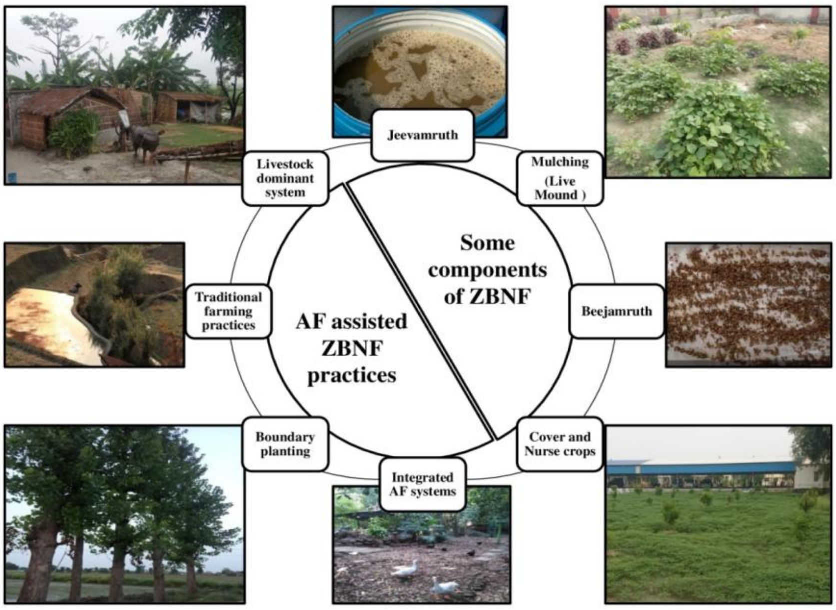

Fig. 2. AF assisted NF practices and its components

2. NEED OF AF ASSISTED NF

Though NF has many advantages, it is facing several challenges (Fig. 3) like low yield in initial years, lacking progressive yield concept, focusing more on cutting cost of cultivation than productivity, lack of local cultivars and livestock, less availability of tree based diverse resources or inputs, dependency on purchase or exchange inputs from other farm or household [5,6]. These challenges can be effectively tackled by following principles and practices of AF in NF. The AF is a land use practice (sustainable and/or resilient) that integrates perennial plant and tree species with crops and livestock systems. Most of the agricultural space can be utilized by AF because of the adoption and availability of fast growing, economic and climate resilient trees along with the livestock that thrive well under limited space. In changing climate scenario, AF is recouping its importance and acknowledging globally for its pivotal role in climate change mitigation, food security, diversifying livelihood, conservation and efficient utilization of natural resources, providing various ecosystem services as well as reducing pressure on forest (Fig. 3).

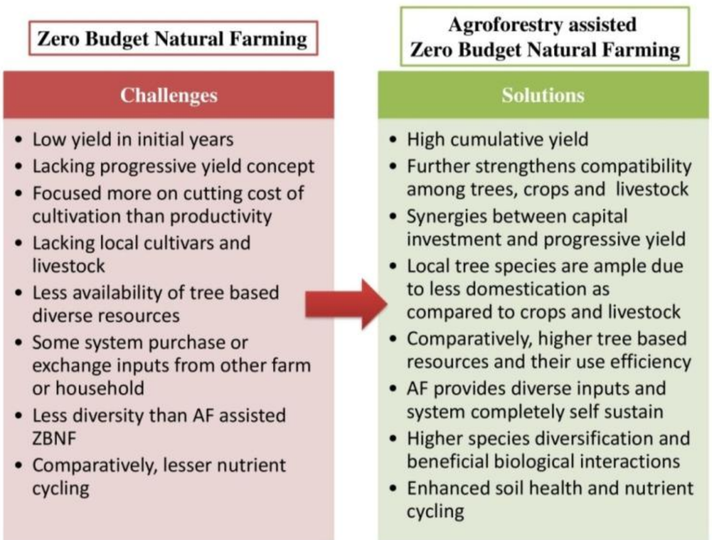

Fig. 3. AF assisted NF solutions to ZBNF challenges

3. DIFFERENCES AND SIMILARITIES AMONG CONVENTIONAL FARMING, ORGANIC FARMING, ZBNF AND AF ASSISTED NF

Differences among the Conventional farming (CF), Organic farming (OF), ZBNF and AF assisted NF are documented in Table 2. These four farming systems are classified on the basis of principles and the mode of practices, level of inputs, credit burden, extent of yield, species selection and arrangements, agro ecological diversity and environmental concern. In contrast, there are few similarities exists among OF, ZBNF and AF assisted NF. These three farming methods are chemical and poison-free, restricts farmers from using chemical fertilizers and pesticides [2,8,10]. Farmers are encouraged to use local or household inputs derived from crops, trees and livestock. In addition, homemade and natural ways of pest control solutions are promoted [2].

Table 2. Differences among Conventional farming (CF), Organic farming (OF), ZBNF and AF assisted NF

Particulars	CF	OF	ZBNF	AF assisted ZBNF
Principles and practices	Deliberate use of fertilizers and pesticides	A holistic approach that aims to maximize production	It aims to enhance agro biodiversity and mimics the nature	In this, principles and practices of AF are used in accordance with ZBNF
Main concerns	Highly commercial emphasis over sustainability or eco-friendly	Helps to create businesses that are both sustainable and eco-friendly	Both agro biodiversity and productivity are concerned	Harmonious way of farming by maintaining synergy between AF and ZBNF
Farm inputs	Uses synthetic chemicals, fertilizers and pesticides	Uses organic manures, such as compost, vermin compost, etc. from external sources	Encourages use of on-farm products, mulching and formulations like Jeevamruth and Beejamruth	Legume trees, nurse and cover crop, leaf litter, livestock manure along with ZBNF formulation
Economy	It maximize the yield of a particular crop or set of crops	It aims to maximize the production	Focusing mainly on reducing credit burden along with the yield	Combined outputs from trees, crop and livestock balance the ill effects
Species selection	Hybrids and modified crops are grown	Native and non-natives are grown	Preferably, native species are grown	Climate resilient trees and livestock along with the native crops
Credit burden	High cost compared to OF and ZBNF	It is still costlier than NF due to the necessity of bulk manures	It will reduce dependency on purchase of inputs and credit burden	AF supplements inputs and reduces credit burden and improves income
Agronomic practices	Intensive soil tilting, manure, fertilizer and weeding etc., required	Soil tilting, manure use, weeding, and other activities are required	There is no soil tilting, fertilizers, and weeding, as it would be in natural ecosystems	System integrates traditional and improved AF practices along with the ZBNF practice
Ecological footprint	High ecological footprint	Medium ecological footprint	Less ecological footprint	Improves the agro ecology with less ecological footprint
Farming principles	Modernized and intensive farming principles	Guided by organic farming principles	Farming practices are guided by natural laws and mimics nature	Integrating AF principles with nature farming laws
System operation	System that intensively demands synthetic inputs	Partially depends on human-supplied inputs	Closed system allowing the complexity of flora and fauna	Preferentially, indigenous trees and livestock integration boosts agro ecology

