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Can organic farming vis-à-vis natural farming sustain sugarcane yield in India?

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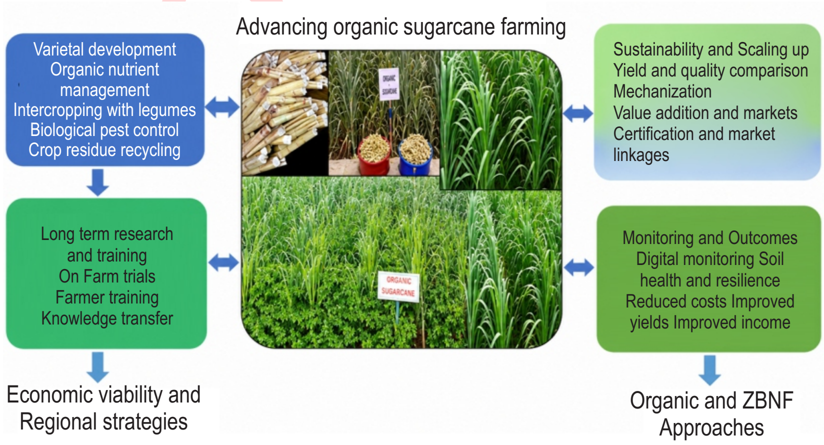
Abstract

The application of modern technologies in sugarcane agriculture has brought forth improvements in cane yield and sugar recovery. Sugarcane is a vegetatively propagated crop that responds well to organic sources of manure and fertiliser. In this series, multiple technologies, including planting methods, nutrient management (utilising organic sources of nutrients, bio-fertilisers, recycling of crop residues, and agro-industrial wastes), intercropping grain legumes with sugarcane, and biological control of insect pests, among others, significantly contribute to improving sugarcane yield besides protecting the soil-water-environment relationship.

Integrating these technologies will definitely play a significant role in maximising sugarcane yields at the field level. Beyond production, we can ascertain that the future of organic sugarcane farming lies in improving economic viability and scalability. Studies on comparative yield, quality, and profitability between organic and conventional systems are vital, alongside research on value addition, market linkages, and certification mechanisms. Mechanisation suited to organic systems, including low-disturbance planters and residue management tools, will enhance labour efficiency. Thus, organic and natural farming (Zero Budget Natural Farming) can sustain sugarcane production in India under appropriate conditions.

In organic farming systems, several researchers have reported higher yields (15-20%) and improvements in soil physical, chemical, and biological conditions. However, maintenance of soil organic carbon (>0.60%) is required for better yield response for a longer period. Natural farming is still at the testing stage, and no scientific reports in a sugarcane-based system are available. Although short-term yield penalties are common, they are often offset by cost savings and potential price premiums. Long-term soil and ecosystem benefits increase resilience and may close the yield gap over time. Countrywide scalability requires region-specific strategies rather than one-size-fits-all prescriptions.

Key words: Beejamrit, Bioagents, Green manuring, Organic farming, Sugarcane



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Introduction

Organic farming is a holistic approach to manage natural resources that support the physico-chemical and microbiological status of the soil, thereby sustaining crop yields and promoting soil health. It emphasises crop management practices that use only organic products, as well as other activities involving substantial use of organic manures, green manuring, and the management of pests and diseases through non-synthetic pesticides and practices. Thus, organic farming prohibits the use of harmful chemicals and promotes the use of renewable organic resources to sustain soil fertility and crop productivity (Gamage *et al.,* 2023). Sugarcane is a perennial crop that takes 12 to 16 months to mature. A 100-tonne crop from a one-hectare area removes about 208 kg N, 53 kg P and 280 kg K, besides removing 30 kg S, 3.4 kg Fe, 1.2 kg Mn, and 0.6 kg Cu. (Shukla *et al.,* 2017). The crop is also attacked by numerous insect pests and diseases throughout its life cycle. The most common insect pests causing 20-80 per cent yield loss in sugarcane have been reported, including top borer, early shoot borer, root borer, white grub, etc. (Kumar *et al.,* 2019). Thus, the use of chemical fertilisers or pesticides has become unavoidable in commercial agriculture.

