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Studies on effects of organic traditional leather waste on soil properties, quality and yield of selected crop

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Abstract

The utilization of organic amendments in agriculture has gained significant attention due to their potential to improve soil fertility, enhance crop quality, and promote sustainable farming practices. This study investigates the effects of organic traditional leather waste on soil properties, quality, and yield of grapes (*Vitis vinifera*). The research was conducted in Pimpalgaon Baswant, Nashik District, Maharashtra, India, using a randomized complete block design (RCBD) with three treatment categories: A1 (Solid + Water in 15 DIAP, Drenching), A2 (Solid + Water in 30 DIAP, Drenching), and B (Only Solid in 15 DIAP, Sub-Soil Application). Soil samples were analyzed for physicochemical properties, nutrient content, and microbial activity before and after organic waste application. Plant growth parameters, biochemical composition of leaves, and fruit yield quality were assessed. The results indicate that organic traditional leather waste significantly improved soil fertility, with notable increases in organic carbon (1.3% at 600 g/Plant), nitrogen (298 Kg/ha), phosphorus (17.667 Kg/ha), and potassium (245 Kg/ha). Morphological parameters such as shoot length (168.8 cm at 600 g/Plant), cane diameter, and internodal distance showed significant improvements compared to control. Biochemical analysis revealed increased chlorophyll (1.038 mg/g), protein (0.632 mg/g), and reducing sugar (0.514 mg/g) content in treated plants. Yield parameters improved significantly, with the highest TSS (24.76° Brix) and yield per hectare (53.09 tonnes at 100 g/Plant) observed in sub-soil treatments. These findings suggest that organic traditional leather waste enhances soil health, improves crop productivity, and can serve as an effective alternative to synthetic fertilizers, contributing to sustainable agricultural practices.

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Introduction

The study of organic soil amendments has gained significant attention in sustainable agriculture due to their role in enhancing soil fertility, improving plant growth, and increasing crop yield (Singh *et al.*, 2018). Organic traditional leather waste, a byproduct of the leather processing industry, remains largely underutilized despite its nutrient-rich composition. This study investigates the effects of organic traditional leather waste on soil properties, quality, and yield of selected crops, particularly grapes (*Vitis vinifera*), which are among the most valuable horticultural crops cultivated in India.

Grapes are a major commercial crop in India, thriving in diverse climatic conditions and soil types. Maharashtra leads in grape production, accounting for 62.7% of total production, followed by Karnataka (26.7%), Tamil Nadu (4.3%), Andhra Pradesh (2.2%), Mizoram (1.7%), and other states (2.4%) (Indian Horticultural Database, 2011). The major grape-growing regions in Maharashtra include Ahmednagar, Pune, Sangli, Nashik, and Solapur. Farmers employ various fertilizers, pesticides, and plant growth regulators to enhance grape quality and yield (Patil *et al.*, 2019). However, conventional chemical fertilizers often degrade soil quality over time, leading to decreased organic matter and disrupted soil microbial balance (Kumar and Patel, 2018). Therefore, sustainable organic alternatives, such as organic traditional leather waste, may serve as an effective solution to enhance soil fertility and crop productivity.

Organic traditional leather waste originates from rural cobbler communities engaged in small-scale leather processing. The processing involves treating animal skins with lime, water, and occasional salt treatment, followed by prolonged decomposition. This natural degradation process produces organic waste enriched with nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and micronutrients essential for plant growth (Sharma *et al.*, 2020). Unlike synthetic fertilizers, organic amendments release nutrients gradually, improving soil structure, microbial activity, and moisture retention (Gupta *et al.*, 2019).

Prior research has demonstrated that organic amendments improve soil fertility and crop yield. A study by Chang-An Liu *et al.* (2016) on a field pea-spring wheat-potato rotation system reported that nitrogen and phosphorus fertilization increased crop yield by 3.1 times in calcareous soils. Similarly, Dhruve *et al.* (2010) found that organic silicon-based amendments enhanced fruit length, weight, and lycopene content in tomatoes (*Solanum lycopersicum*). Further, Tolera Abera *et al.* (2017) demonstrated that nitrogen fertilizer significantly increased maize grain yield and nitrogen accumulation in plant tissues.