4. NF TO DOUBLE THE FARMERS' INCOME

"Zero Budget" denotes zero external financing, dramatic cut in cost of production and non usage of any purchased inputs or off-farm resources like fertilizer, pesticide and other synthetic chemicals [16]. It indicates that any costs incurred in farming system can be counteracting by a multiple source of income. Furthermore, indicated benefits of yield enhancement, improved agro biodiversity and combating land degradation and desertification. Most of the success stories were reported mainly from Andhra Pradesh and Karnataka. ZBNF has been adopted prominently in Karnataka at grass root level as social movement, initiated by the Karnataka Rajya Raitha Sangha (KRRS) that connected farmers through training camps. Survey conducted in Karnataka state during 2012 reported that around three fourth of respondents benefited with increased production, significant improvement in income as well as reduction in production cost [11]. Likewise, in Andhra Pradesh state, through Rythu Sadhikara Samstha around 88 % of farmers benefited higher yields, notable reduced production cost and increased farmers' income [10]. The state government of Himachal Pradesh has allocated funds to support ZBNF and the Gujarat, Meghalaya and Rajasthan state governments have also committed to setting up programs for ZBNF. Study reported that practicing of AF in place of mono-cropping has enhanced 53% more productivity and 83% more water-efficiency as compared to mono-cropping [17]. This hints AF assisted NF to solve socio-economic and agro ecological challenges faced by neglected smallholding farmers of dry land. A critical evaluation of ZBNF is on-going across India through the Indian Council of Agricultural Research (ICAR) to aid further in national level policy making [18].

5. SIGNIFICANCE OF AF ASSISTED NF

Trees and livestock based NF is the foremost nature based solution for solving global issues like climate change, food insecurity and ecological imbalance. AF assisted NF practices can significantly improve nutrition, health and income of dependent communities by providing varied farm outputs, reducing the crop failure threat in adverse conditions, enhancing agro biodiversity and productivity of the system due to efficient resource conservation and their utilization, and reducing effluence, erosion, energy consumption and environmental degradation (Fig. 2). Futuristic view of environmental services through AF assisted NF practices vs. mono-cropping systems are depicted in Table 3. AF can balance the effects and low yield by providing multiple outputs. Study has shown that by applying integrated soil fertility management practices, farmers can increase soil organic matter, physical and chemical properties

Table 3. Futuristic view of ecosystem services through AF assisted NF vs. Mono-cropping system

Services	Mono-cropping systems	AF assisted NF practices	References
Food and nutritional services (FNS)	Use of synthetic chemicals and fertilizers can deteriorate quality of food and fruit productions	Plant diversity is more which promises diverse food and nutritional security also maintains the quality	[17,19]
Regulating services	Frequent outbreak of pest and diseases. Synthetic chemicals decrease faunal diversity	Enhanced pollination, diverse food sources and habitat for beneficial insects	[24,29]
Cultural service	Less Recreational and aesthetics beauty	Trees improve social cohesion and mutual respect. Used during spiritual and religious ceremony	[56]
Water services	Water loss and erosion problems are consistently observed	High water regulation, nutrient enrichment, erosion control are observed under diversified AF system. AF productivity and sustainability are remarkable.	[17,33]
Soil services	Less SOC status and poor in nutrient and soil fertility. Poor microbial diversity	High SOC pool and nutrient availability maximize microbe's population that ensures greater soil fertility and nutrient cycling	[20]
Climate services	Intensive use of chemical fertilizer leads to environmental pollution	Less environmental pollution which maintains climate health and services	[57]

and nutrient cycling with minimal cash inputs to farm [17,19]. Leguminous tress such as Acacia species improve soil quality by nutrient enrichment and provides many valuable products like gum, Cutch and Katha [20]. This maintains socioeconomic status of farmers and ensures ecosystem health and environmental sustainability.

5.1 Significance of Trees, Crops and Livestock in AF

There are various benefits of AF systems such as control soil salinity, enhance soil fertility and nutrient cycle, prevention of runoff and damage to forests, enhance water and other resource management, stabilization of soil and microclimate, and mitigation of climate change. Integration of trees in agro ecosystems can address resource limitation and compensate for climate, food, market and other ecological stresses [20]. The component-wise advantages are as discussed below.

5.1.1 Tree component

Tree planting helps to create amiable habitats and have positive impact on health of native flora and fauna. Also, good controller of CO_2 emissions and improve microclimate of an area. Trees are able to communicate and defend themselves against attacking insects and pests by their chemicals and signal danger to other trees to start their own defense. Planting fruit trees can help food and nutritional security, reduce greenhouse effect and slow the rate of global warming. A diet high in fruits can supplement antioxidants, vitamins, minerals, fibers etc., and help to protect from various infections and diseases. Tree by-products have good medicinal applications and used in the treatments of various ailments. A study revealed that applying 5 % neem leaf extract to crops can effectively prevent the water stress oxidative damage by increasing the accumulation of key osmoprotectants notably proline and glycinebetaine as well as the activities of enzyme antioxidants [21]. AF species produce a good amount of leaf litter and debris that are loaded with allelochemicals which are aften impart species resistance to insects and pathogens [22]. In addition, AF has diverse components which act as biological barriers for the insect and pests, used in bio-pesticides and they also help in biodiversity conservation and harboring beneficial insects which help in pollination.