The use of farm animals in agricultural operations is gradually decreasing. Therefore, the availability of organic manure (FYM) is also being reduced for farm use. Sugarcane cultivators near sugar mills also apply press mud cake (PMC) in their fields. About 10-12 t ha^{-1} of trash is produced annually by 100-ton sugarcane crops, which can be recycled into the subsequent ratoon crop. Sugarcane trash contains 33.3 to 36.1 per cent cellulose, 18.4 to 28.9 per cent hemicellulose, 26.1-40.7 per cent lignin, besides other ash and extractives (Canilha *et al.,* 2013). Trash mulching in sugarcane ratoon crop manages weed growth, conserves soil moisture, and improves soil physical condition by decreasing bulk density (Yadav *et al.,* 2009). After decomposition, the trash also adds some organic matter. Various bio-agents, such as symbiotic and asymbiotic N-fixers (e.g., *Gluconacetobacter diazotrophicus*), *Azotobacter* spp., and solubilisers (e.g., *Pseudomonas* spp., *Bacillus* spp.), are also available for use in organic farming (Shukla *et al.,* 2021).

The requirement for 25% N can be reduced by applying N-fixers and P-solubilisers (Shukla *et al.,* 2020). A application of these bio-agents with organic manures (FYM, PMC, etc.) or trash mulching has been found beneficial (Shukla *et al.,* 2012a). Studies have reported that intercropping of dual-purpose legumes such as French beans, peas, chickpeas and lentils with autumn sugarcane has improved nitrogen use efficiency (Shukla *et al.,* 2017; Nadeem *et al.,* 2020; Shukla *et al.,* 2022) and farm profits. Intercropping urd bean, moong bean, Sesbania and cowpea with spring-planted sugarcane has increased the available nutrient status and yield of the subsequent ratoon crop (Shukla *et al.*, 2017a). Intercropping leguminous crops such as chickpea, peas, lentil, French bean with autumn sugarcane, cowpea, moong bean and urd bean with spring sugarcane in subtropical India has been found beneficial in increasing the overall cane and sugar yields (both plant and ratoon crops), soil organic carbon and nutrient availability in the sugarcane (plant)-ratoon system (Shukla *et al.,* 2022). Bio-composting also enhances the nutrient composition of final product, which is used for agricultural purposes, compared to direct application of various cellulosic materials in fields (Chojnacka *et al.,* 2020). Among the sugar factory wastes, including press mud cake (PMC), molasses, and bagasse, PMC has a promising application in sugarcane fields (Shukla *et al.,* 2013). PMC contains high S content, along with NPK and other micronutrients (Shukla *et al.,* 2009). Thus, it has been found to be superior to FYM or compost due to higher nutrient content (Shukla *et al.,* 2013).

In the sugarcane system, sporadic implementation of Natural Farming is available. Various components of 'Natural Farming', such as no-tillage, no fertiliser use, no pesticides or herbicides, no weeding and no pruning (Fukuoka, 1987), each have their merits and demerits for raising sugarcane profitably. Kawaguchi also reiterated the components of Natural farming as do not plough the fields, weeds and insects are not your enemies, there is no need for fertilisers, and adjust the foods you grow based on your local climate and conditions. These principles are not entirely acceptable in profitable sugarcane farming. Currently, Zero Budget Natural Farming (ZBNF) is also being extensively discussed among the scientific community. The method involves mulching, intercropping, and the use of several preparations containing cow dung, cow urine, and other biological supplements available on fields/farms. These preparations are made on-farm and are said to promote microbial activity and increase earthworm populations. Indian agriculturist Subhash Palekar has researched and written extensively on this method. He recommended that one native Indian cow breed can serve a 30-acre (12 ha) area for natural farming (Khadse and Rosset, 2019). The main components of ZBNF include mulching (applying a layer of organic material to the soil surface), which prevents water loss through evaporation and contributes to the formation of soil humus.

