Natural farming towards crop and economic resilience

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[Received: September 2023 / Revised: October 2023 / Accepted: November 2023]

Abstract: Globalization has resulted in an increase in food demand, which requires advancements in farming techniques to meet the demands. Green revolution based agriculture has made our country self-sufficient in food production. However, the excessive use of agrochemicals has led to degradation of soil, water, environment and human health besides, reduction in biodiversity. This necessitates an alternative of agro-chemicals which are environmentally safe and free from pesticide residues. Under such situation, Natural Farming as promoted by Padam Shri Awardee, Sh. Subhash Palekar has been proving as a viable option to address current farmers' distress, other soil and water issues to sustain farmer's incomes. Natural farming has inbuilt mechanisms to regenerate soil, reduce water usage, use of local available natural resources and enhance crop diversity to maintain crop quality. Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan, HP, India initiated natural farming based planned principles research to establish scientific logics. The farming claims to be environmental-friendly approach than conventional agriculture, capable of attaining sustainable development objectives by using on-farm resources and reduced tillage. Introducing natural production measures to produce chemical free soils towards implementation of more resilient cropping systems through reduction in greenhouse gas emission, restoration of soil fertility and enhanced carbon sequestration. It also holds promise in reducing serious agrarian crises raised due to increase in rural indebtedness as a result of chemical-based farming. This article proposes an ecosystem-mediated farming practices to maintain a balance between social, environmental and economic pillars of sustainability.

Keywords: Natural farming; agriculture; agrochemicals; sustainability

1. Introduction

According to the United Nations World Hunger Report global hunger reached 828 million in 2021, with a rise of 46 million since 2020 and 150 million since 2019, which signified that the world still has a long way to end hunger, food insecurity, and malnutrition by 2030. The commencement of green revolution upsurged the agricultural production over the past 50 years (Anand & Kumar, 2020) through increased use of fertilizers and agro-chemicals, which ultimately led to sustain the growing global population (Stokstad, 2002; Liao *et al.* 2019). However, it also had negative effects, such as soil deterioration (Singh, 2000), loss in biodiversity (DeFries *et al.* 2010; Armanda *et al.* 2019), rise in agriculture costs (Stevenson *et al.* 2013), etc. The projections of soil degradation intensity and vulnerability around the world are concerning (Kaiser, 2004; Reich & Eswaran, 2004). Besides, agriculture has become unsustainable due to increased use of synthetic fertilizers and pesticides, sluggish or declining agriculture production, erratic competitive dynamics, and the consequences of climate change (Sathish *et al.* 2022). The use of chemical fertilizers has posed a significant threat to the ecosystem, as their frequent use have also resulted in the eradication of beneficial soil microflora (Shaikh and Gachande 2015). Furthermore, the widespread use of inorganic agrochemicals has contaminated soil, surface and underground aquifers with toxic compounds, resulting in heavy metal accumulation (Lena *et al.* 1997; Devarinti, 2016). As a result of increased agricultural costs, countless farmers plunged into a financial pitfall, and the farming industry encountered widespread distress (Posani, 2009). No tillage, restricted traffic agriculture, and organic farming are three methods that have recently drawn increasing attention for their potential to improve soil health and fertility, save soil resources, and establish an environmentally friendly agricultural model (Liao *et al.* 2019). Besides, overtime organic farming became more prominent as the demand for organic food items rose exponentially on a global scale (Lohr, 2001; Iqbal, 2015; Shahabi Ahangarkolaee & Gorton, 2021). In 2020-21, India exported organic goods of 8,88,179.68 MT worth INR 7,07,849.52 lakhs (APEDA, 2021). At present, agricultural land in organic farming in India is estimated to cover an area of 26,57,889.33 ha (APEDA, 2021). Despite this, low-income populations cannot afford organic food due to its extremely high price compared to conventional food products (Sathish *et al.* 2022). Small farmers struggle to adopt it since it calls for a substantial amount of FYM/organic fertiliser and expensive certification processes (Mzoughi, 2011).

Natural Farming (NF) is a chemical-free farming method that integrates crops, trees, and livestock, allowing functional biodiversity through agroecology (Rosset and Martinez-Torres 2012). NF is also known as Zero Budget Natural Farming (ZBNF), which is regarded as a disruptive farming approach that addresses farmers' biggest concerns about the mounting cost of production. The natural farming ideology is based on the concept of harnessing natural cycles and functioning in balance with the environment to provide safer and healthier food while preserving the wellbeing of the soil, people, and livestock (Bana *et al.* 2022). It can be used as an innovative approach to develop both conventional and modern agricultural techniques with the objective of preserving the environment, communities, and the general public's health (Mishra, 2013). It is also known as *'do nothing farming'* because the farmer is merely seen as a conduit for Nature, who does the actual labour (Devarinti, 2016). The cardinal rule is to increase the amount of organic matter in the soil since this promotes microbial activity, which enhances soil fertility (Rashid *et al.* 2016). Furthermore, it promotes soil health (Zuraini *et al.* 2010), improves soil organic carbon without requiring a large quantity of FYM like organic farming (Devarinti, 2016) and thus helps to reduce the carbon footprint of agriculture (Hedayati *et al.* 2019; Skinner *et al.* 2019). In order to break the debt cycle for vulnerable farmers, ZBNF claims to stop relying on loans and dramatically reduce production expenses (La Via Campesina, 2016). The scientific community, however, has labelled it as an unscientific and fuss story. Despite popular belief, thousands of farmers in various Indian states use some aspect of NF practices. Numerous NF management techniques are being adopted namely, crop rotation, intercropping and minimal tillage, mulching with crop residues, application of biofertilizers and limiting the use of agro-chemicals (Liao *et al.* 2019). By promoting multiple cropping, year-round soil coverage, and the use of a mixture comprised of cow dung and urine to stimulate the microorganisms in the soil system, it relies more on soil biology than soil chemistry. Several states in India, especially Andhra Pradesh, Karnataka, Maharashtra, and Himachal Pradesh, have adopted this model at varying levels with the goal to make farming a viable and aspirational endeavor by increasing farmers' net incomes.

