

Millet Production in Semi-arid Tropics With Help of Only Tree Leaves and Its Components - a New Focus

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Research Article

Keywords: Tree based farming, veganic technique, tree leaf extracts, foliar sprays, phytocompounds, kodomillet

Posted Date: October 21st, 2025

DOI: <https://doi.org/10.21203/rs.3.rs-3583740/v2>

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Additional Declarations: The authors declare no competing interests.

Abstract

We are pushed to produce eco-friendly foods. This research presents an innovative crop production method that uses only trees, their parts and byproducts to care, protect plants and maintain soil health. Leaves of legumes are known to improve soil fertility, while tree leaf extracts from some native tree species can contribute to foliar nutrition as well as protection against diseases and pests. Study compared novel tree-based crop production practice (vrikshayurvedic farming) with standard crop production guide practices (CPG) and zero-input (do-nothing) practices in kodomillet for two years during *Rabi* season (November-February) 2020-21 and 2021-22 at experimental farm. Biometric observations (plant height and leaf area index), soil health indicators (Organic carbon, nutrient status, microbial load) and economic efficiency of systems were also evaluated. Comparatively more nitrogen and SOC were available in soil when using tree leaf biomass than using CPG practice. Soil enrichment with the use of tree leaves especially *Gliricidia sepium* and 4-times foliar application of *Annona squamosa* leaf extracts recorded maximum pooled grain (974) and straw yields (2887 kg ha⁻¹), with below 10% yield penalty compared to CPG practice, with maximum monetary benefits.

Introduction

The inappropriate usage of agrochemicals in traditional and modern agriculture, calls for a shift to adopt sensible agricultural practices. On the one hand, climate change threatens food security, but., on the other hand, millets thrive in peripheral areas with scarce water resources, low nutrient requirements, low pest and disease frequencies and they can even adapt to hot and dry climates. The need for sustainable and chemical-free cultivation of food grains is therefore increasing the demand for millets produced using traditional techniques. Since 2023 was declared the International Year of Millet, 20 different species are grown worldwide. The oldest crop known to mankind is kodomillet, a C4 plant with its low transpiration ratio supports agriculture and food security in semi-arid climates.

Indian Ancient texts

The Indian Rig-Veda and the Atharva-Veda have older references to the Vrikshayurveda, (Indian botany) which is a term used to denote knowledge regarding plant life and is akin to ayurveda for plants. Several treatises like Surapala's Vrikshayurveda, Amarsimha's Amarkosha, Patanjali's Mahabhasya, Krishi-Parashara, Varahamihira, and Birhat Samhita and other ancient texts viz., Varahamitra, 505 AD., Birhat Samhita, *Vrikshayurveda* Part I, Chapter 55 (edited by M. Ramakrishna Bhat, Motilal Banarasidas, Bangalore, India 1950); Chaundarya, 1025 A.D. Lokopakaran, *Vrikshayurveda*, chapter 6 (edited by H. Shesha lyengar, Government central Manuscripts library, Chennai, India 1950); Sarangadhara, 1363 A.D. *Vrikshayurveda* (edited by S.K. Ramachandra Rao, Kalpatharu Research Academy, P.O. Box 1857, Bangalore, 1993, India) discusses about this ancient science of crop production. It contains information on various aspects of plant science like soil analysis, genetic variability, seed testing, green manure, liquid biofertilizers *etc.* An English translation was published in 1996 by the Asian Agri-History Foundation. A recent publication, "Vrikshayurvedic farming: Traditional Indian Agriculture," demonstrated how *Vrikshayurvedic* practices have been validated through science to create high-quality food, called as *Vrikshayurvedic* farming aka. low budget naturalway farming [1].

Significance of Millets

Small-seeded annual millets are grown for food, forage, and fuel. Over 20 different types of millet have been cultivated worldwide. The most widely grown millets are pearl millet (*Pennisetum glaucum* L.R. Br.) and finger millet (*Eleusine coracana* L. Gaertn) and five nutri-millets like barnyard millet (*Echinochloa frumentacea* Roxb.Link), little millet (*Panicum sumatrense*), kodomillet (*Paspalum scrobiculatum*), prosomillet (*Panicum miliaceum* L.), foxtail millet (*Setaria italica* L. Beauv.). Millet, the sixth most important cereal globally, supports over one-third of the world's population [2]. mainly produced in Asia and Africa.

In addition to CHO, plants need essential elements such as N, P, K; Secondary nutrients (Ca, Mg, S) and trace elements (Zn, Cu, Fe, Mo, Cl, Mn) for their growth. Generally, these nutrients are absorbed from soil or supplied through external application of fertilizers. Tree leaves generally rich in nutrients and phytochemicals that stimulate plant growth and can also protect against diseases and pests. Keeping this in mind. this field research was conducted with the objectives of evolving tree-based crop production (***Vrikshayurvedic farming***) protocols for cultivation of kodomillet (*Paspalum scrobiculatum* L.) in semi-arid climates and compare with zero input (do-nothing) and conventional crop production guide [3] recommendations.

Materials and Methods

Site description and weather conditions

The field research was conducted at Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai (9°54' N, 78°54' E, and 147 m MSL) situated in southern agro-climatic zone of Tamil Nadu, India The site experiences a mean annual rainfall (mean of 30 years) of 846 mm over 43 rainy days with mean maximum and minimum temperatures of 33.3 °C and 24.1°C, respectively. The Field topography was medium; the soil was sandy clay loam in texture belonging to *Madukkur* series and taxonomically as (*Typichapustalf.*) The experimental site was kept fallow for the previous two seasons.

Tree sources for soil enrichment

Leaves of the following leguminous trees were incorporated into the soil before crop sowing.