They also involve waaphasa or soil aeration, through a favourable soil microclimate, aided by microbial culture. Various components of Natural Farming, such as cow dung, *desi* earthworms, *Beejamrit, Jeewamrit, Ghanjeewamrit,* Fafundnasi (Fungicide), Neemastra, Agniastra, Brahmastra, and Achchhadan (trash mulching), as well as multiple cropping, find a good scope for inclusion in organic farming. Thus, considering the potential and limitations of various categories of organic inputs and their applications, this research review focuses on the prospects of integrating components of Organic farming and Natural farming, based on the availability of resources in farmers' fields, for sustainable sugarcane production. Research conducted across different regions have also been analysed to draw valid conclusions for the benefit of sugarcane cultivators and sugar mills, and to develop a sustainable sugarcane production system. The feasibility of multiple components and their impact on soil quality parameters, crop yields and farm profitability has been discussed.

Components of Organic farming

Seed/ Sett treatment: Seed treatment can be performed in various ways to detect seed-borne infections. Sugarcane setts may be kept in hot water at 50°C for 2 hr to control red rot, grassy shoots and other viral diseases. In most hot-air treatments, setts are heated to 54°C and 99% relative humidity for 2 hr. Most hot-air treatments of sugarcane control seed-borne infections of grassy shoot disease, smut and red rot without adversely affecting germination (Singh *et al.,* 1980). Sugarcane setts may be dipped in a microbial inoculant solution prepared by mixing 5 kg of *Azotobacter/ Gluconacetobacter diazotrophic/ phosphate-solubilising bacteria* (PSB) inoculants in 100 l of water for 2 to 3 min just before planting. Shukla *et al.* (2011) in their study have discussed the effects of trash management, FYM (farmyard manure), bioagents and *Trichoderma* on improving the soil health and sugarcane ratoon yield. They reported that incorporating *Trichoderma* and trash increased soil organic carbon, enhanced nutrient uptake, and improved sugarcane yield.

Response to sugarcane planting methods vis-à-vis organic farming: In sugarcane, the root system shifts upward in subsequent ratoon crops. Organic foods contain nutrients in complex proteins, phospholipids and phytin compounds, which are slowly released after breakdown into simpler compounds (Alori *et al.,* 2017; Chojnacka *et al.,* 2020). It has been observed that the effect of FYM on sugarcane crops can persist for upto 3 years after application due to its slow nutrient release. The pit/trench planting method offers the potential for a deep root system due to its higher planting depth (30 cm). Thus, nutrient availability from organic sources improve due to the congenial rhizospheric environment created by breaking the hardpan in the plough layer. Additionally, these planting methods support multi-ratooning and prevent lodging in cane, even though the root system shifts in subsequent ratoon crops. Thus, sugarcane planting through trench or pit method improved the yield of both main crop and ratoon crops (Nadeem *et al.,* 2020; Rana *et al.,* 2023). Input use efficiencies (weed control efficiency, nutrient use efficiency and water use efficiency) also increased through the adoption of these planting methods. These methods promote the growth and development of mother shoots more than late-formed tillers. Thus, due to longer, heavier mother shoots, cane yield can be maximised by adopting these planting methods in organic farming.

Nutrient management

Organic manure/compost: Several researchers worldwide have demonstrated various benefits of applying FYM to soil properties and crop productivity (Shukla *et al.,* 2008; Prabhakar *et al.,* 2010; Srivastava *et al.,* 2018). Wet straw and manure from the animal sheds are collected daily and stored or composted on the farmer's premises. The composted manure is applied either immediately or stored until the next crop season, depending upon the farmer's socio-economic conditions. Thus, organic farming can provide high-quality food without harming soil health or the environment. There is a need to identify/products on a regional basis, suitable crops/products for organic production that meet international market demand (Yadav *et al.,* 2013).