5.1.2 Livestock component

Livestock includes rearing of animals like cattle, buffalo, sheep, pigs, goats, horses, mules, asses and camels, as well as rearing of birds such as chickens, ducks and fowl etc. Livestock supply high-quality meat, milk, food stuffs etc., and by-products such as dung, urine, hide etc. Palekar as suggested to integrate native cattle breeds in ZBNF as they carry higher beneficial microbes in their dung and urine which are useful for preparation of jevamruth and beejamruth. There is a decrease of around 9 % of indigenous cattle population in India [23]. These indigenous breeds carry a unique gene family HSP70 which posses ‘thermometer gene’ makes them more resilient to changing climate [23]. Hence, AF assisted NF is a viable option to conserve these native breeds and also provide greater opportunity for improving food security along with meeting various tangible and intangible needs of farm hold. Study recommended indigenous livestock based AF systems (Fig. 2) to enhance sustainability and/or resilience along with positive economic and ecological benefits in different AF systems [24]. In addition, it also lessens the gap between production and consumption, and the inability of supplies to meet projected demand of animal based food and other output. Livestock helps in land preparation, transportation, energy source and provides by-products like dung and urine which enhance soil health, nutrient cycling and overall crop productivity. Integrating livestock with shade providing and protein rich multipurpose trees improves animal performance, productivity along with other ecosystem services.

5.1.3 Crop component

Crops of agriculture, horticulture and medicinal plants including annual and perennial crops are successfully incorporated and studied the effects of growth, yield and soil properties [22,25]. Studies suggested for growing crops such as pineapple, moong bean, oats etc under different AF land use systems [25,26]. Integrating soybean crop and sheep into tree plantations found to be more profitable than pure plantation without compromising its planting density [27]. Similarly, a study in Phatthalung province of Thailand reported the different types of symbiotic benefits such as enriching the soil nutrients, reducing cost for farm inputs and weeding, and reducing heat stress by providing shelter and quality feed for livestock [28].

5.2 Agro Ecological Diversity

A systematic biodiversity assessment in AF has shown significant increase in both floral and faunal diversity [29]. In contrast, no systematic agro ecological diversity assessments have been conducted for ZBNF. However, some preliminary studies reported that significant improvement of earthworms, insects and other fauna on ZBNF systems as compared to non-ZBNF systems in thirteen districts of Andhra Pradesh during 2018. In addition, ZBNF systems hosted significantly higher number of earthworms per unit area as compared to non-ZBNF systems [10]. Many ZBNF farmers also reported increased soil microbial status, earthworms and beneficial insects like pest antagonists', pollinators, etc. Palekar's ZBNF practices are explicitly focused on agro ecological balance and on-farm biodiversity [11]. He suggested farmers to protect biodiversity in and around farm by practicing complex cropping patterns and crop rotations.

5.3 Soil Health

Soil health is global concern for policy makers, stakeholders, agriculturists, foresters and many researchers. Healthy soil provides an uncountable ecosystem service which maintains environmental health and ecological stability [24]. Soil structure and fertility maintenance, efficient nutrient cycling, carbon sequestration and microbe's population etc., are key ecosystem services provided by healthy soil in the AF assisted system [30]. Tree adds organic matter to the soil through litter fall and root decay, both can enhance organic C content. This added SOC is the primary source of energy for microbial life [31]. SOC pools represent an immense variety of soil inhabiting organism such as beneficial micro and macro fauna and their interactions improve overall soil nutrient and fertility status by releasing immobile or fixed nutrients in soil system [4]. SOC is often referred as an indicator of soil quality [32]. Also, AF practice and scientific management ensures soil quality and improves sequestration capacity of C [24]. AF systems reduce the risk of soil degradation or nutrient loss, adapt to climate change, provide increased protective cover, enhance microclimate and increase organic inputs from decomposition which result to increase SOC and enhance soil health. Moreover, integrating leguminous tree species in AF system can restore fertility and nutrient status of soil by maintenance of nitrogen and carbon status [29]. Thus, leguminous based AF practices enhance soil health and maximize productivity which ensure food and climate security.

5.4 Nutrient Cycling in AF

AF plays a significant role in various soil interactions and mechanisms such as biological nitrogen fixation, nutrient cycling, nutrient pumping, improving soil physico-chemical properties, control weed and pest population. The perennial trees in AF systems contribute to soil conservation by providing continuous surface cover that protects the soil from desertification, erosion, pollution and salinization, enhance infiltration, soil moisture and biological activity [24,33]. Fruit based AF systems showed improved values of soil pH, EC, OC %, C density, N, P and K than mono-cropping in north western region of Indian Himalaya [26]. As these key soil parameters are highly dependent on soil physicochemical properties, this AF system is more sustainable due to proficient nutrient cycling therefore plays a significant role in C stockpiling and CO_2 alleviation along with improving soil properties and food production. Study recommended agriculture land use conversion to fruit based AF systems and suggested conservation tillage, manure application, pulses based cropping system and integrated fruit based AF systems to limit the unfriendly effects of cropping systems [26].

5.4.1 Carbon sequestration

A long term C storage in soils as stable form of organic matter for more than 20 years is termed as SOC sequestration. Around 0.4-8.6 Gt CO_2eq of carbon sequestration has reported under mineral soils in land use farming system including AF practices globally [30]. This sequestration reduced from 3.0-71.0 % (~10-12 Gt CO_2eq yr^{-1}) of net GHGs emissions annually from AFOLU (Agriculture, Forestry and Other Land Use). However, the sequestration potential of SOC in many cropland ecosystems in different countries are depicted in Fig. 4. USA has reported highest SOC sequestration potential (Mt C yr^{-1}) as 124.7 followed by India (103.8) and least value in Nigeria (19.8), respectively [34]. Carbon storage in soil helps in restoring degraded lands by increasing the soil stability that promotes soil aggregation [31]. Carbon sequestration by means of AF practices can sequestrate nearly 2.0-5.8 Mg C ha^{-1} yr^{-1} and it is a low cost, efficient and sustainable as compared to other strategies or systems [25]. AF system reduces pH, enhances amount of organic matter, nutrient cycling and higher microbiological activity. The shading trees also reduce erosive processes and conserve soil and water resources. Studies reported higher values of soil C stock in tree based crop combination as compared to mono-cropping [26]. The substantial rise in soil C stocks under AF systems could be attributed to deposition and degradation of litter, as well as root turnover from tree components, while in common agricultural practice, a large amount of C is depleted each year due to the removal of a large quantity of biomass as crop harvest and continuous cultivation without any fallow period [26].