2. Chemical *vs* Natural Farming

Natural resources are vital for the production of food on this planet. It is imperative to maintain these resources to ensure the food availability and nutritional security. As per the reports, a substantial portion of the country's Gross Domestic Product (GDP) comes from the agricultural sector, which generates 16.77 per cent of the total and contributes approximately US $0.44 trillion annually (Constant, 2015) with annual growth of 3.27 per cent (World Bank, 2021). Although agricultural intensification has been a crucial aspect of Indian agricultural growth and development, the sector remains highly resource inefficient in terms of inorganic fertilizer use, water utilization, mechanization and cropping intensity (Huimin *et al.* 2014; Nath *et al.* 2015). In most cases, fertilizers are applied imprecisely, resulting in little crop uptake. As a result, there is little increment in yield, and a large amount of fertiliser is emitted as pollutants into the air, soil, and water. Soil micro and macrofauna is also diminished, altering carbon to nitrogen ratio in soil and the nitrification process (Shaikh & Gachande, 2015).

Increased use of agrochemicals, inorganic fertilizers and pesticides has led to agricultural pollution and heavy metal buildup in the soil which has negatively impacted ecosystems and the environment (Malik *et al.* 2017). The accumulation of heavy metal ions and other chemical pollutants potentially induce nutrient depletion in the soil (Rani & Saxena, 2021). Furthermore, the enzymatic activity of bacteria can be hampered by heavy metals, which results in a decrease in soil organic matter (Shun-hong *et al.* 2009). In addition to causing negative impacts on the environment, industrialization has led to dramatic increases in production and release of hazardous metals into the environment over the last century (Burger, 2008; Gallego *et al.* 2012). Heavy metals like zinc and copper are important for plant growth, but when present in high amounts, they are toxic and can lead to plant death. As a result of heavy metal contamination, soil bacterial species richness declines, soil actinomycetes increase and as a result, biomass and diversity of bacterial communities in soil decrease (Karaca *et al.* 2010). The numerous negative effects of these toxic elements have also been reported in human system as a result of their metabolization and bioaccumulation in body fat (Alewu & Nosiri, 2011; Pirsaheb *et al.* 2015). Generally, human exposure to these metals occurs via contaminated food or water. Nonetheless, intensification of agriculture has had extensive adverse environmental impacts, including soil degradation, eutrophication, as well as a loss of biodiversity (Pingali, 2012; Foote *et al.* 2015). Numerous studies have also demonstrated that pesticides destroy necessary soil microbial fauna (Iqbal *et al.* 2001). Large-scale chemical use also makes farming unprofitable, which is why an increasing number of individuals are abandoning the agricultural farming. Pesticides and chemical fertilizers result in the emergence of harmful and destructive insects, which require toxic insecticides/pesticides that cause insects to develop even more resistance to them (Xu, 2000). A catastrophe is looming over the planet, as the global population of over 8 billion people poses an increasingly difficult challenge to sustain life. A healthy lifestyle under the motto "Back to Nature" represents a way of life for the global community (Fitrah, 2022). As an alternative to chemical fertilizers with high input costs, ZBNF has been hailed as a sustainable environment friendly agricultural system. The symbiotic and probiotic insights (Gilbert *et al.* 2012; Lorimer, 2017) of soil and plant life developed by biological sciences namely, microbiology, ecology, and soil science are source of idea for the ecological regeneration of agriculture (Kumar *et al.* 2019). With this method, food plants thrive along with the natural biodiversity of each farmed area, encouraging the species diversity of living organisms, including both plants and animals. Furthermore, by following this method, natural cycles in the soil are restored and rebuilt, and water demand is reduced. Soil is home to a microbial consortium of indigenous bacteria that has the potential to improve soil fertility (Rani & Saxena, 2021). In NF, as organic matter decomposes on the soil surface through microbes and earthworms, it gradually adds nutrition to the soil (Chandel & Jangilwad, 2021). So, by adopting NF, the quality of the produce can be improved, with minimized adverse effects on soil and environmental health by using low-cost natural resources. Moreover, if NF is acknowledged as a chemical-free method of production, farmers can begin selling their products as Green Products at a premium price from the very first year (Kumar *et al.* 2020).

3. Climate Resilience

Meteorological parameters might have strong influence on the geographical distribution of agricultural crops (Malla, 2008). Climate change, including rising temperatures, shifting rainfall patterns, and an increase in frequently occurring climatic extremes, has affected ecosystem functioning, crop production, and water accessibility, which has in turn affected food security (IPCC, 2014; Troy *et al.* 2015). It has been projected that crop yield and production efficiency in low-income countries will be severely impacted by climate change (Reed *et al.* 2017; Arshad *et al.* 2018). Agricultural farming is highly impaired by climate variabilities such as flood and drought, resulting in a reduction in farm production (Mendelsohn & Wang, 2017). Globally, a decrease in crop production of 17 per cent is projected without accounting for CO_2 fertilization caused by climate change (Nelson *et al.* 2014). The production of GHGs is a major free-rider problem of intensive Indian agriculture (Chadha *et al.* 2004). Burning agricultural waste can release large amounts of atmospheric pollutants such as CO_2, N_2O, and CH_4, which contribute to global warming, nutrient loss, and soil damage (Naresh *et al.* 2018). India generates 87 per cent of its agricultural-related emissions from primary production inputs and on-farm production (Pathak *et al.* 2010). The impact of climate change and global warming is most pronounced on fruit production, whilst perennial crops are more vulnerable to rapid temperature fluctuations (Saygi, 2020). Extreme weather conditions during bud development, flowering and winter rest are a few recent prevalent phenomena, directly impacting the production and quality of fruit.

In light of a changing climate, it is now commonly acknowledged that a significant change of food systems is required to ensure global food and nutrition security (Sinclair *et al.* 2019). This will have a significant impact on what people consume as well as how food is grown, processed, transported, and sold. By switching to natural inputs from chemical fertilizers, farmers may be able to withstand extreme weather events due to lower input costs, decreased reliance on resources, and increased soil quality (Naresh *et al.* 2018). When compared to traditional agriculture, the use of ZBNF will result in better climate adaptation because farming systems will already be tailored to the local climatic conditions (Kumar, 2022). Reducing use of chemical fertilisers via ZBNF ensures good water quality and availability during severe weather conditions by reducing runoff into rivers and wetlands. Furthermore, reduced tillage, constant vegetation cover on the fields, and bioinoculants application leads to improvement in soil fertility which contribute to greater carbon sequestration and decreased carbon loss in ZBNF soils (UNEP, 2019). The dramatic rise in SOM under ZBNF boosts the soil's capacity to hold water, improving the crops' resistance to harsh weather conditions and assisting in sustaining food production under water-stressed instances (Hati *et al.* 2006; Smith *et al.* 2020). In India, Government of Andhra Pradesh has adopted Climate Resilient Zero Budget Natural Farming (CRBZBNF) as a farming practise that asserts in the natural cultivation of crops without supplying any chemical fertilizers/pesticides, as well as any external inputs for combating extreme climate vulnerabilities (Kumar *et al.* 2019).