It is estimated that nutrient requirements vary significantly from one location to another. Generally, in subtropical regions, recommendations such as 150-180 kg N ha^{-1}, 60-80 kg P_2O_5, and 60 kg K_2O ha^{-1} are followed. In the tropical areas, recommendations include 250-350 kg N ha^{-1}, 100 kg P_2O_5 ha^{-1}, and 80-120 kg K_2O ha^{-1}. In an organic farming system, the nutrients required for sugarcane crop can be fulfilled by applying approximately 10-15 tonnes ha^{-1} of FYM/compost or 5 tonnes ha^{-1} of composted press mud cake. Neem cake and groundnut cakes can also be used, considering their nutrient content and effectiveness. Neem cake, besides providing nutrients, also minimises the population of soil-borne pests. Soil application of *Gluconacetobacter diazotrophicus/ Azotobacter/ Azospirillum* @ 10 kg ha^{-1} containing cfu 107-109 contributes N in soil and supports crop growth (Shukla *et al.,* 2008; Yadav *et al.,* 2009). Besides, trash mulching along with the use of *Cluconacetobacter diazotrophicus* improved soil physical condition by decreasing bulk density (1.37 Mg m^{-3}), improving infiltration rate (4.40 mm hr^{-1}) and increasing the mean weight diameter of soil aggregates (0.69 mm) as compared to the control (Shukla *et al.,* 2012a). At ISRI Lucknow, sugarcane productivity and profitability has increased under the multi-ratooning system. The long-term effect of bio-manure addition on yield, soil quality, and carbon sequestration in the sugarcane plant-ratoon system increased the yield over the recommended fertilisers from 5^{th} to 9^{th} ratoon crop. Addition of biomanure enhanced soil quality by increasing SOC, infiltration rate (up to 47.5%), soil aggregates (up to 20.3%), soil microbial biomass carbon (SMBC), microbial biomass nitrogen (SMBN), and decreasing bulk density (up to 12.1%). The maximum increase in SOC (72%), SMBC (413.86%) and SMBN (113.88%) were registered with SPMC + Gd addition. A two-fold increase in the average annual rate of soil carbon sequestration was observed (1.05 to 2.97 t ha^{-1} yr^{-1}) compared with the control (0.49 t ha^{-1} yr^{-1}; Srivastava *et al.,* 2018).

Management practices that maintain or increase soil organic matter (SOM) have been considered sustainable. Organic matter acts as a primary binding agent between soil aggregates. The binding mechanisms of clay and organic matter affect aggregate stability (Shukla *et al.,* 2012a). The chemical bonding of organic compounds and the physical binding of particles by fungal hyphae and plant roots play essential roles in the fixation, release, and availability of nutrients to crops. Manure application improved the soil's nutrient status and increased soil organic carbon levels. It was also reported that manure application contributed to the accumulation of macroaggregate-protected carbon and nitrogen .

Crop residue management: Crop residue refers to the material left after the main product is extracted. Generally, two types of crop residues, *viz.,* field residues and industrial residues, are produced and available for utilisation in farmers' fields. Field residues of different crops include stalks and stubble (stems), leaves, seed pods, and other plant parts. Such residues can be incorporated directly into the ground and/or chopped and then buried. Proper management of field residues can increase irrigation efficiency and help control erosion. Industrial crop residues are materials left after crops are processed into usable resources. These residues include husks, seeds, roots, bagasse, molasses and press mud. They can be used as animal fodder, soil amendment, fertilisers, and in manufacturing. The trash application regulates the rhizospheric environment and enhances the population of soil microbes, including bacteria, fungi and actinomycetes (Shukla *et al.,* 2012a, b; Yadav *et al.,* 2009).

Yadav *et al.* (2009) at ISRI, Lucknow recorded the maximum net increase in soil organic carbon (SOC) over the initial level with trash mulch + *T. viride* (5.08 Mg ha^{-1}). It was followed by trash burn + *T. viride* (4.71 Mg ha^{-1}) and trash removal + *T. viride* (3.56 Mg ha^{-1}). The higher SOC under trash mulch, particularly when combined with *T. viride*, may be attributed to continuous addition and decomposition of organic residues, greater carbon input, and enhanced microbial activity associated with *Trichoderma*. Overall, the results demonstrated that retention of sugarcane trash as mulch in combination with *T. viride* was the most effective practice for improving SOC accumulation and maintaining soil carbon status, whereas trash removal without *Trichoderma* resulted in least improvement.