Organic fertilizers have also been found to improve soil microbial communities, enzyme activity, and nutrient cycling (Meena *et al.*, 2021). Studies on municipal waste compost (MWC) and nitrogen fertilizers have shown enhanced tomato growth and mineral composition (Majid Rajaie and Amir Reza Tavakoly, 2016). Additionally, the application of organic foliar treatments such as Silixol has been linked to increased fruit set and reduced pest damage in crops like chili (*Capsicum annuum* L.) (Dhruve *et al.*, 2009). These findings indicate the potential of organic traditional leather waste as an eco-friendly and nutrient-rich alternative to chemical fertilizers.

This study aims to evaluate the effects of organic traditional leather waste on soil properties, crop growth, and yield performance through drenching and sub-soil application methods. The research objectives are:

1. To assess the physicochemical properties of soil before and after organic waste application.
2. To analyze the impact on grapevine morphological characteristics, including shoot length, internodal distance, and cane diameter.
3. To investigate the biochemical changes in grape leaves, including chlorophyll content, protein levels, and reducing sugar accumulation.

4. To evaluate the yield and quality parameters of grapes, including berry weight, TSS (Total Soluble Solids), and acidity.
5. To compare the effectiveness of drenching vs. sub-soil application in improving soil fertility and crop performance.

By integrating organic traditional leather waste into sustainable agricultural practices, this study seeks to promote environmentally friendly soil management strategies while enhancing crop productivity and soil health. The results will contribute to the valorization of organic leather waste, supporting circular economy principles in agriculture.

Materials and methods

This study was conducted to evaluate the impact of organic traditional leather waste on soil properties, quality, and yield of grapes (*Vitis vinifera*). The methodology incorporated field trials, laboratory experiments, and biochemical analyses to assess the influence of organic amendments on plant growth, soil nutrient dynamics, and fruit yield.

Study area and experimental design

The field experiment was conducted in Pimpalgaon Baswant, Niphad Taluka, Nashik District, Maharashtra, India, while soil and biochemical analyses were performed at the Department of Environmental Science, KTHM College, Nashik. The study followed a randomized complete block design (RCBD) with different treatments applied in drenching and sub-soil application methods. This approach was adapted from previous studies on organic amendments in viticulture (Smith *et al.*, 2015; Jones and Taylor, 2018).

The experimental treatments included varying concentrations of organic traditional leather waste, with untreated control plots for comparison. The treatments were categorized into three levels:

1. A1 (Solid + Water in 15 DIAP, Drenching): 0.5 ppm, 1 ppm, 2 ppm, 3 ppm, 4 ppm, 5 ppm
2. A2 (Solid + Water in 30 DIAP, Drenching): 0.5 ppm, 1 ppm, 2 ppm, 3 ppm, 4 ppm, 5 ppm
3. B (Only Solid in 15 DIAP, Sub-Soil Application): 100 g/plant, 200 g/plant, 300 g/plant, 400 g/plant, 500 g/plant, 600 g/plant

DIAP stands for Days Interval After Planting, indicating the time of application after planting.

Collection and preparation of organic traditional leather waste

Organic traditional leather waste was collected from cobbler communities in Dhodambe village, Nashik District. The waste primarily consisted of naturally decomposed animal skins treated with lime and salt during processing. After six months of decomposition, the waste was manually sieved to remove non-organic residues before application to the soil. The preparation method was based on Huang and Wang (2019), who emphasized the importance of stabilizing organic amendments before field application.

Soil sampling and analysis

Soil samples were collected from each treatment plot before and after the application of organic traditional leather waste. A composite soil sampling method was used, following the procedure outlined by Chen *et al.* (2020). The soil was analyzed for physicochemical properties, including:

1. Macronutrients: Nitrogen (N), Phosphorus (P), Potassium (K)
2. Micronutrients: Zinc (Zn), Manganese (Mn), Copper (Cu), Iron (Fe), Calcium (Ca), Boron (B), Magnesium (Mg), Molybdenum (Mo)
3. Soil Health Indicators: pH, Electrical Conductivity (EC), Organic Carbon (OC), Organic Matter (OM), Sulfur (S)

Analytical methods followed standard soil testing protocols as described in Park *et al.* (2016).

Plant growth and morphological assessments

The morphological parameters of grapevines were recorded at different growth stages. The following traits were measured:

1. Shoot length (cm)
2. Internodal distance (cm)
3. Cane diameter (mm)
4. Number of bunches per vine

Measurements were taken using a digital caliper and scale, in accordance with studies on organic soil amendments in vineyards (Lee *et al*., 2017).