1. *Albizia lebbek* (L.) Benth: Fabaceae, tropical and subtropical tree. 18–30 m tall
2. *Delonix regia* (Boj.) Raf. (flamboyant), Fabaceae, native to Madagascar tropical / subtropical regions. 10 – 15m tall.
3. *Gliricidia sepium* (Jacq.) Kunth ex Walp., Fabaceae, perennial, medium-sized (2-15 m high) Deciduous in dry season, evergreen in moist areas.

4. *Peltophorum pterocarpum* (DC.) Backer ex K. Heyne, - Golden or yellow flamboyant; Syn. *Peltophorum inermis* and *Peltophorum ferrugineum*) Fabaceae, tropical South-Eastern Asia, ornamental tree. Deciduous tree, 15-25 m height
5. *Pongamia pinnata* (L.) Pierre, Fabaceae. 15–25 m tall, wide canopy, known as *Millettia pinnata*.

The leaf nitrogen content (on air dry basis) was analyzed using an automated Kjelpplus N analyser and it revealed leaf N content in leaves of *Albizia lebbek* (1.85%); *Delonix regia* (2.56%); *Gliricidia sepium* (2.81%); *Peltophorum ferrugineum* (2.17%) and *Pongamia pinnata* (1.75%).

Trees used for foliar spray

The leaf extracts of the following tree species were used which have the potential of acting as biostimulant and protectant.

S ₁	<i>Morinda tinctoria</i> Roxb.	Rubiaceae	Nuna
S ₂	<i>Mangifera indica</i> L.	Anacardiaceae	Mango
S ₃	<i>Moringa oleifera</i> Lam.	Moringaceae	Moringa/Drumstick
S ₄	<i>Aegle marmellos</i> (L.) Correa	Rutaceae	Vilvam/Bael
S ₅	<i>Annona squamosa</i>	Annonaceae	Custard apple

The composition of micronutrients (Iron, Zinc, Manganese and copper) present in tree leaves used for subplot treatments were analyzed using Atomic Absorption

Preparation of fresh leaf extract for foliar spray

Fresh leaf extracts were prepared by grinding fresh leaves with distilled water at (1:1 ratio) in a clean mixer grinder, filtered and used as a stock solution. A 5% solution was made from the stock and subjected to seed fortification and leaf tea spray [1]. During crop growth, foliar nutrition with 5% Leaf tea spray was given thrice during critical stages. i.e., tillering, flag leaf, and booting, inflorescence development.

GCMS analysis

A methodical lab investigation was done to identify and characterize the phytochemicals present in tree leaves used for foliar sprays by Gas Chromatography-Mass Spectroscopy, with extracts obtained using dichloromethane, water, and methanol to identify the metabolites involved in plant growth and development.

Soil analysis

Soil samples from the top 15 cm were collected before seeding and analyzed for different physical and chemical properties, as presented here. In each year after crop harvest, collected four soil samples per block using an auger, were air-dried, ground, and passed through 2.0 mm sieve for physico-chemical analysis. Soil organic carbon (SOC) was analyzed using Walkley-Black method [4]. Soil available nitrogen (SAN) by alkaline-potassium permanganate method [5]; soil available phosphorus (SAP) by Olsen method [6] and soil available potassium by ammonium acetate method [7].

Field experimental design and treatment applications

Two consecutive field trials (2020-2021 and 2021 -2022) were laid out during late *Rabi* (November-February) at experimental farm to compare performance of tree-based farming practices with conventional practices by adopting standard crop production guide [7] procedures and zero input (do-nothing) practice in kodomillet.

Main plot treatments: Tree leaf biomass at N equivalence (dry weight basis) to supply 44 kg Nitrogen ha⁻¹ as recommended in CPG was incorporated six weeks before seeding.

- M₁ - *Albizia lebbek* (L.) Benth (1.38 t ha⁻¹)
- M₂ - *Delonix regia* Boj.ex Hook (1.42 t ha⁻¹)
- M₃ - *Gliricidia sepium* (jacq.) Steud (1.46 t ha⁻¹)
- M₄ - *Peltophorum ferrugineum* (Decne.) Benth (1.37 t ha⁻¹)
- M₅ - *Pongamia pinnata* (L.) (1.67 t ha⁻¹)

Sub plot treatments: Tree leaf extracts were applied as foliar sprays

- S₁ - *Aegle marmellos* (L.) Correa
- S₂ - *Annona squamosa* (L.)

S₃ - *Mangifera indica* (L.)

S₄ - *Moringa oleifera* Lam

S₅ - *Morinda tinctoria* Roxb

Note: Four foliar sprays with respective tree leaf extracts @ 5% concentration were given in line with different critical stages of crop growth.

A total of 25 treatment combinations were involved (M₁S₁, M₁S₂, M₁S₃.....M₅S₅). Before seeding, leaf biomass was incorporated during field preparation, and the field was left undisturbed for 6 weeks to facilitate decomposition of applied leaf litter [8]. Kodomillet variety CO3 seeds, fortified with tree leaf extracts (as per subplot treatments) and sown.

Comparison plots: Two separate plots were maintained outside the experimental layout: one with conventional scientific practices as per CPG (44:22:0 NPK kg ha⁻¹) (<https://agritech.tnau.ac.in/pdf/AGRICULTURE.pdf>) and another with zero input practice, field was just prepared and seeds were sown on the same day along with treatment plots. Kodomillet cv. CO 3 invented by Tamil Nadu Agricultural University was sown at a seed rate of 10 kg ha⁻¹ in the espacements of 22.5 x 10 cm.

Biometrical observations

Observations on growth and yield parameters, including plant height and LAI were recorded at different stages using ten representative plant samples (1 m² area) in the experimental block. Both grain (seed) and straw yields were recorded based on whole plot sampling. The plant height was measured from ground level to the terminal leaves of that plant. LAI was recorded as per [17] and the data presented and discussed.