Industrial sugar crop residue can also be recycled. Sugarcane industrial crop residues, including bagasse, molasses, and press mud cake (PMC), can be utilised to improve soil fertility and produce bioenergy. There are various ways to use the residues appropriately. Composting is one of the best ways. It includes the 'Traditional method of composting'. Composting is an approach to anaerobic decomposition and/or aerobic decomposition based on passive aeration, achieved through measures such as infrequent turnings or static aeration provisions, including perforated poles or pipes. It is a time-consuming process that can take several months to decompose. On the other hand, 'Advanced composting methods or Rapid methods' make use of the treatments introduced recently, such as aerobic decomposition process that reduces the composting period four to five weeks. Kannan (2020) at TNAU, Coimbatore, reported that *in-situ* trash composting reduced the EC, OC and C:N ratio, while increased the N content. Field soil analysis indicated an increase in the primary nutrient content.

Biofertilizers/ bioagents/ seaweed extracts: *Gluconacetobacter diazotrophicusis* a new class of biofertilizer possess excellent biological nitrogen fixation property in sugarcane with a non-inhibitory effect of NO_3-N under microaerophilic conditions. This bacterium is an endophytefound in sugarcane roots, stalks, leaves and trash and can fix substantial amounts of nitrogen (Suman *et al.,* 2001). Diazotrophs living on plant surfaces or as endophytic bacteria may improve crop productivity by producing plant growth-regulating substances, supplying nitrogen, or both. In ratoon crops, the addition of organic matter through trash, root biomass, and rhizodeposition may increase the effectiveness of *Gluconacetobacter diazotrophicus. Trichoderma* spp. are among the most commonly isolated soil fungi. Because of their ability to protect plants and contain pathogen populations under different soil conditions, these fungi have been commercially marketed as biopesticides, biofertilizers and soil amendments (Shukla *et al.,* 2011, 2012a). *Trichoderma* spp. also produce numerous biologically active compounds, including cell-wall-degrading enzymes and secondary metabolites (Vinale *et al.,* 2008). At ISRI Lucknow, carbon sequestration has been improved by 2.64 Mg ha^{-1} yr^{-1} through trash mulching and *Trichoderma* application in the sugarcane-based system (Shukla *et al.,* 2017b).

Intercropping of pulses with sugarcane: Intercropping pulses with sugarcane offers the potential to increase the area and productivity of pulse crops in irrigated agroecosystems (Shukla *et al.,* 2022). Diversification through inclusion of pulses support farmers' multiple needs and generates mid-season income (Shukla *et al.,* 2017a, b). Intercropping legumes maintain soil fertility and reverse organic carbon depletion (Shukla *et al.,* 2022). Fixed nitrogen can be utilized by growing sugarcane crops, and benefits can be derived in subsequent ratoon crops as well, thereby the nitrogen requirement of subsequent ratoon crops can be reduced. Cultivating sugarcane in wide row spacing (more than 120 cm) offers ample scope for intercropping in autumn sugarcane with minimum crop competition between the main crop and component crop.

Intercropping of pulses, *viz.,* rajmash, chickpea and lentil, with autumn (October)-planted cane in the furrow-irrigated raised-bed system (FIRBS) is well-suited and improve crop yields. Sugarcane in the FIRB system can be grown in furrows, and intercrops can be planted on raised beds. This system offers excellent scope to increase crop yield and minimise input use. At ISRI Lucknow, intercropping French beans with autumn sugarcane was found to be the most profitable option, yielding the highest B:C ratio (Singh *et al.,* 2002). Intercropping two rows of French bean (PDR-14) showed a distinctly positive effect on sugarcane growth, similar to potato crop. Intercropping chickpea with autumn sugarcane reduced nitrogen use by 25% (Shukla *et al.*, 2017a). Thus, input use efficiencies (NUE, WCE, WUE) and the land equivalent ratio (LER) can be improved through intercropping pulse crops with sugarcane. At ISRI Lucknow, intercropping lentils (DPL 15) in two rows and inoculating with *Azospirillum* produced the highest sugarcane equivalent.