5.4.2 Biological Nitrogen fixation

Along with good quality food and forage production, trees such as *F. albida*, *P. timoriana* and *M. scabella* also help in biological nitrogen fixation (BNF) [25]. Some legume trees reduce pest incidence as well as fertilizer and pesticide needs [25, 29]. Many studies reported significant improvement of N use efficiency under various AF land use systems through BNF and nutrient pumping [25,29]. Some genera including Albizia, Ateleia, Erythrina, Inga, Mimosa and Vachellia are the famous examples of promising N fixers around the world. However, N fixing efficiency of native leguminous tree species need further research in order to encourage this species under AF systems [20].

5.4.3 Phyto-remediation

One of the common problems induced as a result of green revolution is the chemical residue caused due to excess application of fertilizer, herbicides and pesticides [35]. Phyto-remediation is the process of removing the contamination of chemical pollutants and heavy metals using flora and rhizogenic microorganisms [36]. In this process, plants restore the soil health as well as the ground water quality. Chemicals are trapped inside the plant in the roots, stems or leaves as phyto-extraction [36]; it might be changed into less harmful chemicals as phyto-degradation or phyto-stabilization [37] within the plant and it might be also converted into gases that released out to the atmosphere through transpiration, known as phyto-volatilization [37]. Species viz. *Azadirachta indica, Dalbergia sisso, Terminalia arjuna*, *Madhuca longifolia*, *Manilkara hexandra*, *Diospyros malabarica*, *Pongamia pinnata*, *Moringa oleifera* are recommended for remediation [38]. Similarly, in surface crusting and water logged soil species like *Eucalyptus robusta*, *Salix tetrasperma*, *Dalbergia latifolia* and *Eucalyptus camaeldulensis* are suitable for integrated farming systems. These plants are become popular as hyper accumulator, their fast growth and higher biomass production [39]. Hence, integration of such types of AF species under NF may reduce the ill effects of chemical fertilization.

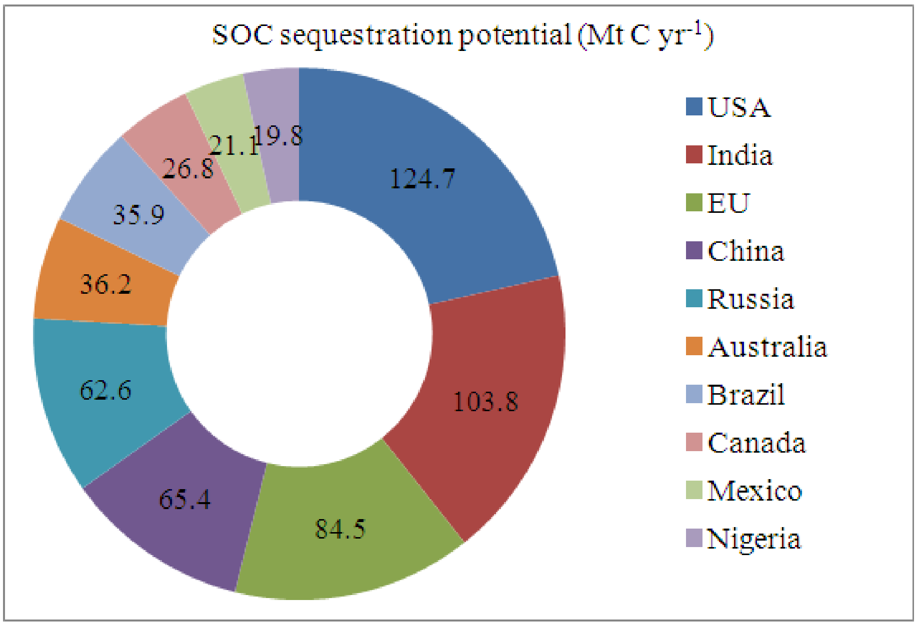

Fig. 4. Global SOC sequestration potential (Mt C yr^{-1}) in croplands [34]

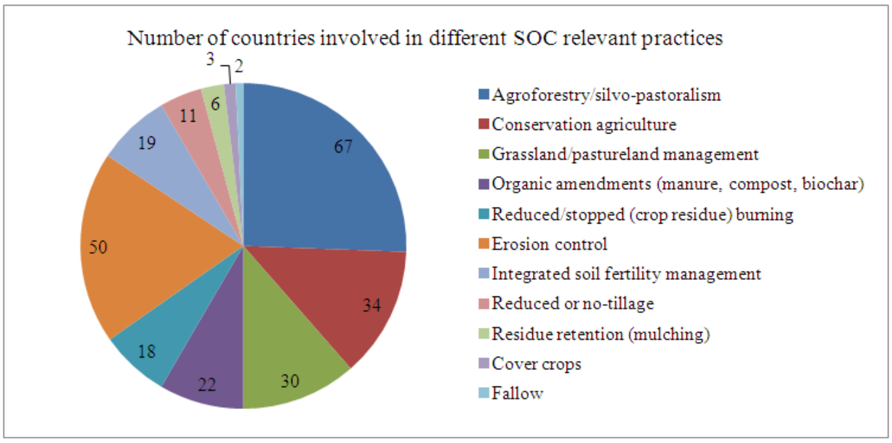

Fig. 5. Number of countries involved in different SOC relevant practices [49]

5.4.4 Reduction of CH_4 and N_2O emission

AF practices are greatly recognized as a mitigation strategy for reduction of emission of methane (CH_4) from ruminating livestock by reducing heat stress and increasing the feed quality [25]. In Brazil, livestock contributed 64 % of the total agricultural methane emission [40]. Another study indicated that AF practices can help in the reduction of nearly 40 % of methane emission in Brazil [41]. Experiment in controlled condition showed inverse correlation between methane emission and temperature at 5-20°C [42]. However, emission of methane is highly complex course of action and it needs further field studies to validate the extent of AF systems in reduction of methane emission.

Studies on AF practices as an adoption strategy to the emission of nitrous oxide (N_2O) have been reported conflicting results [25,43,44]. Earlier study reported that N_2O emission from AF practices are in the range of tropical and subtropical forest emissions [43], which indicates that AF per se does not enhance N_2O release for atmosphere. In contrast, other study indicated that AF emits N_2O as equal as agriculture LUS [44]. AF system with leguminous trees has lesser N_2O emissions as compared to mono-cropping system [45]. AF practices with leguminous trees as well as application of organic manure, residues incorporation and crop rotation etc., helps in N_2O reduction [25].