Statistics and design

The experiment was set up in a randomised split-plot design with two replications. Field was divided into main plots and subplots to study their interaction effects on crop growth and yield. Main plot will house one component and the subplot will house another factor. Data from triplicate samples were analyzed using excel 2019 and statistical analysis of experimental data among different treatments was performed using IRRI STAR software, following the method of [9] for split plot design. Least significant differences (L.S.D.) were calculated for the field experiment with a probability of 5% (p<0.05).

Economics

Cost of cultivation, gross return, and net return were calculated using current input costs and market prices as suggested by [10]. Total cost of cultivation was expressed in Indian National Rupees (Rs. ha⁻¹). Gross return (Rs. ha⁻¹) based on economic yield and current market price for inputs and outputs and Net return (Rs ha⁻¹) was arrived by deducting the total cost from Gross returns.

Results

The experimental results of the two field trails are discussed below. Plant height, an indicator of plant vertical growth and vigour, is associated with life cycle, seed mass and maturity. In this investigation, plant height of kodomillet was measured at tillering and panicle initiation stages. Table (1) showed minimal variation between treatments at tillering stage and taller plants were seen in M₄S₂ (31.47 cm) and (33.90 cm) in both the years respectively, statistically comparable (p<0.05) to M₄S₄, M₅S₁, M₅S₄, M₅S₃, M₄S₅, M₅S₂, M₄S₄ using the least significant difference of 4.41 and 2.66 for the respective years. At panicle initiation, M₄S₄ recorded the tallest plants (47.66) during first year and M3S4 (78.86) in second year.

Table 1. Kodomillet plant height (cm)

Treatments / Year	Plant height at tillering stage			Plant height at panicle initiation stage		
	20201-21	2021-22	Mean	20201-21	2021-22	mean
M ₁ S ₁	21.62	30.35	26.0	35.18	77.5	38.1
M ₁ S ₂	24.37	31.55	28.0	44.56	76.41	41.0
M ₁ S ₃	15.47	31.95	23.7	40.69	71.99	36.8
M ₁ S ₄	23.41	33.85	28.6	24.97	76.53	37.5
M ₁ S ₅	26.57	28.85	27.7	43.02	77.86	40.8
M ₂ S ₁	29.19	32.30	30.7	44.27	74.25	42.2
M ₂ S ₂	29.10	31.90	30.5	42.15	76.68	42.1
M ₂ S ₃	20.42	32.20	26.3	33.98	72.02	37.0
M ₂ S ₄	20.52	29.05	24.8	29.5	72.14	35.2
M ₂ S ₅	14.42	31.05	22.7	40.58	75.93	36.9
M ₃ S ₁	21.74	30.50	26.1	38.06	70.57	37.4
M ₃ S ₂	29.11	32.60	30.9	30.75	75.56	39.8
M ₃ S ₃	26.56	31.80	29.2	41.96	73.9	40.7
M ₃ S ₄	30.37	32.05	31.2	41.41	78.86	42.8
M ₃ S ₅	27.39	31.50	29.4	36.92	71.19	39.3
M ₄ S ₁	28.33	28.10	28.2	29.2	70.49	36.9
M ₄ S ₂	31.47	33.90	32.7	24.29	69.08	38.3
M ₄ S ₃	27.74	32.55	30.1	23.66	73.8	37.6
M ₄ S ₄	31.04	29.50	30.3	47.66	66.19	40.9
M ₄ S ₅	30.63	30.85	30.7	28.05	70.34	38.1
M ₅ S ₁	29.48	28.90	29.2	33.02	74.47	39.0
M ₅ S ₂	30.77	34.30	32.5	37.76	69.95	41.1
M ₅ S ₃	30.38	28.20	29.3	29.87	67.49	37.0
M ₅ S ₄	30.29	28.65	29.5	31.6	67.39	37.5
M ₅ S ₅	29.19	32.95	31.1	39.62	71.84	40.9
L.S.D (p<0.05)	4.41	2.66		8.66	2	
S.Ed	2.13	5.55		4.2	4.19	
S.Em	0.426	1.11		0.84	0.83	

Main plot: Tree leaf biomass: M₁ – *Albizia lebbek* / M₂ – *Delonix regia*/ M₃ – *Gliricidia sepium* M₄ – *Peltophorum ferrugineum*/ M₅ – *Pongamia pinnata*; **Sub plot:** Foliar spray S- *Aegle marmellos* / S₂ -*Annona squamosa* / S₃ - *Mangifera indica* / S₄ – *Moringa oleifera* / S₅ - *Morinda tinctoria*

The main plot, sub plot and their interactions registered a statistically positive significant interaction for plant height of kodomillet at tillering and panicle initiation stages. while main plot treatments showed minimal differences in plant height at tillering, except for M₅, and others were comparable. The height growth response was mixed between stages and years, due to the reflection of soil and growth factors. but remained statistically significant and though values are apart from each other, yet are comparable at harvest. Tallest plant (76.06 cm) was noticed in M₁ with no statistical significance among subplot treatments. The interaction was significant at both stages of observations. At the outset, main plot treatments viz., M₁, M₂ and M₃ positively influenced the vertical growth. It confirms that due to nitrogen release from leaf litter decomposition which in turn influenced height of kodomillet.