Use of sugar factory wastes

Press mud cake: Sugarcane press mud is a byproduct of sugar industry, characterized by a soft, spongy, amorphous, dark brown to brownish material. It is produced during the purification of sugar, either by carbonation or solvent extraction. Both processes separate clear juice from the top and mud from the bottom. Generally, after crushing 100 tons of sugarcane, about three tons of press mud is produced. Typically, it is considered waste material from sugarcane industries, causing storage problems and polluting the surroundings of sugar mills due to open storage.

It contains sugar, which facilitates its decomposition under field conditions (Dotaniya *et al.,* 2013a, b). It is an excellent source of plant nutrients improves soil water-holding capacity and soil chemical properties after application, providing nutrients to crop plants. Generally, the amount of sugar press mud produced depends on the sugar filtration process. It contains 50–70% moisture, which is most favourable for soil microorganisms, especially earthworms. It also contains significant amounts of iron, manganese, calcium, magnesium, silicon and phosphorus, thereby enhancing SPM's suitability as a source of plant nutrients (Yadav and Solomon, 2006). At ISRI Lucknow, the application of PSB + PMC moderately increased the shoot population density in ratoon cane. Ratoon yield improved by 15.86% with the application of PSB + PMC over control (67.86 tons ha^{-1}; Shukla and Yadav, 2011). At ISRI Lucknow, application of composted press mud cake improved the infiltration rate to 5.4 mm hr^{-1}, decreased the soil bulk density (1.36 Mg m^{-3}) and increased nutrients (NPK) availability in sugarcane ratoon crop (Shukla *et al.,* 2013).

Bagasse ash: The quantity of sugarcane bagasse ash produced is 0.3% on a cane-weight basis. Spreading in the field as a fertiliser has been the usual practice of its disposal, as it is a rich source of silica, potash, iron oxide, and lime. Bagasse ash, a byproduct of sugar industry, alone as well as with farmyard manure, was examined as an alternate carrier for *Azotobacter chroococcum*. The high water-holding capacity and rich nutrient content of mixed carrier supported the growth and survival of *Azotobacter* (Suman *et al.,* 2002).

Spent wash: Distillery effluent, also known as wastewater from distillery industry, is of purely plant origin and contains a large number of nutrients. Spent wash is also known as liquid spent wash, slops, vinasse, or stillage in different countries. Due to high manure value, it is being used as a soil conditioner. Additionally, it serves as a reclaiming agent or a liquid fertiliser. Diluted spent wash, when applied to soil, improved the soil pH and EC values, increasing the status of total nitrogen, available P and K and total K. Additionally, it improved the soil physical parameters (Narain *et al.,* 2012).

Molasses: Water remediation treatment– Molasses is commonly used in water remediation treatment to maintain the biological efficiency of pollution control process.

Anaerobic digesters: Due to increased pressure to use renewable energy sources and find suitable ways to dispose of particular organic wastes, anaerobic digestion is gaining popularity for the production of biogas. Biogas can be burned to produce heat and electricity, while the digested material can be used as a soil conditioner. Molasses and related co-products are excellent high-energy liquids that can improve the plant's overall efficiency and generate significant biogas.

Liquid fertilisers: Molasses and related co-product liquids provide a valuable source of nutrients, promoting healthy plant growth and enhanced levels of beneficial soil microorganisms. The natural origin of these liquids offer growers an attractive alternative to conventionally manufactured fertilisers (Abofard *et al.,* 2021).