5.4.5 SOC restoration in AF for climate change mitigation

Climate change is a key environmental challenge today. The changing climate and related C footprint not only affects the AF productivity but also influence soil, food and environmental security. Sequestration of organic C into the soils removes excessive carbon (0.79-1.54 Gt C yr^{-1}) from the atmosphere [46]. This process maximizes biomass and carbon into vegetation and soils under AF system. SLU practices including AF systems, forests and plantations ensure higher biomass and productivity along with maintenance of C storage and flux in the ecosystem [47]. Similarly, agriculture, forestry and AF based SLU practices ensure higher SOC pools which maintains climate resilient environment [48]. Of all, AF system is greatest technology that enhances organic carbon into the soil and in turn greater SOC pools ensure higher AF productivity which promise land degradation neutral (LDN) concept and its sustainability. Number of countries involved in different SOC relevant practices is depicted in Fig. 5 [49].

6. AMALGAMATION OF TRADITIONAL AND IMPROVED AF PRACTICES TO ENHANCE NF

In traditional AF system, farmers were engaged in different forms of tree based farming and they were also well aware about the benefits of different forms of AF practices. However, some progressive farmers are showing interest to modify and improve their present AF practices with mechanization and sustainable and/or resilient management practices for added profits. Traditional farming practitioners are facing some problems such as biomass and residue burning, bare and long fallow phase, injudicious cultivation, mining of soil fertility, careless cropping and irrigation practices [50]. These problems can be overcome by following recommended management practices such as conservation tillage, cover and nurse cropping, crop rotation, integrating climate resilient trees and crops with livestock, efficient cropping and irrigation practices, mulching, proper use of resources and sensible use of off-farm inputs [50]. Some studies compared the adaptation and benefits of these two forms of AF practices [50,51]. Studies reported nearly threefold increase in annual income and diverse benefits from improved AF practices as compared to traditional AF practices [51]. In conclusion, it is important to maintain harmony with nature in the changing climate scenario by adopting best recommended management practices and modifications are needed for faulty ongoing practices to enhance food security and ecological balance. Study recommends preferentially, climate resilient, economical and indigenous trees and livestock incorporation, and amalgamation of traditional and improved AF practices to enhance NF.

7. CONSTRAINTS IN AGROFORESTRY PROMOTION AMONG FARMERS

AF practices are recognized as climate resilient eco-friendly practices. They are location specific practices and highly acceptable among farmers but still many constraints exist behind its promotions. Farmer's awareness and their approach towards AF implementation are poor due to long gestation period of tree species which require long term investment. These are major constraints behind AF adoption among farmers. Farmers do not aware about the tree benefits and ecosystem services (tangible and intangible) under AF system. Research and institutional constraints are also identified behind successful adoption of AF systems. Some farmers have small land holding which also affects AF adoption and its promotion in these regions. Size of land, livestock and lack of awareness induces negative perception and attitude among farmers towards AF adoption [52]. Poor irrigation facility and water shortage are another constraint which affects AF adoption among farmers. Harvesting of trees and their movement into markets are highly checked by forest department which also discourage farmers attitude towards AF adoption and its practices.

8. POLICY AND INSTITUTIONAL SUPPORT

Government of India is promoting NF through Paramparagat Krishi Vikas Yojana (PKVY) scheme. It aims to promote traditional native practices which reduce external inputs and mainly focused on on-farm resources with use of mulching technique, cow dung-urine formulations and periodic soil aeration. The NF program has been adopted in State of Andhra Pradesh, Karnataka, Kerala, Gujarat, Himachal Pradesh and Uttar Pradesh. Nity Aayog along with Ministry of Agriculture and Farmers welfare (MoAFW), Government of India (GOI) estimated that around 2.5 million farmers in India are already practicing regenerative agriculture. It is expected to reach 2 million hectares within next 5 years in any form of OF, including NF, of which 1.2 million hectares are under NF [53]. Recently 29 member's panel has been constituted under MoAFW to provide suggestions on five points regarding NF including suggestions for programs and schemes for value chain development, protocol validation and research for future needs, and support for area expansion under NF.

GOI also promoting the AF through Sub-Mission on AF (SMAF) under National Mission for Sustainable Agriculture (NMSA). Under this mission some of the important programs like Har Medh Par Pedh, Sericulture based AF Convergence Model etc., gaining importance around the country. Har Medh Par Pedh program encourages integrating trees in the bunds and boundaries of agricultural farms, canal banks and river banks to provide various economic and ecological benefits. Sericulture based AF Convergence Model encourages sericulture host plants e.g. *Heteropanax fragrans, Litsaea polyantha, Morus alba, Persea bombycina, Terminalia arjuna,* etc. to be cultivated both as block plantations and boundary plantations on farmlands. Planting sericulture based tree species will help in creating additional income for farmers besides their regular agriculture income. In addition, government initiative "Green India Mission" includes AF as a solution for different challenges in Indian agriculture [19]. Apart from these missions, Rashtriya Gokul Mission, National Food Security Mission, Rashtriya Krishi Vikas Yojana, Mission for Integrated Development of Horticulture and National Bamboo Mission should act as supporting hand for promotion of AF in Indian agricultural system. Therefore, the synergy among these missions encourages to improve farmers income through improved agronomic practices, integrated farming practices, enhancing resource use efficiency, pest, disease and nutrient management, insurance, credit and market support. Some organizations associated to AF like Food and Agriculture Organization (FAO), World Agroforestry Centre (WAC) etc., are fulfilling policy space, conducting scientific studies, providing best practices and publishing guidelines. There is an increase of interest in AF as an important component of SLU and development.

Similarly, policy for regular tracking and its monitoring of SOC in AF models by better soil sampling and geospatial tools are needed for assessing organic carbon changes over time. This will help in identifying organic carbon status and its dynamics on which different AF models are based in any agro-ecological region. These are key topic which must be discussed in reframed and updated policy. Addressing poor soil C content through adopting climate resilient AF system is smart choice which needs more scientific plan and policy reformation. Moreover, from the Andhra Pradesh and Karnataka context it was confirmed that the success of NF is also depend on initiating farmer-led and farmer-focused knowledge exchange programs as well as financial and technical support from governments, institutions and organizations.