4. Myth or Reality

In order for India to achieve and sustain 8 per cent GDP growth rate, we must produce 457 MT of food grains by 2050 (NAAS, 2019). This would involve a six-fold rise in labour productivity, a four-fold growth in land productivity, a three-fold increase in water use efficiency, doubling of energy consumption efficiency, with around half of that efficiency coming from labour and capital substitution (Chand, 2012). To meet the demand for increasing food, there is an urgent need to improve the nutrition quality of soils and crops. Soil nutrient stocks are depleted by continuous crop cultivation, and soils must be supplied with essential plant nutrients. Later, a shortage of secondary and micronutrients also develops and may reduce output; which needs to be rectified. However, considering a limited capacity of soil for delivering nutrients, ZBNF cannot meet this demand and hence crop productivity remains low. ZBNF is a form of organic farming which forbids the use of artificial fertilizers and pesticides. The only difference implies is ZBNF intended to lower cultivation costs to zero, whereas organic farming did not include such measures (Smith, 2020). There are several myths related to ZBNF namely, poor quality of food products produced via natural farming, use of poisonous pesticides, food poisoning, high produce costs, inefficiency of natural products to feed global population, threat to animal welfare and zero budget farming (Prajapati, 2019).

But in reality, these myths have been invalidated as the crops produced via use of on-farm inputs in natural farming contains no or minor number of contaminants. These inputs are meant to boost soil health, improve microbial activity and nutrient cycling leading to better produce and even more nutritious food (Bharucha & Mitjans, 2020). Secondly, the elimination of chemical fertilizers in natural farming and adoption of readily available homemade amendments (Duddigan *et al.* 2022) reduce the risk of food poisoning (Devarinti, 2016). Regarding the usage of pesticides, it is clear that natural farming practises prioritize the prevention rather than minimising its need. Also, the cost efficiency of organic produce is more compared to conventional farming due to cut down on extravagant expenses over chemical fertilizers and pesticides (Duddigan *et al.* 2022). Besides, use of multiple cropping systems, crop rotations, substitution of cow dung and urine for pesticides has contributed to the lower cost of producing organic food (Korav *et al.* 2020). The food products produced from natural farming, however is inefficient to produce higher yields but are highly nutritious to contribute to global nutritional security and even eliminate the hidden hunger faced by today's society. Studies have also found that naturally grown plants are higher in antioxidant content, essential minerals such as, potassium, phosphorus, magnesium, zinc, iron, calcium, and copper (Baranski *et al.* 2014). Another myth regarding animal welfare is dissolved as natural livestock standards place a premium on the welfare of animals and their ability to behave as nature intended. To address the myth of zero cost of cultivation, it has been devised that the phrase "zero budget" does not actually imply that costs are zero, but instead that there is no need for external financing of agriculture. Moreover, although using family labour, on-field produced fertilizers and pesticides may reduce the cost of production, it will never be completely zero (Prajapati, 2019).

5. Sustenance through Natural Inputs

It has been estimated by the Food and Agriculture Organization (FAO), United Nations in 2015 that only 60 harvesting years remain as a result of soil degradation according to National Centre for Organic and Natural Farming. Sustainable agriculture is globally seen as a means of solving problems and constraints that threaten the economic, environmental and social problems of agricultural production systems (Renagold *et al.* 1990). It is defined by the Agricultural Research Service of USDA as agriculture that will strive to be profitable, competitive, and productive for the foreseeable future while preserving natural resources, safeguarding the environment, and improving public health, food quality, and safety (Parr *et al.* 1994). Sustainable intensification, which entails producing more food from the same amount of land while minimising environmental impacts, has been proposed in recent times as a solution to the problem of feeding 9 billion people by 2050 according to Royal Society of London (2009). Agricultural intensification causes soil degradation and water shortages, increasing water use and reducing soil fertility, which threaten long-term crop productivity (Gomiero *et al.* 2011). Nowadays, chemical-based agriculture has increased production costs and reduced crop yields (Korav *et al.* 2020), due to reduced soil fertility and vitality, soil erosion, groundwater contamination and overgrazing (Sreenivasa *et al.* 2010; Singh *et al.* 2011). Currently, soil erosion is causing major modifications to the biogeochemical cycles that regulate carbon, nitrogen, and phosphorus (Quinton *et al.* 2010). The stabilizing effect of organic matter and vegetation cover is closely related to soil erosion resistance (Gomiero *et al.* 2011). The top soil layer that contains organic matter comprises of around 95 per cent of the soil's N and 25-50 per cent of its P (Lal, 2010). Where, intensive use of chemical fertilizers leads to oxidation of organic matter in soil and thus increased soil erosion (Montgomery, 2007). Natural farming practices including no-till agriculture, or minimum tillage can cut down incidences of soil loss and restore soil fertility (NRC, 2010). Additionally, it promotes soil aeration, bunding and topsoil mulching, and intercropping. These practises do not immediately increase productivity but instead help farmers increase their income by creating self-sustaining systems after at least three years of the conversion period (Ranjan & Sow 2021).

Currently, 70 per cent of 3,800 km^3 of water use is directed towards agriculture, which is expected to rise by 13 per cent by 2050 (Molden, 2007). Agro-intensive irrigation can cause waterlogging and salinization (Gomiero *et al.* 2011) as well as the depletion and contamination of surface and groundwater resources (Pimental *et al.* 2004; Moss, 2008). As a result of avoiding chemical fertilizer application in natural farming, water quality is improved and water availability is increased during extreme weather events (Korav *et al.* 2020). Another serious impact on environment is the residual effects of chemical fertilizers which can be drastically altered through natural farming, leading to improved soil and environmental health. The use of on-farm inputs with indigenous cow breed products have led to maintain soil health, increase microbial activity and nutrient cycling without any need to purchase inputs such as chemical or organic fertilizers and pesticides (Ranjan & Sow, 2021). The utilization of chemical fertilizers has also showed a direct effect on local biodiversity leading to even outbreak of more diseases and pests due to development of resistance (Xu, 2000). Bee activity, in particular, is being negatively affected by chemical use (Gomiero *et al.* 2011). The biodiversity richness can be obtained through the system that mimics natural ecosystem (Scherr & McNeely, 2007), as nature is inclined to establish more biodiversity compared to humans. A productive hectare of agricultural land is home to approximately thousands of species weighing as much as 10 tons (Pimentel, 2006). In this way, natural management of farms can conserve biodiversity when managed correctly.