Table 2. Leaf Area Index of kodomillet

Treatments / Year	LAI at tillering stage			LAI at panicle initiation stage		
	2020-21	2021-22	mean	2020-21	2021-22	mean
M ₁ S ₁	0.17	1.81	0.99	0.44	1.38	0.96
M ₁ S ₂	0.18	1.69	0.18	0.66	2.17	0.80
M ₁ S ₃	0.1	1.52	0.81	1.52	1.55	1.10
M ₁ S ₄	0.38	1.74	1.06	0.27	1.56	1.00
M ₁ S ₅	0.21	1.7	0.96	1.67	1.89	1.29
M ₂ S ₁	0.53	2.07	1.30	1.37	1.69	1.39
M ₂ S ₂	0.50	1.9	1.20	0.77	1.81	1.24
M ₂ S ₃	0.19	1.91	1.05	0.97	2.1	1.24
M ₂ S ₄	0.14	1.58	0.86	0.55	1.34	0.89
M ₂ S ₅	0.10	1.81	0.96	1.13	2.11	1.22
M ₃ S ₁	0.13	2.04	1.09	0.98	2.18	1.28
M ₃ S ₂	0.51	2.01	1.26	0.87	2.12	1.35
M ₃ S ₃	0.37	2.27	1.32	0.41	1.71	1.22
M ₃ S ₄	0.71	2.01	1.36	0.76	1.4	1.25
M ₃ S ₅	0.34	1.68	1.01	0.79	1.82	1.13
M ₄ S ₁	0.26	1.88	1.07	0.33	1.81	1.07
M ₄ S ₂	0.54	2.28	1.41	0.15	1.36	1.15
M ₄ S ₃	0.53	2.21	1.37	0.14	1.28	1.11
M ₄ S ₄	0.81	1.16	0.99	1.47	1	1.09
M ₄ S ₅	0.71	1.53	1.12	0.24	1.8	1.08
M ₅ S ₁	0.45	1.13	0.79	0.48	1.61	0.89
M ₅ S ₂	0.58	2.54	1.56	0.54	1.71	1.39
M ₅ S ₃	0.46	1.35	0.91	0.39	1.81	0.98
M ₅ S ₄	0.42	1.46	0.94	0.39	1.54	0.95
M ₅ S ₅	0.46	1.99	1.23	0.59	1.59	1.17
L.S.D (p<0.05)	0.31	0.04		0.38	0.05	
S.Ed	0.15	0.1		0.19	0.1	
S.Em	0.03	0.02		0.038	0.02	

LAI is a plant growth rate indicator, expresses the leaf area per unit ground area of a single plant. Maximum LAI of 0.81 was observed in M₄S₄ at tillering stage in the first year and it was on a par with half of the other treatments except for a few. The minimum was noticed in M₂S₅ and M₁S₃. At panicle initiation stage, a maximum LAI of 1.67 was observed in M₄S₄ which was on a par with M₂S₁, M₁S₅ and M₁S₃. During second year, significant interactions were observed across main plot, sub plot and also their interactions at tillering and panicle initiation stages. Among subplot S₂ had maximum LAI at tillering (2.08) and panicle initiation stage (1.83), which are statistically significant to other subplot treatments. M₃ exhibited the highest LAI at both stages in main plot. Regarding interactions, greatest LAI of 2.18 was recorded in M₃S₁ which is comparable to M₃S₂ at panicle initiation stage (Table 2).

Table 3 Influence of different farming practices on crop yields

Treatments / Year	Grain yield (kg ha ⁻¹)			Straw yield (kg ha ⁻¹)		
	2020-21	2021-22	mean	2020-21	2021-22	Mean
M ₁ S ₁	645	755	700.0	1932	2260	1258.4
M ₁ S ₂	600	702	651.0	1724	2017	1138.8
M ₁ S ₃	700	819	759.5	1945	2275	1299.7
M ₁ S ₄	801	937	869.0	2164	2531	1460.4
M ₁ S ₅	698	817	757.5	1865	2182	1263.9
M ₂ S ₁	758	887	822.5	1978	2314	1351.9
M ₂ S ₂	725	848	786.5	1965	2299	1324.7
M ₂ S ₃	585	684	634.5	1595	1866	1072.9
M ₂ S ₄	535	626	580.5	1489	1742	994.5
M ₂ S ₅	717	839	778.0	1845	2158	1267.4
M ₃ S ₁	632	739	685.5	1797	2102	1191.1
M ₃ S ₂	898	1050	974.0	2661	3113	1739.2
M ₃ S ₃	835	977	906.0	2485	2907	1622.0
M ₃ S ₄	698	816	757.0	1842	2155	1253.6
M ₃ S ₅	798	934	866.0	2085	2439	1424.4
M ₄ S ₁	408	477	442.5	1412	1652	878.3
M ₄ S ₂	825	965	895.0	2763	2362	1562.0
M ₄ S ₃	448	524	486.0	1714	1465	927.4
M ₄ S ₄	432	505	468.5	1687	1442	906.9
M ₄ S ₅	570	667	618.5	2763	1482	1220.1
M ₅ S ₁	418	489	453.5	1638	1400	879.7
M ₅ S ₂	862	1008	935.0	2962	2532	1659.8
M ₅ S ₃	594	694	644.0	1971	1685	1117.6
M ₅ S ₄	575	672	623.5	1737	1485	1018.5
M ₅ S ₅	465	544	504.5	1698	1452	932.7
L.S.D(p<0.05)	27.72	32.4		75.42	88.2	
S.Ed	13.79	16.1		37.5	43.9	
S.Em	2.76	3.22		7.5	8.78	

With respect to economic output of kodomillet table (3) revealed, grain yield ranged between 408 to 898 kg ha⁻¹ in first year with the highest grain yield (898 kg ha⁻¹) achieved in treatment M₃S₂, i.e. leaf biomass transfer of *Gliricidia sepium* and foliar spraying of leaf extracts of *Annona squamosa* four times during crop growth. It was followed by M₅S₂ (863 kg ha⁻¹), which is comparable to M₃S₃. In second year, grain yield ranged between 477 and 1050 kg ha⁻¹ with a statistically significant (p<0.05), highest grain yield (1050 kg ha⁻¹) was realized from same treatment M₃S₂, (*Gliricidia sepium* + *Annona squamosa*). It was followed by M₅S₂ (1008 kg ha⁻¹), which is comparable to M₃S₃ (977 kg ha⁻¹).