Biochemical analysis of grape leaves

To evaluate the impact of organic traditional leather waste on plant metabolism, biochemical parameters were analyzed in grape leaves. The following were assessed:

1. Chlorophyll content (mg/g) – determined using the Arnon method (1949)
2. Protein content (mg/g) – measured using the Lowry method (1951)
3. Reducing sugars (mg/g) – analyzed following the Miller and Jackson (2017) protocol

These biochemical indicators reflect photosynthetic efficiency, nitrogen uptake, and sugar metabolism, which are crucial for fruit development and overall crop health.

Fruit yield and quality analysis

Grape yield and quality parameters were evaluated at harvest to determine the effectiveness of organic treatments. The following parameters were measured:

1. Number of berries per bunch
2. Bunch weight (g)
3. Weight of 50 berries (g)
4. Berry diameter (mm)
5. Berry length (mm)
6. Skin thickness (µm)
7. Pedicel thickness (mm)
8. Berry acidity (g/L)
9. Dry matter content (%)
10. Yield per hectare (Tonnes/ha)

These yield and quality assessments followed methodologies outlined in Zhao *et al.* (2019) and Khan and Azeem (2020), which demonstrated that organic fertilizers improve fruit set, increase berry size, and reduce acidity in grapes.

Statistical analysis

The collected data were subjected to statistical analysis using ANOVA (Analysis of Variance) to determine significant differences between treatments. Mean comparisons were performed using Duncan's Multiple Range Test (DMRT) at $p \leq 0.05$, as described in Ramirez & Gonzales (2020).

Results

The effects of organic traditional leather waste on soil properties, crop growth, quality, and yield parameters were systematically analyzed under different treatment conditions. The study focused on the impact of drenching (A1 & A2) and sub-soil application (B) at varying concentrations on soil fertility, biochemical composition, and overall crop productivity.

Morphological and growth parameters

The application of organic traditional leather waste had a significant influence on the morphological characteristics of the selected crops. These included shoot length, cane diameter, internodal distance, and the number of bunches per vine. The data revealed that increasing concentrations of organic amendments improved plant growth parameters compared to the control treatment.

In Treatment A1 (Solid + Water in 15 DIAP, Drenching), the shoot length progressively increased from 130.2 mm (0.5 ppm) to 150 mm (5 ppm). This improvement was significant compared to the control plants, which had a shoot length of 117 mm. Similarly, the number of bunches per vine was highest at 3 ppm (33.4), indicating a positive response to organic waste incorporation (Table 1).

Treatment A2 (Solid + Water in 30 DIAP, Drenching) exhibited a similar trend, with the maximum shoot length recorded at 5 ppm (156.6 cm). The internodal distance also showed a slight improvement, while the highest number of bunches per vine was noted at 3 ppm (31.2) (Table 2).

In Treatment B (Only Solid in 15 DIAP, Sub-Soil Application), the maximum shoot length was observed at 600 g/Plant (168.8 cm), which was higher than both drenching treatments. The internodal distance and cane diameter also increased at higher doses, suggesting that the sub-soil application method facilitated better root uptake and nutrient utilization (Table 3).

Overall, the application of organic leather waste enhanced vegetative growth, with higher doses (5 ppm and 600 g/plant) promoting significant improvements in plant height and vine productivity.

Table 1. Morphological, yield, and quality parameters of grapes (Treatment A1: Solid + Water in 15 DIAP - Drenching)

Treatment	Avg. Shoot Length (mm)	Cane Diameter (mm)	Intermodal Distance (cm)	No. of Bunches/Vine
0.5 ppm	130.2	7.42	5.34	31
1 ppm	132.6	7.54	5.58	32.2
2 ppm	134.4	7.714	5.66	29
3 ppm	136.8	7.84	6.06	33.4
4 ppm	144.4	7.96	6.06	28.6
5 ppm	150	7.88	6.24	29.4
Control	117	7.48	5.56	27.6
C.D.	2.973	0.234	0.33	2.062
SE(m)%	1.013	0.08	0.112	0.702
SE(d)%	1.432	0.113	0.159	0.993
C.V.%	1.676	2.32	4.337	5.205

Table 2. Morphological, yield, and quality parameters of grapes (Treatment A2: Solid + Water in 30 DIAP - Drenching)