6. Philosophical, Social and Economic Approach

Mokichi Okada (1993) declared that 'Kyusei Nature Farming' was an environmentally friendly method for growing high-quality food crops. This technique, known from even before the green revolution, harnesses the resources that are already accessible to produce high yields in a sustainable way. Diverse plant colonies develop in a healthy condition in forests, on plains, in or near lakes and marshes, and they retain productivity without being significantly harmed by pests and diseases. Nature has the ability to support all living forms, including humans. Moreover, it continually incorporates plants and animals into a diverse environment without making any distinctions between the various life forms in the planet, thus maintaining natural biodiversity. Besides, humans are continually persisted in their conflict with nature over biodiversity to eliminate weeds and insects by employing pesticides. During the initial periods of adoption of natural farming, many scientists, decision-makers, and farmers thought that utilising pesticides would eradicate insects and diseases and put an end to famines. As a result, the nature farming idea put forth at the time received criticism and was even referred to as an evil philosophy. Okada claimed that because people were unaware of the strength of soil, they significantly undermined it by using chemical fertilisers. He stated that in order to retain the strength of soil, it was vital to keep the soil clean by only incorporating natural composts. He also found that crops cultivated under natural conditions are less prone to wind damage as plants grown under naturally have longer and a greater number of roots compared to chemically cultivated plants.

Fukuoka pioneered natural farming in Japan by experimenting with nature and using organic methods of crop multiplication, where without soil erosion, he produced yields comparable to those of chemical farming (Fukuoka, 1978; Devarinti, 2016). With the similar principle Subash Palekar in India has developed Zero-Budget Natural Farming (ZBNF) by using local supplements (Palekar, 2010). Thus, the natural farming philosophy strives to promote the growth of beneficial microorganisms without relying on external manure or chemical pesticides (Devarinti, 2016). As per FAO (2012), agriculture development that preserves land, water, plant, and animal genetic resources is both economically and socially feasible. In terms of social aspect, low input and reduced cultivation costs allow farmers to have consistent crop yields to sell in the market, enhancing the security of their livelihoods (Korav *et al.* 2020). In India, agricultural production costs and credit rates are high, crop prices are volatile, and fossil fuel-based inputs and private seed costs are rising (Koner and Laha 2020). Consequently, Indian farmers (particularly smallholders) are increasingly in debt. There have been more than a quarter of a million suicides among farmers in India over the past two decades (Parvathamma, 2016). ZBNF system cuts off the use of external inputs like synthetic fertilisers, pesticides, and herbicides, especially from large corporations, and generating employment to locals and thus uplifting their socio-economic status (APZBNF 2018). According to some studies, every dollar spent to encourage a farmer to use ZBNF yields immediate advantages of 13 dollars. As a result, there is a reduction in cultivation costs, a higher yield, more income from intercrops, and a slight price increase. Other social and environmental advantages include the security of food, nutrition, and health, employment generation, soil and water security, coastal ecosystem regeneration, climate resilience, biodiversity protection, and reduced risk (Korav *et al.* 2020).

7. Components of Natural Farming

Natural farming has several successful implementations around the world. Zero Budget Natural Farming (ZBNF), developed by Subhash Palekar in India, is one of them. With the help of natural farming practises and locally accessible farm-based resources, even commercial-level farming can be carried out on essentially with zero budget. This can be achieved by following five different components of natural farming:

7.1 Bijamrit

It is a treatment applied to any planting material, including seeds and seedlings. It is made up of 20 L of water, 5 kg of cow dung, 5 L of urine, 50 g of lime, and a handful of soil, which are all deeply mixed together and kept in a tank. Cow dung is rich in naturally occurring beneficial microbes, which are used as an inoculum for the seeds (Devarinti, 2016). Through *bijamrit* application, young roots are well shielded against fungus, as well as from soil-borne and seed-borne pathogens that frequently harm plants. In addition, it also serves as a source of important growth regulators namely Indole-3-acetic acid (IAA) and Gibberellic acid (GA_3) (Sreenivasa *et al.* 2010). Any crop's seeds can be coated with bijamrita by hand mixing, then properly dried before being used for sowing (Asokan *et al.* 2020).

7.2 Jivamrit

It is a type of bio-fertilizer that enriches the soil with nutrients for healthy plant growth, as well as stimulates earthworm and soil microbial activity. It is composed of some important classes of microbes namely, plant growth promoting rhizobacteria (PGPR), cyanobacteria, phosphate solubilising bacteria (PSB), nitrogen-fixing bacteria, and mycorrhizal fungi (Chen *et al.* 1995). Inoculating jivamrita into soil helps the microbes convert non-available forms of nutrients to dissolved forms and also exhibits antagonistic effects on harmful pathogens (Glick & Bashan, 1997; Korav *et al.* 2020). It is composed of a mixture of 20 kg cow dung, 5-10 L urine, 2 kg dicot flour (*besan*), which is kept in a tank and allowed to ferment. The aerobic and anaerobic bacteria found in the cow dung and urine grow enormously during the 48-hour fermentation process as they consume organic ingredients. Then, 2 kg jaggery, handful of soil, and 200 L of water is also added, stirred and stored in shade. 200 L of *Jivamrita* is required for 1 acre of land, applied twice a month as 10 per cent foliar spray or along with irrigation water.

7.3 Acchadan/Mulching

Mulching is covering the soil with plant or dust debris, which has a number of benefits. It increases soil aeration and maintains soil moisture by reducing water evaporation and decreases the incidence of weed emergence (Ranjan & Sow, 2021). Based on ZBNF model, it is generally of three types: straw mulch, soil mulch and live mulch (Asokan *et al.* 2020). Straw mulching is composed of the dead remains of any living organism which implies that dry organic matter will eventually decompose and turn into humus through the action of the soil microflora activated by microbial cultures. Soil mulching encourages aeration and soil water retention while protecting topsoil during cultivation and preventing its destruction by tilling. Live mulching suggest that it is essential to develop multiple cropping patterns of monocotyledons and dicotyledons grown in the same field to supply all essential elements to the soil and crops. Cover crops, such as legumes can help control weed growth, improve water infiltration and increase N fixation through root nodules (Korav *et al.* 2020).