As regards straw yield, it ranged between 1400 to 2661 kg ha⁻¹ and a statistically significant (p<0.05) and a maximum yield of 2661 kg ha⁻¹ was realized from the treatment M₃S₂ during first year. It was followed by M₅S₂ (2532 kg ha⁻¹), which is comparable to M₃S₃. During second year, it ranged between 1638 to 3113 kg ha⁻¹, with the highest yield of 3113 kg ha⁻¹ was realized from the treatment M₃S₂. It was followed by M₅S₂ (2962 kg ha⁻¹), which is comparable to M₃S₃ (2907 kg ha⁻¹).

Table 4. Growth and yield performance of Kodomillet under CPG and Zero input practices.

Parameters	2020-21		2021-22	
	CPG	Zero Input	CPG	Zero Input
Grain yield (kg ha ⁻¹)	945	195	1087	215
Straw yield (kg ha ⁻¹)	2885	807	3181	887
Panicle length (cm)	8.01	4.68	9.01	4.78
No. of panicles	13.68	7.00	15.68	7.90
Plant height at harvest (cm)	71.02	51.55	72.08	57.55

Regarding comparison plots, during first year, conventional scientific method (CPG) produced an estimated grain yield of 945 kg ha⁻¹ and a straw yield of 2885 kg ha⁻¹, while zero input yielded 195 kg of grains and 807 kg of straw/ha. During second year, CPG Practices produced 1087 kg ha⁻¹ of grains and 3181 kg ha⁻¹ of straw. while zero input yielded about 215 kg of grains and 887 kg of straw per hectare of land.

Pooled analysis of grain yield

Vrikshayurvedic farming (Tree based) practices significantly influenced yield and yield parameters. (Figures 1&2) showed a positive and significant impact on both grain and straw yields. The pooled analysis on grain yield reflected that, incorporating tree leaf biomass of *Gliricidia sepium* six weeks before sowing and four-time foliar spraying of *Annona squamosa* leaf extract at 5% concentration gave a pooled maximum mean grain yield of 974 kg ha⁻¹. The next best was *Mangifera indica* 5% leaf extract, yielded 906 kg ha⁻¹ of grains. The same combo performed better in terms of straw yields also with 2887 and 2696 kg ha⁻¹, respectively.

Analysis on soil nutrient status

Table (5,6) showed the analysis of soil available nutrients, revealed that, the application of tree leaf biomass resulted in higher available N P and SOC at harvest compared to CPG recommendations. The SOC increased from time zero to end, indicating the ability of tree leaf biomass in building soil organic carbon content. However, available K increased, while other nutrients decreased in CPG plots at harvest.

Table 5. Time zero and end values of soil nutrients during first year

	Soil Available N (kg ha ⁻¹)		Soil available P (kg ha ⁻¹)		Soil available K (kg ha ⁻¹)		SOC g kg ⁻¹	
	Time Zero value	End value	Time Zero value	End value	Time Zero value	End value	Time Zero value	End value
Leaf biomass								
M1	216*	232.3	19	18.2	260	270.2	6.0	6.4
M2	216	236.4	19	17.6	260	253.4	6.0	6.8
M3	216	242.3	19	19.3	260	248.3	6.0	7.0
M4	216	238.8	19	18.9	260	236.4	6.0	6.3
M5	216	248.4	19	17.9	260	222.6	6.0	6.6
CPG	216	225.2	19	12.8	260	281	5.4	5.2

*data not statistically analyzed

Table 6. Time zero and end values of soil nutrients during second year

	Soil Available N (kg ha ⁻¹)		Soil available P (kg ha ⁻¹)		Soil available K (kg ha ⁻¹)		SOC (g kg ⁻¹)	
Leaf biomass	Time Zero value	End value	Time Zero value	End value	Time Zero value	End value	Time Zero value	End value
M1	223.8	240.7	15.2	14.6	246.7	256.4	5.8	6.1
M2	223.8	244.9	15.2	14.1	246.7	240.4	5.8	6.1
M3	223.8	251.0	15.2	15.4	246.7	235.6	5.8	6.8
M4	223.8	247.4	15.2	15.1	246.7	224.3	5.8	6.3
M5	223.8	257.4	15.2	14.3	246.7	211.2	5.8	6.6
CPG	223.8	251.3	15.2	10.2	246.7	266.6	5.0	5.2

*data not statistically analysed

From Table (6 & 7) it is inferred that, the application of tree leaf biomass had comparatively higher SOC than CPG recommendation. with slight increment in SOC content which may influenced by changes in soil microbial load.

Table 7. Soil microbial status of the experimental field

	Bacteria population		Fungi		Actinomycetes population	
Leaf biomass	Time Zero value#	End value	Time Zero value#	End value	Time Zero value#	End value
M1	35.4	44.2	34.4	36.2	29.4	30.3
M2	39.3	52.4	31.7	33.4	32.2	33.2
M3	43.7	53.3	31.5	33.2	33.3	34.3
M4	45.0	56.3	29.1	30.6	30.7	31.6
M5	30.6	43.1	30.7	32.3	31.4	32.4
CPG	38.8	39.6	31.4	32.07	30.2	32.36

*data not statistically analyzed

Same treatments were adopted for previous crop, hence variations in values among treatments

The incorporation of tree leaf biomass consistently increased SOC, regardless of the litter source highlighting the importance of organic matter, especially tree leaves which undergo decomposition, also influenced the soil microbial counts. Generally, the bacterial population changed greatly than other two organisms indicating that effective organic fertility management should focus on providing long-term nourishment for the soil's microbial life. Crop diversity, including legume rotations and the use of legume tree leaves, further boosts soil carbon and nutrient availability, as SOC acts as an energy source for active proliferation of microorganisms in soil and increasing nutritional availability to crops [11].