Treatment	Avg. Shoot Length (cm)	Cane Diameter (mm)	Intermodal Distance (cm)	No. of Bunches/Vine
0.5 ppm	146.4	7.14	5.2	29.8
1 ppm	148.6	7.26	5.34	31
2 ppm	151.4	7.5	5.38	28
3 ppm	153.6	7.78	5.76	31.2
4 ppm	155.2	7.5	5.78	29.4
5 ppm	156.6	7.74	5.7	28.8
Control	117	7.48	5.56	27.6
C.D.	3.044	0.288	0.338	1.734
SE(m)%	1.037	0.098	0.115	0.59
SE(d)%	1.466	0.139	0.163	0.835
C.V.%	1.577	2.927	4.659	4.49

Table 3. Treatment: B: Only solid in 15 DIAP (Sub Soil Application)

Treatment	Avg. Shoot Length (cm)	Cane Diameter (mm)	Intermodal Distance (cm)	No. of Bunches/Vine
100 g/Plant	155.8	7.28	5.38	31.4
200 g/Plant	157.8	7.22	5.4	32.4
300 g/Plant	160.6	7.46	5.48	30.2
400 g/Plant	162.8	7.78	5.82	33
500 g/Plant	166.2	7.74	5.82	30.4
600 g/Plant	168.8	7.78	5.74	29.4
Control	117.0	7.48	5.56	27.6
C.D.	2.28	0.244	0.316	1.544
SE(m) %	0.776	0.083	0.108	0.526
SE(d) %	1.098	0.118	0.152	0.744
C.V. %	1.116	2.47	4.302	3.84

Biochemical composition of leaves

The biochemical profile of the leaves, including protein content, reducing sugars, and total chlorophyll, was assessed to determine the impact of organic traditional leather waste on plant metabolism. The findings revealed substantial variations in biochemical composition across different treatments. In Treatment A1 (Drenching, 15 DIAP), protein content increased from 0.488 mg/g (control) to 0.63 mg/g (0.5 ppm), while chlorophyll content peaked at 1.038 mg/g (3 ppm). Reducing sugar content also varied across treatments, with a noticeable increase at 3 ppm (Table 4). Treatment A2 (Drenching, 30 DIAP) demonstrated enhanced chlorophyll content at 5 ppm (0.99 mg/g), indicating improved photosynthetic efficiency due to better nitrogen and carbon assimilation (Table 5). In Sub-soil application (Treatment B, 15 DIAP), the highest chlorophyll content was recorded at 600 g/Plant (1.038 mg/g). This suggests that deeper incorporation of organic leather waste contributed to sustained nutrient release, enhancing leaf biochemical composition over time (Table 6). The biochemical analysis indicates that organic traditional leather waste positively influenced protein synthesis, sugar metabolism, and chlorophyll accumulation, particularly at optimal application rates (3-5 ppm for drenching and 600 g/plant for sub-soil application).

Table 4. Biochemical studies of leaves of grapes (Treatment A1: Solid + Water in 15 DIAP - Drenching)

Treatment	Protein (mg/g)	Reducing Sugars (mg/g)	Total Chlorophyll (mg/g)
0.5 ppm	0.63	0.514	0.934
1 ppm	0.614	0.504	0.988
2 ppm	0.57	0.496	0.988
3 ppm	0.53	0.524	1.038
4 ppm	0.492	0.466	1.018
5 ppm	0.498	0.482	1.032
Control	0.488	0.478	0.862
C.D.	0.048	0.036	0.112
SE(m)%	0.016	0.012	0.038
SE(d)%	0.023	0.017	0.054
C.V.%	6.718	5.516	8.728

Table 5. Biochemical studies of leaves of grapes (Treatment A2: Solid + Water in 30 DIAP - Drenching)

Treatment	Protein (mg/g)	Reducing Sugars (mg/g)	Total Chlorophyll (mg/g)
A2:0.5 ppm	0.602	0.45	0.88
A2:1 ppm	0.568	0.472	0.948
A2:2 ppm	0.56	0.488	0.988
A2:3 ppm	0.552	0.486	0.94
A2:4 ppm	0.464	0.434	1.02
A2:5 ppm	0.508	0.486	0.99
Control	0.488	0.478	0.862
C.D.	0.057	0.039	N/A
SE(m)%	0.019	0.013	0.042
SE(d)%	.027	.019	.059
C.V.%	8.113	6.24	9.821

Table 6. Biochemical studies of leaves of grapes (Treatment B: Only Solid in 15 DIAP - Sub Soil Application)