9. OUTCOME OF THE NF AND FARMERS MESSAGES

Many studies reported the shifting of farmers from conventional farming to organic and natural farming, especially in the states of Andra Pradesh, Karnataka, Maharastra Telangana and Tamil Nadu [54]. Farmer’s survey reported better plant health, vigour and climate resilence in ZBNF system incorporated with arable and horticultural crops under dry spells, flooding and cyclone situations in some districts of Andra Pradesh [10]. Apart from increase in crop yields and incomes, farmers were also experienced encouraging outcomes across a range of farm health indicators, agro biodiversity, sustaino-resilence etc. [10]. ZBNF practitioner using Jeevamruth through drip irrigation in Andra Pradesh has reported dramatic improvement in leaf-growth, budding and greater number with superior quality of fruits per tree which helps to fetch a higher market price. Another ZBNF practitioner reported improved porosity and increased numbers of earthworms in his farm, year-round income through intercropping, insects and pest control through hens and turkeys, mulching, integrated cattle for cow dung and cow urine, and value addition for higher market price [10]. Study reported that the Palekar’s training camps act as revival meetings in which farmers are repeatedly invited, constantly engaged and solemnly vow to transform themselves to a “saint protector of nature” by practicing ZBNF [55].

10. CONCLUSION

In this review, we presented the topic of AF assistance to NF through focused regional and national perspectives. In the present climate change scenario, sustainable and/or resilient AF systems can be synergized with NF, regionally or nationally. It provides continues supply of inputs for jeevamrut, beejamrut and preparations of various plant protection formulations along with continuous biomass mulching through nitrogen fixing trees. In addition, AF assisted NF practices may also helpful to reduce methane emission from ruminating livestock. Study recommends preferentially, indigenous trees and livestock incorporation and amalgamation of traditional and improved AF practices to enhance NF. For large-scale implementation of this program, ensuring availability of livestock and trees are great concern. Further, scientific validation, improved germplasm, production techniques and other strategies are needed to achieve this target. The global threats like climate change, food insecurity, ecological imbalance, market fluctuations etc. are posing serious challenges for the growth of the organic or NF sector to transform in economies of scale due to some reasons like less production, short shelf life, low awareness, lack of knowledge and awareness, lack of institutional and policy support, and technical and financial constraints. Studies on ZBNF initiated by the ICAR-Indian Institute of Farming System Research (IIFSR), Modipuram at several locations in the country along with State Agricultural Universities (SAUs), have clearly indicated that yield levels were drastically reduced in several cropping systems. Few studies focused only on multi-location evaluation of different cropping systems rather integrating tree and animal components. Therefore, it would be premature to recommend its wide-spread adoption prior to scientific validation. Although ZBNF has been taken up by some states but there is a research gap in scientific validation due to meager proportion of preliminary studies and no systematic data have been generated so far to prove the superiority of this technology. Hence, this needs further studies to help practitioners to integrate AF in NF, researchers to investigate its numerous interesting aspects and for the policymakers to develop scientific and sustainable policies to promote AF assisted NF at local, state and national scale.

11. RESEARCHABLE ISSUES AND THE WAY FORWARD

- Cooperation among agriculture, forestry, horticulture and livestock related ministries with their supporting policies and schemes are great concern.
- Authors suggested for the development of successful regional models which integrate native and naturalized perennial species along with their regular and successful cropping systems.
- AF assisted NF needs economic support to small landholding farmers, including the incentives and subsidies, promotion of good markets for sale and input supply, institutional and policy support, credit schemes and subsidies, and efficient extension services
- There is a need of multi dimensional research and examination of NF before initiating the large scale implementation.
- Scientific revalidation of available traditional knowledge of the country related to farming is necessary.
- Studies on choice of species, compatibility and interaction among crops, livestock and trees are required.
- Research on farmer's perception and adaptive capacity are essential.

ACKNOWLEDGEMENT

Authors are gratified to Ms. Shridevi Basappa Teli for the relevant corrections to a first draft of the manuscript. Thanks also extended to Mr. Thousif PK and Mr. Ashwath MN for the assistance in providing original photographs for the present article.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Rakesh S, Sarkar D, Sinha AK, Abhilash PC, Rakshit A. Climate Change and Agricultural Policy Options: Indian Story. Climate Change and Environmental Sustainability. 2019;7(2):208-11. Available:https://doi.org/10.5958/2320642X.2019.00027.9
2. Biswas S. Zero budget natural farming in India: aiming back to the basics. Int J Environ Climate Change. 2020;10:38-52. Available:https://doi.org/10.9734/IJECC/2020/v10i930228
3. FAO. India at a Glance. FAO in India. Available: http://www.fao.org/india/fao-in-india/india-at-a- glance/en/ last assessed on 14th September 2019.
4. Srinivasarao Ch, Rakesh S, Kumar G R, Manasa R, Somashekar G, Subha Lakshmi C, Kundu S. Soil Degradation Challenges for Sustainable Agriculture in Tropical India. Current Science, 2021; 120: 492-500.
5. Korav S, Dhaka AK, Chaudhary A, YS M. Zero Budget Natural Farming a Key to Sustainable Agriculture: Challenges, Opportunities and Policy Intervention. Ind J Pure App Biosci. 2020; 8(3):285-95. Available: http://dx.doi.org/10.18782/2582-2845.8091
6. Smith J, Yeluripati J, Smith P, Nayak DR. Potential yield challenges to scale-up of zero budget natural farming. Nature sustainability, 2020; 3(3): 247-252.
7. Kawaguchi Y. Interviewed in S. Kang and P. Lydon (directors). Final Straw: Food, Earth, Happiness; 2015.
8. Dev P, Paliyal SS, Rana N. Subhash palekar natural farming-scope, efficacy and critics. Environ Conserv J, 2022; 23: 99-106. Available:https://doi.org/10.36953/ECJ.021896-2158
9. Palekar S. The principles of spiritual farming (2nd ed.). Zero Budget Natural Farming Research, Development & Extension Movement, Amravati, Maharashtra, India; 2006, Available: http://www.vedicbooks.net/principles-spiritual-farming-volume-p-14779.html
10. Bharucha ZP, Mitjans SB, Pretty J. Towards redesign at scale through zero budget natural farming in Andhra Pradesh, India. Int J Agricul Sustain. 2020;18(1):1-20. Available:https://doi.org/10.1080/14735903.2019.1694465
11. Khadse A, Rosset PM, Morales H, Ferguson BG. Taking agroecology to scale: The zero budget natural farming peasant movement in Karnataka, India. The Journal of Peasant Studies, 2018; 45(1):192-219.