7.4 Whapasa/Moisture

Water conservation and precise water application based on crop water requirements are the key issues at hand. *Whapasa* describes soil conditions where both air and water molecules are present. As only a limited amount of water (in the form of vapour) is required for crop growth, *Whapasa* aims to improve water use efficiency by reducing irrigation frequency and quantity (Ranjan & Sow 2021). In soil, water and air make up an equal proportion of soil mineral and organic matter. It is possible that plants suffer from oxygen deficiency and eventually die if higher amounts of water are applied and air space is confined in the soil. Plant growth is also highly dependent on soil aeration, so the interval between applications should be extended (Korav *et al.* 2020).

7.5 Plant Protection

Pests and diseases cause high yield losses to crops, followed by weeds. The protection against such losses can be made through application of biological concoctions. Plant extracts are used to create a compound capable of killing or controlling pests in crops (Korav *et al.* 2020). Bio-pesticides namely, *Neemaster, Agniaster, Bramhaster* made from natural or organic or bio-products is only permitted to be used in ZBNF during the times of pests and diseases outbreaks to prevent economic injury to plants. Pests such as aphids, jassids, mealybugs, white flies, etc., are effectively controlled by them (Ranjan & Sow, 2021).

7.6 Biological Factories

Inorganic fertilizers and agrochemicals are increasingly being used, resulting in agricultural pollution and degradation of the environment (Pankaj *et al.* 2016; Malik *et al.* 2017; Bhatt *et al.* 2019). The soil contamination through chemicals and heavy metals alters the soil structure as well as nutrient concentration. Heavy metal pollution adversely affects the size, composition, and activity of the microbial community, as well as the yield and quality of plants (Wang *et al.* 2016). Organic matter is the major indicator of soil quality, which considerably decreases in soil due to heavy metal interference with microbe enzymatic activity (Shun-hong *et al.* 2009). As part of the ongoing agricultural crisis, the novel microbial practices aim to restore soil health at low cost (Munster, 2021). A healthy soil consists of fungi and soil microbes that fix, decompose, solubilize and mineralize all nutrients needed by plants through fixation, decomposition, and solubilization (Phillips, 2017). Plants provide soils with carbon, but microbes control its fate by converting it to food and ensuring that at least some remains in the soil (Wallenstein, 2017). The soil is inhabited by indigenous microbial consortiums with the power to boost soil fertility. Natural farming is based on the premise that nature is in an exquisite state of balance, with everything interdependent and dependent on each other (Fukuda, 2018). Consequently, organic or synthetic fertilizers are not required, instead the biological entities such as microorganisms and enzymes, should be allowed to carry out their usual functions. According to Kawaguchi (2014), plants grow best in natural soil, though neutralization of chemicals may take some time.

Soil serves as a habitat to billions of micro and macroscopic organisms (Xu, 2006). *Jivamrit* does not function as a fertiliser when put to the soil, hence plants are not able to absorb it. Instead, it nourishes and stimulates the activity of the soil's microbes leading to bio-diversitical saturation of soil (Palekar, 2010). In a gram of cow dung, there are an estimated 300 to 500 billion beneficial microorganisms. These microorganisms act as catalysts and break down the dried biomass in the soil and turn it into plant accessible nutrients (Asokan *et al.* 2020). ZBNF is an alternative agronomy that relies on reviving purportedly "old farming practises" along with modern scientific advancements to stimulate microbial life in the soil. With the aid of microbial agents, ZBNF strives to build and maintain soil fertility and health (Munster, 2021). Humans, plants, cows, and microorganisms must all coexist harmoniously in order to maintain healthy soil. Organic matter placed as mulch cover on the ground feeds earthworms and microbes. During this process, humus is produced near the root zone and nutrients are supplied to the plants. In addition, ZBNF emphasizes the importance of natural biomes (seeds, microbes, earthworms and cows) in the recovery of India's rural health and prosperity.

Numerous bacteria in the rhizosphere have positive effects on crop productivity including, plant growth promoting rhizobacteria (PGPR), arbuscular mycorrhizal fungi (AMF) and cyanobacteria which promote plant growth as well as protect them from pathogens (Devarinti, 2016). Despite the fact that chemical pollution may take years to neutralize, nature makes the best soil for growing plants, in which living things (microbes and enzymes) should be enabled to carry out their regular functions normally (Kawaguchi, 2014; Fukuda, 2018). By enriching the organic matter level in the soil, microbial life can flourish, thus increasing soil fertility (Paul *et al.* 2021). Among the soil's functions related to greenhouse effect mitigation, the most important is the process of plant uptake of CO_2 and the emission of O_2 by photosynthetic microbes. Innately, it reflects the potential for the activation of various microbes and the addition of biomass to the soil to regenerate the nutrients needed for plant growth under NF (Kumar, 2020).

A total of 150 species of AM fungi has been identified which colonize plant roots (Kumar, 2020). Plants furnish AM fungi with photosynthetic sugars, and the fungi benefit the plants in return by accelerating the water and nutrients uptake. Aside from stabilizing soil aggregation and soil carbon accumulation, it improves water use efficiency as well as N, P and S uptake. The use of NF practices such as non-usage of synthetic fertilizers and use of cover crop results in decreasing soil temperature, improving soil moisture and thereby stimulating soil bacterial growth. In this way, it also aids in building a soil C sponge that soaks up water and makes it available to the plants (Phillips, 2017). Jehne (2019) contends that 95 per cent of soil fertility depends on microbial processes rather than the actual nutrient content of soil or fertilizer applications.

8. Nutri-Food Model

As the world's population increases, its resources are strained, resulting in environmental degradation, health risks, and food shortages (TERI, 2014). According to United Nation's FAO, food production will need to increase 70 per cent by 2050 to feed 2.3 billion additional people (FAO, 2009). In the long run, this shortage in meeting food demands ultimately impacts the nutritional status of the population. Due to this nearly 30 per cent of the world's population suffers from malnutrition, a condition that contradicts the idea of a healthy lifestyle. Malnutrition includes both undernutrition and overnutrition; undernutrition is typically found in rural and developing areas of the world, which threatens both human development and economic development. It is imperative to meet the nutritive food requirements at farm level only. In addition to addressing nutritional needs, it also contributes to the income of farming families by reducing food expenditures and medical expenses (Singh *et al.* 2020). As a way to address the lack of access to diverse and nutritious diets, the term 'nutri-gardens' was introduced which utilize land to grow vegetables and fruits that can support the nutritional needs of the community? Through income generation, nutri-gardens can enhance diet quality by complementing on-farm production, increasing access to diverse foods for household consumption, and facilitating the impact of nutrition behaviour change communication on market purchases of nutrient-dense foods. It is cheap and convenient to grow a nutri-garden, which provides a regular supply of fresh vegetables, which is a key component of good health. It focuses more on long-term health and productivity by enhancing soil fertility.