Comparison of three different practices

Comparison of kodomillet yields in three systems is presented in Fig. (3). Two- year mean grain yield under CPG practice was 1016 kg ha⁻¹ while, zero input practice yielded 40 percent less of CPG. But, best performing *Vrikshayurvedic* farming practice, *Gliricidia sepium* as tree leaf biomass and *Annona squamosa* as seed fortifier and foliar spray, showed a yield reduction of 4.13% than CPG and 55% increase over zero input farming. It clearly demonstrated that reduction in yield was meagre. *Mangifera indica* foliar spray also outperformed with 55.3% yield increase over do-nothing practice and 10.3% lower than CPG. The next best tree leaf biomass was *Albizia lebbek*. Generally, grain yield showed an increasing trend from first to second crop. With expectations of continued growth from third season/year onwards and, in a span of 3-4 years yield from any organic way of crop production potentially matching the conventional yield on sustainable manner. As regards straw yield, trends mirrored grain yield with the highest of 2887 kg ha⁻¹ under the *Gliricidia sepium* and *Annona squamosa* combo.

Economics

The cost of cultivation, gross returns and net returns were calculated for tree based (*vrikshayurvedic*) farming, CPG and zero input systems using pooled data to assess monetary benefits.

Table 8. Pooled analysis for economics in terms of Net returns – Descending order

Treatments	Grain yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)	Gross returns Rs/ha	Cost of cultivation (Rs/ha)	Net returns Rs/ha)	Return of rupee invested
M ₃ S ₂	974	2887	54292	17700	36592	2.07
M ₅ S ₂	935	2747	52112	17700	34412	1.94
M ₃ S ₃	906	2696	50504	17700	32804	1.85
M ₄ S ₂	895	2563	49866	17700	32166	1.82
M ₁ S ₄	869	2348	48382	17700	30682	1.73
M ₃ S ₅	866	2262	48196	17700	30496	1.72
M ₂ S ₁	822	2146	45747	17700	28047	1.58
M ₂ S ₂	787	2132	43818	17700	26118	1.48
CPG	1016	3033	56638	30756	25882	0.84
M ₂ S ₅	778	2002	43291	17700	25591	1.45
M ₁ S ₃	760	2110	42328	17700	24628	1.39
M ₁ S ₅	757	2024	42141	17700	24441	1.38
M ₃ S ₄	757	1999	42135	17700	24435	1.38
M ₁ S ₁	700	2096	39024	17700	21324	1.20
M ₃ S ₁	686	1950	38218	17700	20518	1.16
M ₁ S ₂	651	1871	36273	17700	18573	1.05
M ₅ S ₃	644	1828	35877	17700	18177	1.03
M ₂ S ₃	635	1731	35358	17700	17658	1.00
M ₅ S ₄	624	1611	34723	17700	17023	0.96
M ₄ S ₅	618	1608	34392	17700	16692	0.94
M ₂ S ₄	581	1616	32359	17700	14659	0.83
M ₅ S ₅	505	1575	28169	17700	10469	0.59
M ₄ S ₃	486	1590	27128	17700	9428	0.53
M ₄ S ₄	469	1565	26186	17700	8486	0.48
M ₅ S ₁	453	1519	25295	17700	7595	0.43
M ₄ S ₁	443	1532	24748	17700	7048	0.40
ZI	205	847	11487	5250	5937	1.13

*Cost of grains as per market value- Rs.55/kg; Straw cost Rs. 0.25/kg

Discussions

Climate change poses challenges like rising temperatures water scarcity, and malnutrition. In the future, millets would become vital global food grains due to their adaptability to hot, dry conditions including low fertile soils, low pest and disease prevalence, and minimal nutrient requirements. Growing food security needs in developing countries undeniably boosting millet demand, making it an economic crop for trade. Additionally, millet is a nutritious, gluten-free ingredient rich in B vitamins and minerals, often lacking in gluten-free products, this research was designed to addressed the scientific cultivation of kodomillet in semi-arid areas.

This research aimed to utilize traditional natural resources and knowledge to increase the food grain productivity and quality from traditional agricultural achieving sustainable yield equivalent to modern scientific agriculture. Generally, growth and physiological parameters were assessed through plant height, leaf area index, straw yield and grain yield. The study found that plant height, LAI and yields were greater when tree leaf biomass was incorporated and foliar sprays with tree leaf extracts. This could be due to continuous and subsequent availability of nutrient supply from decomposed tree leaf biomass, which promoting cell division and elongation, thereby increasing plant growth.

Similarly, grain and straw yield reflects the crop return on inputs. This study revealed *Gliricidia sepium* leaf biomass incorporation conjoint with four foliar sprays of *Annona squamosa* and *Mangifera indica* at 5% concentration yielded the highest among Vrikshayurveda treatments in both years. Improvement in field emergence by botanical leaf extracts could be ascribed to cell activation, resulted in enhancement of mitochondrial activity and producing high energy compounds and vital bio-molecules during early phase of germination. [12][13]. Application of tree extracts @ 5% increased growth and yield attributes of kodomillet. likely due to growth hormones and micronutrients, (table 9), present in leaf extracts, which support growth and yield across various crops ranging from cereals to oilseeds.

The combinations of *Gliricidia sepium* leaf biomass and four foliar sprays of *Annona squamosa* or *Mangifera indica* leaf extracts yielded almost equally to CPG practice, with a reduction of less than 10%, indicating a modest yield decline. This could be due to mobilization of organically bound nutrients into inorganic forms through microbial decomposition, leading to an increase in soil organic carbon, leads to increase in soil fertility and nutrient availability. The role of trees in increasing soil productivity is well documented [14], a pioneer and eminent scientist in agroforestry research. Vrikshayurvedic practices, involving tree leaf biomass incorporation and facilitating their decomposition over a period of 6 weeks, combined with tree leaf extracts, enhance nutrient uptake, boosting photosynthetic activity, biomass production and N supply during flowering and pod filling phases. Foliar spray with tree leaf extracts containing macro- and micronutrients and growth hormones promote nutrient uptake from the soil and enhanced the metabolic activity of the plants (table 10).