Biocontrol of insect pests and diseases: Sugarcane is an annual crop and is attacked by several insect pests and diseases. They can cause economic and qualitative damage to sugarcane crop and even crop products. Managing insect pests and diseases in sugarcane crops is crucial, and selecting an effective strategy is equally important (Hussain *et al.*, 2018). The insect pests like borers (early shoot borer *Chilo infuscatellus* Snellen, internode borer *Chilo sacchariphagus indicus* (Kapur), top borer *Scirpophaga excerptalis* (Walker), stalk borer *Chiloauricilius* Dudgeon, root borer *Emmalocera depressella* Swinhoe, Gurdaspur borer *Acigona steniellus* (Hampson) and Plassey borer *Chilo tumidicostalis* Hampson), sucking pests (foliage feeders, pyrilla *Pyrilla perpusilla* Walker, woolly aphid *Ceratovacuna lanigera* Zehntner, whitefly *Aleurolobus barodensis* Maskell *Cavelerius excavatus* Distant, black bug *Cavelerius excavatus* Distant, web mite *Schizotetranychus andropogoni* (Hirst), scale insect *Melanaspis glomerata* (Green) and mealy bug *Saccharicoccus sacchari* (Cockerell)), subterranean pests (termite (Cockerell) and white grub *Holotrichia consanguinea* Blanchard (major species), and non-insect pests (rodents *Bandicota bengalensis* and mites *Schizotetranychus* and *ropogoni*) are commonly affected sugarcane crop. For the management of insect pests, ecologically based approaches should be adopted, such as selecting resistant varieties, timely irrigation, mechanical removal of damaging pest stages and crop residues, earthing-up, tying and propping of cane stalks, and the release of natural enemies. Similarly, sugarcane diseases are caused by fungi, bacteria, viruses and nematodes. Among these, the contribution of fungal diseases is significant. These diseases must be managed at early stages of infection; else they may cause economic damage to the crop and reduce product quality. As mentioned above, botanicals and biocontrol agents are used alongside insect pest management approaches to control insect pests.

Natural farming: Natural farming, also referred to as "the natural way of farming", is an ecological farming approach established by Masanobu Fukuoka (Fukuoka,1987). Fukuoka, a Japanese farmer and philosopher, introduced the term in his book 'The One-Straw Revolution '. Various components of Natural Farming are being followed at several locations in India. Kawaguchi's recognition outside Japan has widened since his appearance as the central character in the documentary "Final Straw: Food, Earth, Happiness," which led to his interviews being translated into several languages. Natural farming recognizes the soil as a fundamental natural asset. Ancient soils possess physical and chemical properties that enable them to support abundant life. It can be argued that tilling degrades the delicate balance of a climax soil. Tilling may destroy the crucial physical characteristics of soil, such as its ability to retain water even during dry spells. A study suggests that reduced tillage preserves crop residues on the soil surface, enabling easy formation of organic matter. As a result, the total organic carbon and nitrogen content increased compared to conventional tillage. Increased levels of organic carbon and nitrogen support higher populations of aerobic, facultative anaerobic and anaerobic bacteria (Sylvia *et al.,* 1999). Tillage over-pumps oxygen into the local soil, benefiting residents such as bacteria and fungi. As a result, the chemistry changes. Biological decomposition accelerates, and the microbiota mass increases at the expense of other organic matter. Tilling uproots all the plants in the area, turning their roots into food for bacteria and fungi. This damages their ability to aerate the soil. Some types of roots contribute directly to soil fertility by forming symbiotic relationships with certain bacteria (*Rhizobium* and *Gluconacetobacter*) that can fix nitrogen.

Zero Budget Farming: Zero Budget Farming is a variation of natural farming, developed in the Southern India and primarily practised there. It is also called spiritual farming. The method involves mulching, intercropping and several preparations, including cowdung. These on-site preparations are central to the practice and are said to promote microbial and earthworm activity in the soil. In this context, a study was conducted to assess if this practice has reduced production cost and doubled farmers' incomes. ZBNF has been found to partially improve the soil health compared to non-adopters' lands, possibly due to rapid development of heterotrophic microbial communities and flora. Numerous studies have demonstrated the capacity to enhance soil microbes for nitrogen fixation and phosphorus solubilization through application of organic manure containing cow urine. The farmers cited the ability to produce chemical-free food and reduce costs associated with fertilisers and pesticides as a primary reason for adopting ZBNF. However, acceptance of technology is possible only if the farmers' net returns and the impact on consumer prices are well documented.