Natural farming is encouraged in India as part of the *Bharatiya Prakritik Krishi Paddhati* (BPKP) under *Paramparagat Krishi Vikas Yojana* (PKVY) of Government of India. Consuming fruits and vegetables from Agri-Nutri Gardens, which are cultivated without the use of pesticides, is anticipated to contribute to the development of a society that is healthier and more resilient (Roshni, 2022). The strategic approach for constructing organic carbon in sufficient quantities in soils would be centred on the proposed nutritional and ecological models that can re-establish soil organic carbon equilibrium and its subsistence by appropriate management techniques. Therefore, nutri-gardens may be seen as a straightforward alternative to: a) reduce the disparity between the available resources and sustainable use of resources b) address issues like malnutrition c) create more chances for farming communities, particularly women, to generate income d) introduce healthy eating habits. This ensures nutrition rich food while reducing the cost incurred by marginal households for health care and vegetable consumption. With this in mind, Government of India had emphasized and launched the 'National Nutrition Mission' (NNM) or '*Poshan Abhiyaan*' with the aim to ensure development of malnutrition-free India by 2022 (Suri, 2020). Nutri-gardens can improve the diet of the family and offer a number of other advantages for small and marginal farmers, especially for women. With a focus on "nutrition-sensitive, and women-controlled approach to household food production," this idea, also known as Integrated Homestead Food Production (IHFP), entails the cultivation of small-scale plots that are frequently next to households for improved food security and nutrition. In hilly areas, malnutrition is a major problem due to small and scattered land holdings, low soil fertility, and primarily rain-fed agriculture. Apple, pear, peach, plum, citrus, apricot, and walnut are examples of temperate and subtropical fruit crops that can be successfully grown in the hill region due to its geographical and climatic characteristics (Mamgai *et al.* 2021). These can be successfully cultivated in nutri-gardens to ensure nutrient-rich food availability and diversified dietary intake. Thus, several nutri-gardens have been established in different parts of the country including low-cost techniques to raise the nutritional levels with minimum investment.

9. Organic *vs* Natural Farming: A Regenerative Farming

In both of these approaches, farmers are discouraged from using chemical fertilizers and pesticides on plants and in any agricultural practices. Despite the organic food market's rapid expansion, organic farming has a questionable history and is viewed as an ineffective method of food production. Consumers of organic goods have recently experienced frequent shortages of these goods despite the growing trend in demand, partly because the supply of organic foods was unable to keep up with the sharply rising demand (Dimitri & Oberholtzer, 2009). Based on data from 2022, the reports of 'The world of Organic Agriculture' shows that organic farmland increased in India by 15.6 per cent which accounted for almost 359 thousand ha of the world's agricultural land (Willer *et al.* 2022). In addition, due to increased labour expenses, certification fees, handling fees, and often lower yields, organic products are typically 3-4 folds more expensive (Rao, 2019). A farmer who wants to switch to organic farming must go through a three-year transition phase during which time they must practise organic farming but are not authorised to label their produce as organic. The high cost of organic goods is partly a result of the logistical expenses required in obtaining them from farms that have earned their organic certification. These expenses, along with the cost of distribution inside the city, drive up the price of the goods (Kumar, 2020).

All India Network Project on Organic Farming (AI-NPOF) project demonstrates that using an organic technique has a greater cost of cultivation. According to the CSE research, the high cost is driven by the market-based predominance of organic and bio-inputs used in AI-NPOF. According to Connor (2008), organic agriculture can only support 3-4 billion people, much lower than the current and projected global population in 2050. However, Badgley *et al.* (2007) argued that it has the potential to improve crop productivity in developing countries as well as feed the entire planet. Searchinger *et al.* (2018) exemplified that organically grown crops have a bigger climatic impact than conventional systems due to larger land requirements. This might be linked to the significantly larger area of land used to produce the same amount of organic food as that of conventional practices, which indirectly contributes to higher carbon emissions. Additionally, the requirement of external inputs such as FYM in huge quantities leads to increased costs, making it economically unviable. Also, in organic farming through *Eisenia foetida* is commonly used, that feeds solely on the soil surface organic matter, and thus the soil at lower surfaces remains undisturbed which is the richest source of mineral nutrients (Rose *et al.* 2021).

In contrast, if NF is recognized as a chemical-free method of production, farmers can market their output as “Green Product” from the very first year at lower prices. It is a low-cost venture, with minimized emissions and thus economically more viable system than organic farming. In this, there is no need for excessive chemical use as biofertilizers, rhizobium, and acetobacter may improve soil health to some extent. Additionally, this would assist the government in reducing its expenditure on fertiliser subsidies, which are expected to cost Rs 1.1 lakh crore in 2023, with the potential for a rise to Rs 2.5 lakh crore because of greater inflationary pressures (Paliath, 2022). The primary reason for farmers to adopt ZBNF is health benefits (due to reduced chemical exposure), food self-sufficiency, environmental considerations, reduced costs, and economic independence (Khadse *et al.* 2018). In addition, better farm incomes through intercrops fringe benefit in NF (Kumar *et al.* 2020).