Our team [15] identified various phytochemicals in milli-Q water leaf extracts of tree species through GCMS analysis with area percentage., *Mangifera indica* leaf had Catechol (15.50%), Cyclohexanone, 2-pentyl- (15.05%), 2-Dodecylcyclobutanone (11.84%), Catechol (11.13%) and 1,2-Cyclohexanediol (8.78%) with retention time of 13.241, 16.986, 17.527, 13.375 and 9.035 minutes. *Annona squamosa* leaf extracts had Benzofuran, 2, 3-dihydro (21.48%) with a retention time of 13.550 min, Benzeneethanol, 4-hydroxy (13.13%) with a retention time of 19.408 min, and 9-Oxa-bicyclo[3.3.1]nonane-1,4-diol (10.18%) with a retention time of 22.697 min. while *Moringa* leaf had 25 components, abundant phytochemicals were, 2-Piperidinone, 2-Pyrrolidinone, Catechol, Catechol and Benzene ethanamine with 26.50%, 11.92%, 9.33%, 8.74% and 7.56% retention time. We also found that alkaloids (32%) and phenolic compounds (24%) were major secondary metabolites in moringa leaf. Similarly, *Annona* leaves had 25% phenolics, 16% terpenoids, and 12% fatty acids, whereas *Mango* leaves contained 24% phenols and 32% other derivatives. Development of active substances for plant-based foliar nutrition and plant protectants. with *Annona* extracts considerably improved germination and seedling development.

Another plausible reason is the highest soil available nutrients in *Vrikshayurvedic* farming, as evidenced from this study, and also due to better soil physico-chemical properties due to higher microbial activity, nutrient mobilization and root activity in rhizosphere soil. During mineralization, microorganisms convert organically bound nutrients to inorganic form, enhancing nutrient availability.

Table 9. Micronutrient content in tree leaves used for foliar spray

Tree species	Iron (Fe)	Zinc (Zn)	Copper (Cu)	Manganese (Mn)
<i>Morinda tinctoria</i>	1.35	0.40	0.19	1.80
<i>Mangifera indica</i>	1.49	0.23	0.14	0.54
<i>Moringa oleifera</i>	1.23	0.30	0.27	0.49
<i>Aegle marmellos</i>	1.06	0.20	0.17	0.24
<i>Annona squamosa</i>	1.93	0.31	0.18	0.80

Table 10. Principal compounds present in leaf tea spray through GC-MS analysis

S.No	Tree species	Dichloromethane	Methanol	Water extract
1.	<i>Morinda tinctoria</i>	Squalene – 49.61% Phytol – 22.94%	Phytol – 39.10% Cholest-5-en-3-ol (3. beta.)-carbonochloridate – 17.11%	9-Oxa-bicyclo [3.3.1] nonane-1,4-diol - 15.90% 1-Heptatriacotanol - 9.14
2.	<i>Mangifera indica</i>	Vitamin E – 14.48% Bis (2-ethylhexyl) phthalate – 11.45%	Hexanoic acid, 2-ethylhexyl ester – 29.53% 4H-Pyran-4-one, 2,3-dihydro-3,5-dihydroxy-6-m – 24.24%	Catechol - 15.50% Cyclohexanone, 2-pentyl - 15.05%
3.	<i>Moringa oleifera</i>	9,12,15-Octadecatrienoic acid, ethyl ester – 10.96% Tetrapentacontane – 8.62%	Octadec-9-enoic acid – 74.03% n-Hexadecanoic acid – 15.17%	2-Piperidinone - 26.50% 2-Pyrrolidinone - 11.92%
4.	<i>Aegle marmellos</i>	Lup-20(29)-en-3-ol, acetate, (3.beta.) – 18.14% Phytol – 5.82%	Caryophyllene – 20.44% Phytol – 15.82%	cis-9-Hexadecenal - 14.08% 1H-1,2,4-Triazole-1-acetic acid, methyl ester - 11.99%
5.	<i>Annona squamosa</i>	Ethyl Oleate – 37.01% Hexadecanoic acid,	Phytol – 25.93% 11-octadecenoic acid, methyl ester – 18.92%	Benzofuran, 2,3-dihydro - 21.48% Benzeneethanol, 4-hydroxy - 13.13%

In addition to discussed above qualities, another reason for better kodomillet performance under vrikshayurvedic practices is due to leaf nutrient content and phytocompounds. Our study supported this concept because tree leaves used for foliar nutrition contained micronutrients (Table 9) and various other growth-promoting phytocompounds (Table 10).

Sangeetha [13] found that kodomillet seeds fortified with 5% *Moringa oleifera* leaf extract showed enhanced germination and root length, While *Mangifera indica* @5% extract showed improved seedling vigour index I and II. However, all three leaf extracts positively impacted germination related metrics and biochemical modifications in kodomillet, as measured by response index (RI). As a result, research findings scientifically confirmed tree leaf extracts as growth bio-stimulant in crop production enabling chemical-free, high-quality food grains in kodomillet compared to synthetic treatments Vrikshayurvedic farming studies [12] with *Delonix regia* leaf biomass and 5% *Moringa oleifera* spray showed growth and yield parameters comparable to conventional practices (RDF @ 25:50:25 NPK kg ha⁻¹ and spray with DAP 2% twice @ 30 and 45 DAS) in blackgram. It is inferred that vrikshayurveda treatments improved plant growth, DMP, seed yield, pod yield equivalent to conventional practice and superior to do-nothing practice. It also helps to improve and maintain long term soil. Recent publication [16] showed, agrochemical-free, high-quality foodgrains in prosomillet is achievable by Vrikshayurvedic practice with biomass transfer of *Albizia lebbek* and *Gliricidia sepium* on nitrogen equivalent basis and leaf tea spray (LTS) with leaf extracts of *Mangifera indica* and *Moringa oleifera* at 5% showed <10% in yield reduction, compared to conventional CPG practice.