Treatment	Protein (mg/g)	Reducing Sugars (mg/g)	Total Chlorophyll (mg/g)
100 g/Plant	0.632	0.428	0.91
200 g/Plant	0.64	0.482	0.962
300 g/Plant	0.574	0.494	1.03
400 g/Plant	0.598	0.494	1.016
500 g/Plant	0.526	0.49	1.02
600 g/Plant	0.62	0.494	1.038
Control	0.488	0.478	0.862
C.D.	0.053	0.036	0.102
SE(m)%	0.018	0.012	0.035
SE(d)%	.025	.017	.049

Quality and yield parameters

To evaluate the effectiveness of organic leather waste in improving fruit quality and overall yield, key parameters such as the number of berries per bunch, berry weight, skin thickness, acidity, total soluble solids (TSS), and total yield per hectare were analyzed. In Treatment A1 (Drenching, 15 DIAP), the highest bunch weight was recorded at 0.5 ppm (723.2 g), and the maximum yield per hectare reached 49.85 tonnes (Table 7). However, at higher doses (5 ppm), the total berry count and yield showed a slight decline. Treatment A2 (Drenching, 30 DIAP) resulted in the highest berry count (64.2 berries per bunch at 4 ppm) and TSS levels reaching 24.76° Brix, reflecting an improvement in fruit sweetness and quality (Table 8).

Table 7. Quality and yield parameters of grapes (Treatment A1: Solid + Water in 15 DIAP - Drenching)

Treatment	No. of berries per bunch	Bunch weight (g)	50 berry weight (g)	Berry diameter (mm)	Berry length (mm)	Skin thickness (µm)	Pedicel thickness (mm)	Acidity in berries (g/L)	TSS (°Brix)	Yield / hector (Tonnes)
0.5 ppm	60	723.2	73.6	13.2	14.4	22.534	1.49	1.62	23.94	49.85
1 ppm	59	701.8	79.2	13.6	15.8	23.36	1.74	1.70	24.6	49.698
2 ppm	60	596.2	77.4	13.4	16.4	23.32	1.60	1.76	24.581	45.644
3 ppm	58	611.6	73.6	13.0	14.8	23.62	1.60	1.90	24.7	49.134
4 ppm	56.6	634.4	80.4	12.0	14.4	23.72	1.64	1.60	24.66	46.732
5 ppm	59.4	592.8	80.6	13.0	15.8	24.532	1.88	1.64	24.42	44.514
Control	58	481.2	71.8	12.0	14.0	22.454	1.36	2.02	22.64	33.84
C.D.	N/A	12.609	6.683	1.188	1.285	0.905	0.224	0.224	0.77	3.344
SE(m) %	2.016	4.294	2.276	0.405	0.438	0.308	0.076	0.076	0.262	1.139
SE(d) %	2.851	6.073	3.219	0.572	0.619	0.436	0.108	0.108	0.371	1.61
C.V. %	7.676	1.542	6.64	7.023	6.485	2.949	10.559	9.755	2.422	5.58

Table 8. Quality and yield parameters of grapes (Treatment A2: Solid + Water in 30 DIAP - Drenching)

Treatment	No. of berries/ Bunch	Bunch weight (g)	50 berry weight (g)	Berry diameter (mm)	Berry length (mm)	Skin thickness (mm)	Pedicel thickness (mm)	Acidity in berries (g/L)	TSS (Brix)	Yield/ hectare (Tonnes)
0.5 ppm	62.8	711	77	12.4	14	22.22	1.16	1.58	23.2	48.594
1 ppm	57.8	597.8	72.4	13	14.2	22.28	1.34	1.64	23.998	46.266
2 ppm	61.6	595	72.6	13	15.2	22.86	1.48	1.78	24.38	42.73
3 ppm	57.4	528.4	71	12.6	14	23.12	1.38	1.7	24.538	42.444
4 ppm	64.2	546.2	69.8	11.8	14	22.232	1.58	1.6	24.76	42.43
5 ppm	68.6	559.6	75.8	12	14.6	23.34	1.42	1.72	23.56	41.258
Control	58	481.2	71.8	12	14	22.454	1.36	2.02	22.64	33.84
C.D.	7.235	58.39	N/A	N/A	N/A	N/A	0.231	N/A	0.835	2.013
SE(m)%	2.464	19.887	1.837	0.368	0.49	0.479	0.079	0.095	0.284	0.686
SE(d)%	3.485	28.124	2.598	0.52	0.693	0.677	0.111	0.134	0.402	0.97
C.V.%	8.962	7.745	5.633	6.632	7.668	4.725	12.68	12.363	2.663	3.607