10. Sustainable and Local Food Systems

In response to the food price spikes and anxiety about climate change and key resource pressures, the concept of food security has resurfaced in international debate (Ambler-Edwards *et al.* 2009; MacMillan & Dowler 2011). Such constrained perspectives on food security and the global food crises have detrimental effects on the function and growth of local food systems, whereas more comprehensive perspectives may also provide important insights for them (Kirwan & Maye, 2013). In public discourse, local food systems are increasingly connected to sustainability (Friedmann, 2007). A local food system refers to the production, processing and retailing of foods within a defined geographical area in which the local is always perceived and understood in relation to regional, national, and global scales (Kneafsey *et al.* 2013). Therefore, ‘local’ refers to the smallest unit of origin, and consumers are acquainted with the place in which the food is produced and can distinguish between ‘local’ and ‘regional’ food origins (Markuszewska *et al.* 2012). Sustainability of local food systems encompasses the environmental, social and economic aspects. A sustainable agriculture is explicitly dependent on localization as ‘food miles’ are associated with fossil fuels and climate change (Najam *et al.* 2007). Consequently, local food is more sustainable because it requires fewer transportation efforts (Stein & Santini, 2021). This notion may seem logical at first, but it ignores the fact that there are several factors other than transportation that have a greater impact on a product’s carbon footprint, including land usage, manufacturing techniques, and storage (Ritchie & Roser, 2020). Moreover, in terms of carbon footprint, consumers’ eating choices have a much bigger influence on food systems than the localness of the food (Benis & Ferrao, 2017; Ritchie, 2020).

Natural farming implies avoidance of chemical fertilisers and pesticides and using natural processes and inputs to increase the health of the soil and thereby improving the nutritional quality of the crop. In contrast with contemporary farming, NF emphasizes close relationships between land, farmer, and consumer. The consumers demand related to health benefits can be optimally fulfilled through naturally grown crops along with reduced carbon footprints. Additionally, the use of practices like no-tillage and intercropping (Devarinti, 2016) to fulfil the consumers demand ensures reduced environmental stresses with improved quality of produce (Stein & Santini, 2021). In addition to improving the ecology, the technique reduces production risks by using homegrown fertilisers, fungicides, and insecticides (Kumar *et al.* 2020). In this day and age, people are reconnecting to their community through food by building local food networks (Duram, 2010). Local food systems involve short supply chains which are environment friendly due to direct contact between customers and producers as they might need less packaging and experience fewer food losses during the manufacturing and retail phases (Galli & Brunori, 2015; Tasca *et al.* 2017). Furthermore, the local food systems have a much bigger impact on social and economic benefits. In order to produce shared value for farms, localising food systems at a regional level requires the development of a competitive strategy, especially for small family farms that find it difficult to work with conventional food systems (Gibbons, 2020). Farming profitability can be achieved by improving crop yield, reducing cultivation costs, and increasing product prices. In spite of crop yield issues, NF has inadvertently reduced cultivation costs, thus being economically sustainable. Consequently, a higher farm income directly impacts the social well-being of the adopter-farmers (Kumar *et al.* 2020). By building local food networks, people are getting reconnected to their community through food (Duram, 2010).

10.1 Carbon Sequestration and Climate Resilience

Climate change is considered by many environmental activists as the greatest environmental challenge of our time, both because of its irreversibility and wide-ranging impact on people and ecosystems (Tal, 2018). Global temperatures are predicted to rise by 1.8 to 4.0 °C by 2100 as a result of climate change. A 100-fold increase in carbon dioxide is also anticipated by the year 2100 (Rajan *et al.* 2020). The dynamic change in climate results in alteration in crop productivity by severely affecting flowering, growth physiology and disease pest incidence, etc. Farmers in the nation are already dealing with the consequences of climate change in addition to the consequences from agricultural policies that were rescinded. Maintenance of soil health is crucial as changes in land use pattern and conventional farming methods have significantly degraded the soil, which has decreased India's GDP (Reddy, 2003; Bhattacharyya *et al.* 2015). According to forecasts, agricultural demand will increase by 50 per cent as compared to 2013, which calls for a transformation in our approach towards holistic practices, such as agro-ecology, conservative agriculture and climate-smart agriculture (FAO, 2017).

Carbon sequestration refers to the process of effectively lowering or completely removing CO_2 emissions from the atmosphere and storing it in another form that is productive for the ecosystem (IPCC, 2018). The removal of carbon from atmosphere by the plants occurs through the process of photosynthesis, in which CO_2 is stored in various photosynthetic or non-photosynthetic plant elements *viz*., trunk, stems, leaves, and roots. Approximately 416.14 ppm of GHGs in the atmosphere are attributed to CO_2 (NOAA, 2021). Land management practices (Lal 2018) and anthropogenic activities namely, fuel burning, agriculture and land use pattern (Friedlingstein *et al.* 2020) are the factors directly linked to the alteration in the carbon balance of the planet (Sharma *et al.* 2021). Net ecosystem carbon balance (NECB), ranging from 0.6 to 5.9 ton C/ha/year, suggests the possibility of carbon sequestration through long-lasting woody, leaf, fruit, and root structures (Scandellari *et al.* 2016). Furthermore, the decomposition of these components leads to carbon addition to soil C-pool, where it is stored and retained in the form of humus (Patil & Kumar, 2017; Cotrufo *et al.* 2019). As atmospheric CO_2 and global temperatures continue to rise, soil carbon inputs may be affected in a variety of ways, including changes in photosynthetic rates and respiration and decomposition. Plant respiration from increased root biomass and accelerated SOM decomposition may result in carbon loss (Hungate *et al.* 1997; Zak *et al.* 2000). Similarly, higher temperatures may affect the carbon balance by reducing the water availability and lowering photosynthetic rates (Ontl & Schulte, 2012).

Commercial fruit tree orchards can be used in both agricultural and degraded sites for carbon sequestration since they are recurrent crops that remain productive for decades (Rajan *et al.* 2020). Fruit trees are good at capturing carbon from the atmosphere and storing it as cellulose due to their heavy bearing ability (Patil & Kumar, 2017; Zade *et al.* 2020). According to Bhatnagar *et al.* (2016), fruit crops could accumulate carbon at a rate of 32-41 per cent, whereas, only about 25 per cent is stored in branches, stems, and twigs. Avocado, banana, citrus, mangosteen, and mango trees stimulate photosynthesis to increase biomass leading to enhanced carbon sequestration (Sharma *et al.* 2021). Farmers benefit from the effects of NF by imparting resilience to their crops against weather extremes. According to the studies, ZBNF can reduce groundwater extraction, recharge aquifers, and increase water levels. With the aid of organic carbon, minimal or no tillage, and plant diversity, soil structure has changed in a way that supports plant growth even in the face of extreme conditions like prolonged periods of drought and the ability to withstand severe flood damage and wind damage during cyclones (ICRAF-RySS, 2020). This is proved by the studies in Vishakhapatnam in which it was reported that ZBNF based paddy cultivation fared better against cyclonic winds than non-ZBNF paddy (Tripathi *et al.* 2018). In addition, ZBNF could reduce sediment and fertiliser runoff due to year-round soil coverage and lower chemical inputs, which would lessen eutrophication and enhance the quality of water (Rose *et al.* 2022). Intercropping is also recommended by ZBNF to boost crop diversification, which can enhance soil quality and mitigate pest risk (Sharma *et al.* 2017). Farmers also perceived that ZBNF plants had deeper roots that penetrated deeper into the soil, making them relatively stronger in comparison to other plants (Khurana & Kumar, 2020).