Other components of natural farming: Natural farming is different from organic farming. In organic farming, crop nutrition and crop protection are managed organically. However, in Natural farming, all practices revolve around the use of no external inputs, and the nutritional and protection aspects are also taken care of by farm resources and products generated/developed on the farm. Thus, Natural Farming is a form of agriculture, whereas organic farming refers to the use of inputs derived from organic sources. The main components of natural farming have been discussed by Moses Shyam *et al.* (2019).

The seed/seedling treatment 'Beejamrit' is considered to protect young roots from fungal and soil-borne diseases, as well as to provide a small number of essential nutrients to the soil (Smith *et al.,* 2020). *Beejamrit* is also used for seed treatment purposes in different crops. Treatment of sugarcane setts can also be done using Beejamrit to detect fungal-borne diseases. However, dilution will be required to treat the sugarcane setts. In 200 l of water, sugarcane setts can be treated for planting in a one-acre area through *'Beejamrit'* prepared as above. Jeewamrit is considered an ocean of microbes. Mandrewar *et al.* (2025) indicated that the Jivamrut-treated field showed significant improvements in sugarcane growth and soil quality as compared to untreated field. This study highlights the potential of Jivamrut as a sustainable, eco-friendly alternative to chemical fertilisers, boosting agricultural productivity and soil health. Gurjar *et al.* (2024) reported improved soil organic carbon, available nitrogen, phosphorus, and potassium after the application of Jeevamrit fortified with vermi tea or neem cake. The efficacy of fortified Jeevamrit could be further improved by adding a consortium of biofertilizers, including PSB, *Azotobacter* or VAM fungi. The treatments also significantly enhanced soil microbial activity.

Trash mulching and multiple cropping are also two other components of Natural farming. However, these are well-accepted in the organic farming system and have been discussed previously. Trash mulching increases earthworm populations, in addition to other functions such as controlling weeds, conserving moisture, and regulating rhizospheric temperatures. Following the principles of crop rotation in multiple cropping systems is necessary. The component crop and the main crop should coexist. Thus, water and nutrients are depleted in different soil layers. The main crop should not face any physical competition during the growth phase. The duration of both crops in the intercropping system should differ, allowing the main crop sufficient time for vegetative growth. In this series, the intercropping of pulses with autumn sugarcane is the best option.

Future Research Priorities in Organic/Natural Sugarcane: Future research in organic and natural sugarcane production should focus on breeding and identifying sugarcane varieties specifically suited to low-input organic conditions and developing region-specific integrated organic crop management packages. These technologies need to be validated through systematic multi-location trials under diverse agro-climatic conditions. Greater emphasis is required on understanding nutrient dynamics, carbon balance, soil organic matter build-up, and effective integration of biofertilizers in organic production systems. Long-term studies are also required to assess changes in the soil health, biological activity, and microbial ecology under natural farming inputs. Research should further address eco-friendly pest and disease management strategies and develop reliable forecasting models. Strengthening organic seed cane production, rapid multiplication, quality assurance, and certification systems will be essential for wider adoption. Improving water-use efficiency through micro-irrigation, along with residue-based moisture conservation practices, should also receive priority. In addition, research should evaluate the productivity, profitability, value addition, processing potential, and market linkages of organic sugarcane to ensure economic viability for farmers. Finally, greater emphasis should be given to farm mechanization, participatory on-farm research, and use of digital technologies for crop monitoring, decision support, and efficient management of organic and natural sugarcane production systems.

Summary and Conclusion: Natural and organic farming in sugarcane offers a sustainable, eco-friendly, and resource-efficient production pathway. The long-term success of organic sugarcane farming depends on its economic viability and scalability. Comparative studies on yield, quality, and profitability of organic versus conventional systems, along with research on value addition, market linkages and certification mechanisms, are essential. Mechanization compatible with organic systems can improve labour efficiency, while long-term on-farm participatory research will support technology refinement and farmer adoption. Establishing measurable monitoring and evaluation indicators supported by digital tools will ensure continuous system improvement. With region-specific strategies, organic and natural (ZBNF) farming can sustainably support sugarcane production in India, where short-term yield reduction may be offset by lower costs, price premiums, and long-term gains in soil health and resilience.

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