Conclusions

Vrikshayurvedic farming with *Gliricidia sepium* (jacq.) Steud leaf biomass and four foliar sprays of *Annona squamosa* (L.) extract yielded 974 kg ha⁻¹ of grain and 2887 kg ha⁻¹ of straw with a meagre reduction (10%) in yield compared to conventional CPG practice. Application of tree leaf biomass improved higher available nitrogen and increased SOC in soil by 1.0 g kg⁻¹.

Our team has conducted many field studies and highlight the potential of such novel approaches, inspiring researchers to explore India's natural resources. This scientific validation of those information paves the way for new agricultural research era, offering an alternative way of crop production similar to organic farming what we call the "Tree Leaf Revolution".

Statements and Declarations

Authors Contributions:

CS conceptualized and supervised the experiment; PN, SK recorded biometric observations and conducted soil and plant analysis; KS assisted in data analysis. CS wrote and improved the manuscript and KS edited it.

Acknowledgement:

We thank Tamil Nadu Agricultural University, Centre of Innovation, Madurai and Agronomy GOI-DST-FIST lab for providing facilities.

Conflicts of interest statement:

The authors declare no conflicts of interest.

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Figures

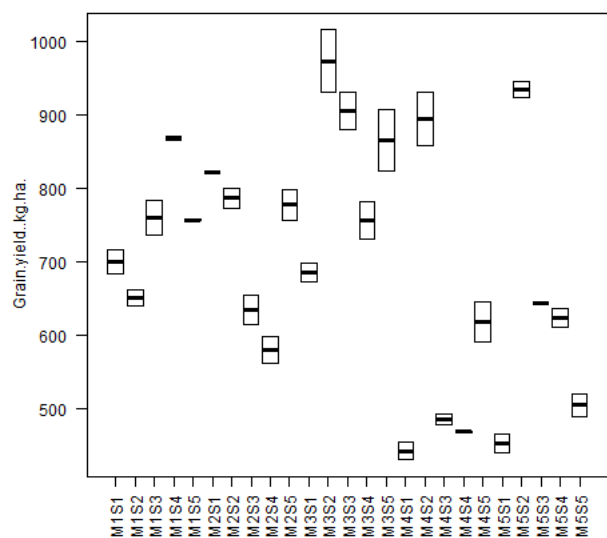


Figure 1

Box plot for grain Pooled analysis

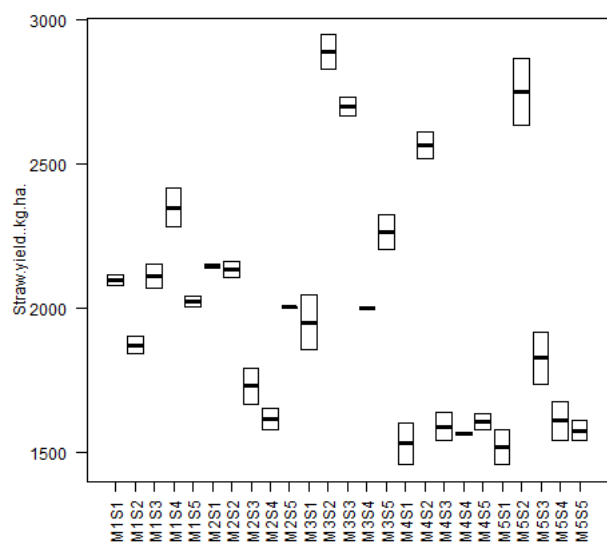


Figure 2

Box plot for grain Pooled analysis

Fig. 3. Comparison of kodomillet yields in three systems

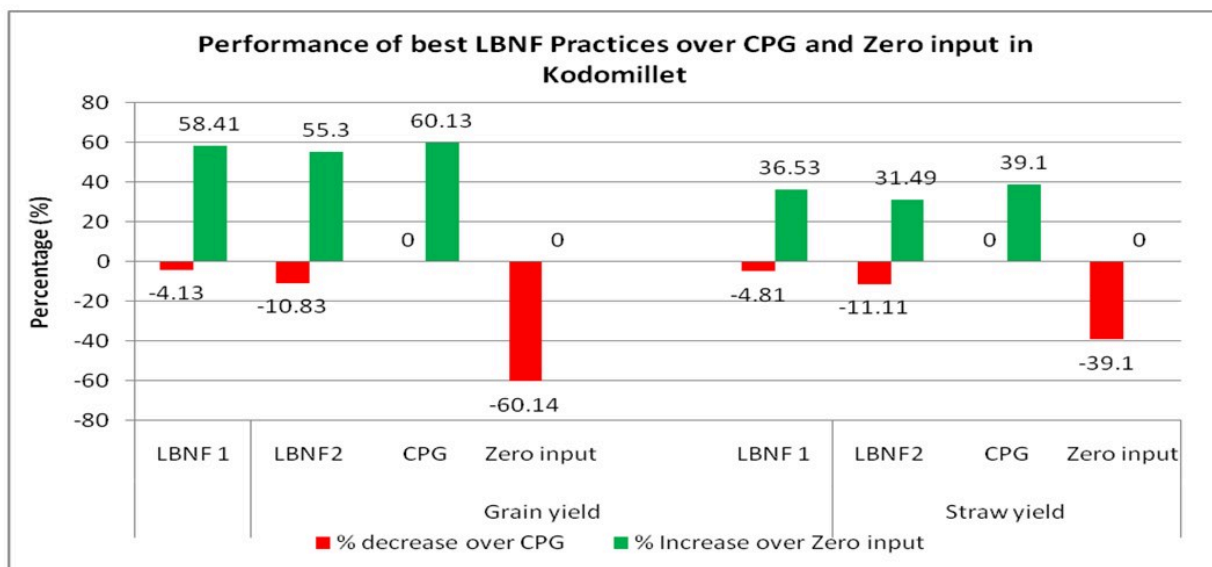


Figure 3

Comparison of kodomillet yields in three systems