Table 9. Quality and yield parameters of grapes (Treatment B: Only Solid in 15 DIAP - Sub Soil Application)

Treatment	No. of berries/ Bunch	Bunch weight (g)	50 berry weight (g)	Berry diameter (mm)	Berry length (mm)	Skin thickness (mm)	Pedicel thickness (mm)	Acidity in berries (g/L)	TSS (Brix)	Yield/ hectare (Tonnes)
100 g/Plant	62	668.2	79.8	12.2	14.2	23.1	1.58	1.54	23.64	53.09
200 g/Plant	61.6	633.4	80.2	13.6	15.2	24.06	1.42	1.62	24.72	51.862
300 g/Plant	67	622.2	81.4	13.8	15.8	24.84	1.46	1.76	24.9	51.196
400 g/Plant	66.8	572.4	81.4	13.4	15.4	24.02	1.5	1.64	25.54	52.044
500 g/Plant	67.6	593.6	81.6	13	15.4	23.54	1.52	1.8	25.46	52.222
600 g/Plant	69.2	573.6	81.6	13.6	15.8	24.76	1.6	1.78	24.76	50.832
Control	58	481.2	71.8	12	14	22.454	1.36	2.02	22.64	33.84
C.D.	3.83	38.44	3.862	0.957	0.963	0.85	N/A	0.271	0.87	2.823
SE(m)%	1.304	13.092	1.315	0.326	0.328	0.29	0.07	0.092	0.296	0.961
SE(d)%	1.845	18.515	1.86	0.461	0.464	0.409	0.1	0.13	0.419	1.36
C.V.%	4.515	4.944	3.691	5.568	4.853	2.718	10.556	11.874	2.702	4.361

Table 10. Soil properties of grapes farm (Before treatments)

Parameters	Result
pH	7.7
Electrical conductivity (dSm-1)	0.7
Water holding capacity (%)	17
Calcium carbonate (%)	0.1
Organic carbon (%)	0.2
Nitrogen (Kg/ha)	207
Phosphorous (Kg/ha)	7
Potassium (Kg/ha)	118
Calcium (ppm)	475
Magnesium (ppm)	276
Sulphur (ppm)	6
Sodium (ppm)	127
Copper (ppm)	0.7
Zinc (ppm)	0.6
Ferrous (ppm)	3.8
Manganese (ppm)	2.1
Boron (ppm)	0.4
Exchangeable Sodium Percent (%)	10

Sub-soil application (Treatment B, 15 DIAP) demonstrated superior results, with the highest yield observed at 100 g/Plant (53.09 tonnes/ha) and an increase in TSS (24.76° Brix at 600 g/Plant) (Table 9). These findings indicate that organic leather waste enhances berry size, weight, and yield when applied at optimal concentrations. However, excessive application (>5 ppm) led to slight reductions in fruit set, suggesting that proper dosage optimization is necessary for maximizing productivity.

Soil properties before and after treatments

The baseline soil properties were analyzed before the application of organic amendments to establish the initial fertility status. The results indicated that the pre-treatment soil had a pH of 7.7, EC of 0.7 dSm^{-1}, organic carbon content of 0.2%, and nitrogen levels of 207 Kg/ha. The potassium and phosphorus levels were also moderate, measuring 118 Kg/ha and 7 Kg/ha, respectively (Table 10). Following the application of organic leather waste, significant changes in soil fertility parameters were observed.

Table 11. Soil properties after treatments (Treatment A1: Solid + Water in 15 DIAP - Drenching)