Available:https://doi.org/10.1080/03066150.2016.1276450

12. Turner N. Fertility Farming. Faber and Faber Limited; 1951, ISBN 978-1601730091.
13. Kat AM. Native American Knowledge and the Management of California's Natural Resources. Tending the Wild: Native American Knowledge and the Management of California's Natural Resources (1 ed.). University of California Press; 2005.
ISBN:9780520238565. JSTOR 10.1525/j.ctt1ppfn4
14. Xu HL. Nature Farming: history, principles and perspectives. Journal of Crop Production. 2001;3(1):1-10.
15. Thanh DN. Low External Input Sustainable Agriculture (LEISA) in Selected Countries of Asia. RAP Publication 1996;19.
16. Dangi RS, Singh N, Joshi E, Sasode DS, Chouhan N. Zero Budget Natural Farming. Biotica Research Today. 2022;4(2):110-112.
17. Žalac H, Zebec V, Ivezić V, Herman G. Land and Water Productivity in Intercropped Systems of Walnut—Buckwheat and Walnut–Barley: A Case Study. Sustainability. 2022;14(10): 6096.
Available:
https://doi.org/10.3390/su14106096
18. Tiwari R ICAR to study zero budget farming before its rollout. The Economic Times; 2019,
Available:https://economictimes.indiatimes.com/news/economy/agriculture/icar-to-study-zero-budget-farming-before-its-rollout/articleshow/70201301.cms
19. Sarvade S, Singh R, Ghumare V, Kachawaya DS, Khachi B. Agroforestry: An approach for food security. Indian Journal of Ecology. 2014;41(1):95-98.
20. Raj A, Jhariya MK. Effect of environmental variables on *Acacia* gum production in the tropics of Chhattisgarh, India. Environment, Development & Sustainability. 2021;24(5):6435-6448. Springer Nature.
Available:https://doi.org/10.1007/s10668-021-01709-1
21. Naz H, Akram NA, Ashraf M, Hefft DI, Jan BL. Leaf extract of neem (*Azadirachta indica*) alleviates adverse effects of drought in quinoa (*Chenopodium quinoa* Willd.) plants through alterations in biochemical attributes and antioxidants. Saudi Journal of Biological Sciences, 2022; 29(3):1367-1374.
Available:https://doi.org/10.1016/j.sjbs.2022.01.038
22. Rizvi SJ, Tahir M, Rizvi V, Kohli RK, Ansari A. Allelopathic interactions in agroforestry systems. Critical Reviews in Plant Sciences. 1999;18(6):773-96,
Available:https://doi.org/10.1080/07352689991309487
23. Srivastava AK, Patel JB, Ankuya KJ, Chauhan HD, Pawar MM, Gupta JP. Conservation of indigenous cattle breeds. Journal of Animal Research. 2019;9(1):1-2. Available: http://dx.doi.org/10.30954/2277-940X.01.2019.1
24. Raj A, Jhariya MK, Yadav DK, Banerjee A. Climate Change and Agroforestry Systems: Adaptation and Mitigation Strategies. Apple Academic Press Inc., CRC Press- a Taylor and Francis Group. 2020;383.
Available:https://doi.org/10.1201/9780429286759
25. Coelho GC. Ecosystem services in Brazilian's southern agroforestry systems. Tropical and Subtropical Agro ecosystems, 2017;20(3):475-492.
Available:http://www.revista.ccba.uady.mx/urn:ISSN:1870-0462-tsaes.v20i3.2421
26. Zahoor S, Dutt V, Mughal AH, Pala NA, Rashid M, Khan PA. Influence of intercropping on soil properties and nutrient status of fruit based agroforestry systems in north western region of Indian Himalaya. Indian Journal of Agroforestry. 2022; 24(1): 85-92.
27. San N, Deaton BJ. Feasibility of integrating sheep and crops with smallholder rubber production systems in Indonesia. J Agribusin. 1999; 17:105–122.
Available: https://doi.org/10.22004/ag.econ.14727
28. Stroesser L, Penot E, Michel I, Tongkaemkaew U, Chambon B. Income diversification for rubber farmers through agro-forestry practices: how to overcome rubber prices volatility in Phatthalung province, Thailand. In: IRRDB-2016 international rubber conference; 2016.
29. Kumawat A, Bamboriya SD, Meena RS, Yadav D, Kumar A, Kumar S, Raj A, Pradhan G. Legume-based inter-cropping to achieve the crop, soil, and environmental health security. In: R.S. Meena and Sandeep Kumar (ed.).

Advances in Legumes for Sustainable Intensification, Elsevier Inc. 2022;307-328. Available: https://doi.org/10.1016/B978-0-323-85797-0.00005-7