The impact of large-scale ZBNF adoption on GHG emissions is uncertain, however, a cut-back in fuel consumption, decrease in emissions linked to manufactured inputs, and lowering of N_2O production through reduced fertilizer use lead to reduced agricultural emissions per unit of cultivated area (Rose *et al.* 2021). The Life Cycle Analysis performed by Center for Study of Science, Technology and Policy (CSTEP) found that ZBNF systems reduce water usage by 50-60 per cent, energy usage by 45-70 per cent, and GHGs emission by 55-85 per cent (CSTEP, 2020). In India, the Government of Andhra Pradesh (GOAP) promotes ZBNF primarily because of the potential benefits it may bring in terms of adaptation and mitigation to climate change. In Andhra Pradesh, there are six agro-climatic zones and 13 districts characterized by varying rainfall, soil degradation, and cyclonic vulnerability. Reduced rainfall and higher temperatures are the main causes of Andhra Pradesh's agricultural sector's climate vulnerability, with each district's susceptibility depending on the projected consequences of climate change as well as its own climate sensitivity and ability to adapt. Agricultural practices such as excessive tillage, deforestation, imbalanced fertilizer use, and other unsustainable practices have contributed to soil degradation (Bhattacharyya *et al.* 2015). ZBNF proponents assert that it can aid farmers in reducing soil degradation caused by rainfall variability and can mitigate effects of climate change through reduced use of synthetic fertilizers and increased carbon sequestration. With 9.76 million USD spent on fertiliser subsidies in 2018-19, the GOAP is prompted to reduce water and fertiliser subsidies (Gupta *et al.* 2020). In the long run, ZBNF could result in healthier soil through soil carbon sequestration, increased soil water holding capacity, and by following climate resilient farming systems.

10.2 Case Studies

It is estimated that 1.71 lakh farmers in Himachal Pradesh are partially or fully engaged in natural farming (IANS 2022). A project report on revealed that 'Effect of SPNF inputs on growth performance, flowering and yield of strawberry cv. Sweet Charlie in coriander and fenugreek-based cropping system was published by Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan (HP), India. A review of the data revealed that varied SPNF inputs had a favorable effect on vegetative, production and microbiological parameters of strawberry. In the study, SPNF inputs namely, *Ghan-Jeevamrit* and *Jeevamrit* were applied as soil applications and *Agniaster* and *Bramashter* (500 ml/ 15 L water) as foliar sprays at 15 days interval. The results of the study demonstrated that vegetative growth and production parameters were significantly increased through application of *Ghan-Jeevamrit* @2.5 kg/m^2 + *Jeevamrit*-2.0 L/ m^2. Both plant height and number of flowers per plant reported 1.1 folds increase through application of treatment *Ghan-Jeevamrit* @ 5 kg/m^2 (T_2) over *Jeevamrit*-2.0 L/ m^2, which recorded the minimum values. The superior combination exhibited an increase of 14.9 and 13.0 per cent on fruit set and fruit yield respectively, over *Jeevamrit*-2.0 L/ m^2. The result also demonstrated that soil bacterial count (x 10^6 cfu) and fungi (x 10^3 cfu) were recorded maximum in *Ghan-Jeevamrit* @2.5 kg/m^2 + *Jeevamrit*-2.0 L/ m^2, whereas, AM fungal count was registered maximum in the combination of *Ghan-Jeevamrit* @ 2.5 kg/ m^2 + *Jeevamrit*-1.0 L/ m^2. Similarly, pomegranate cultivars namely, Kabuli Kandhari and Sindhuri were evaluated for horticultural traits under the SPNF system during 2020-2021. The results also depicted that the cultivar 'Sindhuri' exhibited the highest plant height (121.4 cm), canopy spread (84.2, 72.6 cm), and tree girth (10.6 cm). However, cultivar Kabuli Kandhari showed the maximum shoot growth (37.3 cm) when SPNF inputs such as *Jeevamrit* and *Ghan-Jeevamrit* were applied as soil application and *Agniaster* and *Bramashter* as foliar spray at 15-day intervals.

A study on 'Evaluation of Guava cultivars under SPNF system' was carried out during the year 2020-2021 on the cultivars, Lalit and Allahabad Safeda cultivars. Maximum plant height (121.8), trunk girth (6.3 cm), shoot growth (85.6 cm), number of primary branches (6.5), number of secondary branches (10.7) and number of fruits (6.0) were all reported for the cultivar Lalit. However, for the examined vegetative characteristics, both cultivars were statistically similar under applied SPNF inputs, namely *Jeevamrit* and *Ghan-Jeevamrit* as soil treatment and *Agniaster* and *Bramashter* as foliar spray applied at 15-days intervals. Furthermore, an assessment of horticultural traits was conducted on two apple cultivars namely, Gale Gala and Jeromine under SPNF system. The cultivar Gale Gala exhibited maximum plant height, canopy spread, and trunk girth. Both cultivars, however, showed similar results for canopy spread (north-south) and number of primary branches under applied SPNF inputs including *Jeevamrit* and *Ghan-Jeevamrit* as soil application and *Agniaster* and *Bramashter* as foliar sprays. A project report published on 'Impact of SPNF inputs and *Azolla* extract on cropping behaviour of strawberry cv. Sweet Charlie in guava-fenugreek-coriander based farming system. The data also indicated that the combined application of SPNF inputs and *Azolla* extract had a significantly positive effect on strawberry production parameters with increased plant height, leaf area, number of fruits and fruit yield exerted per cent increase of 72.9.

Acknowledgments: We are thankful to all the supporting staff of SPNF Unit of Dr YS Parmar University of Horticulture & Forestry for their valuable assistance time to time.
Funding: Not applicable
Ethics approval: All methods were in compliance with relevant institutional, national, and international guidelines and legislation.
Consent for publication: Not applicable.
Competing interests: All the authors declare that they have no competing interests for the publication of the manuscript.

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