30. Sharrow SH, Ismail S. Carbon and nitrogen storage in agroforests, tree plantations, and pastures in western Oregon, USA. Agrofor Syst. 2004;60:123-130.
31. Rakesh S, Sarkar D, Sinha AK, Shikha, Mukhopadhyay P, Danish S, Fahad S, Datta R. Carbon mineralization rates and kinetics of surface-applied and incorporated rice and maize residues in Entisol and Inceptisol soil types. Sustainability. 2021;13(13):7212. Available:https://doi.org/10.3390/su13137212
32. Rakesh S, Sinha AK, Mukhopadhyay P. Vertical Distribution of TOC, TN and Other Important Soil Attributes and Their Relationship in Alfisol and Entisol of West Bengal. International Journal of Environment and Climate Change. 2020;10(1): 62-73, ISSN: 2581-8627.
33. Ong C, Black CR, Wilson J, Muthuri C, Bayala J, Jackson NA. Agroforestry: hydrological impacts. In: Van Alfen, Neal K, (ed.) Encyclopedia of agriculture and food systems, (2nd ed.), Amsterdam, Academic Press. 2014;244-252. Available:https://doi.org/10.1016/B978-0-444-52512-3.00028-0
34. Zomer RJ, Bossio DA, Sommer R, Verchot LV. Global sequestration potential of Increased organic carbon in cropland soils. Scientific Reports. 2017;7(1): 15554. Available: https://doi.org/10.1038/s41598-017-15794-8
35. Hamzah A, Hapsari RI, Wisnubroto EI. Phytoremediation of cadmium-contaminated agricultural land using indigenous plants. International Journal of Environmental & Agriculture Research. 2016; 2(1):8-14
36. Jacob JM, Karthik C, Saratale RG, Kumar SS, Prabakar D, Kadirvelu K, Pugazhendhi A. Biological approaches to tackle heavy metal pollution: a survey of literature. Journal of environmental management. 2018; 217: 56-70. Available:https://doi.org/10.1016/j.jenvman.2018.03.077
37. Marques AP, Rangel AO, Castro PM. Remediation of heavy metal contaminated soils: phytoremediation as a potentially promising clean-up technology. Crit. Rev. Env. Sci. Technol, 2009; 39: 622-654. Available: https://doi.org/10.1080/10643380701798272
38. Manikandan M, Kannan V, Mahalingam K, Vimala A, Chun S. Phytoremediation potential of chromium-containing tannery effluent-contaminated soil by native Indian timber-yielding tree species. Preparative Biochemistry and Biotechnology. 2016;46(1):100-8. Available:https://doi.org/10.1080/10826068.2015.1045607
39. DalCorso G, Fasani E, Manara A, Visioli G, Furini A. Heavy metal pollutions: state of the art and innovation in phyto-remediation. Int J Mol Sci. 2019;20(14): 3412, Available:https://doi.org/10.3390/ijms20143412
40. Ministério da Ciência. Tecnologia e Inovação-MCTI. Estimativas anuais de emissões de gases de efeito estufa no Brasil. 2014; 81, Available:https://repositorio.mctic.gov.br/bitstream/mctic/4303/1/2013_estimativas_anuais_emissoes_gases_efeito_estufa_brasil.pdf
41. Pontes LD, Barro RS, de Camargo EF, Porfirio-Da-Silva V, Cezimbra IM, Berndt A, Bayer C, Carvalho PD. Methane emissions from ruminants in integrated crop-livestock systems. Tropical Grasslands. 2014; 2:124-126.
42. Ngwabie NM, Jeppsson KH, Gustafsson G, Nimmermark S. Effects of animal activity and air temperature on methane and ammonia emissions from a naturally ventilated building for dairy cows. Atmospheric Environment, 2011;45(37): 6760-8. Available:https://doi.org/10.1016/j.atmosenv.2011.08.027
43. Rowlings DW, Grace PR, Kiese R, Weier KL. Environmental factors controlling temporal and spatial variability in the soilatmosphere exchange of CO2, CH4 and N2O from an Australian subtropical rainforest. Global Change Biology. 2012; 18: 726-738. Available:https://onlinelibrary.wiley.com/journal/13652486
44. Kim DG, Kirschbaum MU, Beedy TL. Carbon sequestration and net emissions of CH4 and N2O under agroforestry: Synthesizing available data and

suggestions for future studies. Agriculture, Ecosystems & Environment. 2016;226:65-78.
Available:https://doi.org/10.1016/j.agee.2016.04.011
45. Bayer C, Gomes J, Zanatta JA, Vieira FC, de Cássia Piccolo M, Dieckow J, Six J. Soil nitrous oxide emissions as affected by long-term tillage, cropping systems and nitrogen fertilization in Southern Brazil. Soil and Tillage Research. 2015;146: 213-22.
Available:https://doi.org/10.1016/j.still.2014.10.011
46. IPCC. Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (ed. Shukla PR et al.); 2019.
Available:https://www.ipcc.ch/site/assets/uploads/2019/11/SRCCL-Full-Report-Compiled-191128.pdf
47. Dinesha S, Dey AN, Deb S, Debnath MK. Litterfall Pattern and Nutrient Dynamics of *Swietenia macrophylla* Plantation in Terai Region, West Bengal, India. Indian Forester. 2020;146(1):7-12.
Available:http://dx.doi.org/10.36808/if%2F2020%2Fv146i1%2F144390
48. Sanz MJ, De Vente J, Chotte JL, Bernoux M, Kust G, Ruiz I, Almagro M, Alloza JA, Vallejo R, Castillo V, Hebel A. Sustainable Land Management contribution to successful landbased climate change adaptation and mitigation. United Nations Convention to Combat Desertification, Bonn, Germany; 2017. ISBN 978-92-95110-96-0
49. Wiese L, Wollenberg E, Alcántara-Shivapatham V, Richards M, Shelton S, Hönle SE, Heidecke C, Beáta EM, Chenu C. Countries' commitments to soil organic carbon in Nationally Determined Contributions, Climate Policy. 2021;8: 1005-1019.
Available:https://doi.org/10.1080/14693062.2021.1969883
50. Patle GT, Kharpude SN, Dabral PP, Kumar V. Impact of organic farming on sustainable agriculture system and marketing potential: A review. Int J Env Clim. 2020;10(11): 100-120,
Available:https://doi.org/10.9734/IJECC/2020/v10i1130270
51. Paudel D, Tiwari KR, Raut N, Sitaula BK, Bhattarai S, Timilsina YP, Thapa S. Which agroforestry practice is beneficial? A comparative assessment of the traditional and the improved agroforestry techniques in the midhills of Nepal. Advances in Agriculture. 2021;1-8.
Available:https://doi.org/10.1155/2021/2918410
52. Dhyani S, Karki M, Gupta AK. Opportunities and Advances to Mainstream Nature-Based Solutions in Disaster Risk Management and Climate Strategy. In: Dhyani S, Gupta AK, Karki M (ed.) Nature-Based Solutions for Resilient Ecosystems and Societies: Disaster Resilience and Green Growth, Springer, Singapore. 2020;1-26.
53. Dorin B. Theory, practice and challenges of agroecology in India. Int J Agricul Sustain. 2022;20(2):153-167.
Available:https://doi.org/10.1080/14735903.2021.1920760
54. Nayana H, Veni CP. SWOT analysis of Zero Budget Natural Farming. Biotica research today 2020; 3(6):547-549.
55. Münster D. Performing alternative agriculture: Critique and recuperation in zero budget natural farming, South India. Journal of Political Ecology. 2018;25(1):748-764.
56. Jinger D, Khatri P, Kumari K, Kumar D, Dinesh D. Agroforestry-Based Ecosystem Services for Livelihood Resilience. Food Sci Rep. 2022;3:50-54.
57. Pavlidis G, Tsihrintzis V. Pollution control by agroforestry systems: a short review. Eur Water. 2017;59:297–301.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/95292