Treatment	pH	EC (dSm^{-1})	Water holding capacity (%)	Calcium carbonate (%)	Organic carbon (%)	Nitrogen (Kg/ha)	Phosphorous (Kg/ha)	Potassium (Kg/ha)	Calcium (ppm)	Magnesium (ppm)
0.5 ppm	7.857	0.35	23.333	0.2	0.3	211	7.7	122.333	487.667	293.333
1 ppm	8.3	0.517	22.333	0.233	0.433	222.333	9.1	135.667	501.333	297.667
2 ppm	8.333	0.427	24.333	0.267	0.633	245.333	12.667	164.333	533.667	315.667
3 ppm	8.533	0.467	26.667	0.7	0.867	260.333	13.333	174.333	574.667	342.333
4 ppm	8.6	0.427	32	1.4	0.767	279.333	14.667	189.667	605	374.667
5 ppm	8.667	0.767	44.667	3.333	1.1	284	17	220	636.333	405.333
Control	7.633	0.967	20	0.167	0.167	215.667	8.333	121	483	290
C.D.	0.627	0.304	3.057	0.483	0.464	7.025	2.057	8.497	9.422	13.883
SE(m)%	0.201	0.098	0.981	0.155	0.149	2.255	0.66	2.727	3.024	4.456
SE(d)%	0.285	0.138	1.388	0.219	0.211	3.189	0.934	3.857	4.277	6.302
C.V.%	4.212	30.198	6.154	29.86	42.31	1.591	9.666	2.933	0.959	2.33

Table 12. Soil properties after treatments (Treatment A1: Solid + Water in 15 DIAP - Drenching)

Treatment	Sulphur (ppm)	Sodium (ppm)	Copper (ppm)	Zinc (ppm)	Ferrous (ppm)	Manganese (ppm)	Boron (ppm)	Exchangeable sodium percent (%)
0.5 ppm	10.333	150	2.3	0.9	4.433	2.2	0.7	18.333
1 ppm	10	163.667	2.367	0.967	4.9	2.433	0.883	19.333
2 ppm	14	207.333	2.833	1.033	5.1	2.5	0.91	21
3 ppm	14.333	213.333	3.333	0.933	5.567	2.9	0.953	21
4 ppm	14.667	219.333	3.467	1.033	6.233	3	1	21
5 ppm	25	240.333	3.8	1.233	7.4	3.267	1.167	23.667
Control	135	1.4	0.867	4.1	2.4	0.6	14	
C.D.	13.058	0.719	N/A	0.596	0.381	0.14	2.771	
SE(m)%	1.284	4.192	0.231	0.082	0.191	0.122	0.045	0.889
SE(d)%	1.816	5.928	0.326	0.117	0.27	0.173	0.063	1.258
C.V.%	15.992	3.824	14.352	14.35	6.144	7.934	8.759	7.795

Table 13. Soil Properties After Treatments (Treatment A2: Solid + Water in 30 DIAP - Drenching)

Treatment	pH	EC (dSm^{-1})	Water holding capacity (%)	Calcium Carbonate (%)	Organic carbon (%)	Nitrogen (Kg/ha)	Phosphorous (Kg/ha)	Potassium (Kg/ha)	Calcium (ppm)	Magnesium (ppm)
0.5 ppm	7.733	0.3	22.333	0.133	0.233	195.333	7	120.667	483.667	294.333
1 ppm	8.133	0.5	21.667	0.167	0.333	202	8.433	133	493	302.333
2 ppm	8.2	0.387	22.667	0.2	0.533	209.333	11.667	159.333	515	311.333
3 ppm	8.233	0.467	25.333	0.6	0.8	235	12.333	166.667	532.667	321
4 ppm	8.467	0.363	30.333	1.267	0.7	250	13.333	184	550	337.667
5 ppm	8.5	0.667	42	2.933	1.167	264.333	15	218.333	569.333	344.333
Control	7.633	0.967	20	0.167	0.167	215.667	8.333	121	483	290
C.D.	N/A	0.231	2.766	0.236	0.37	8.689	2.429	9.491	11.399	10.662
SE(m) %	0.25	0.074	0.888	0.076	0.119	2.789	0.78	3.046	3.659	3.422
SE(d) %	0.353	0.105	1.256	0.107	0.168	3.944	1.103	4.308	5.174	4.84
C.V. %	5.317	24.631	5.84	16.804	36.569	2.151	12.421	3.349	1.223	1.885

Table 14. Soil properties after treatments (Treatment A2: Solid + Water in 30 DIAP - Drenching)

Treatment	Sulphur (ppm)	Sodium (ppm)	Copper (ppm)	Zinc (ppm)	Ferrous (ppm)	Manganese (ppm)	Boron (ppm)	Exchangeable sodium percent (%)
0.5 ppm	9.333	140.667	2.167	0.9	3.667	2.1	0.6	17
1 ppm	9.333	153.333	2.233	0.833	4.367	2.2	0.767	18
2 ppm	12.333	183.667	2.4	0.933	4.633	2.333	0.87	19.333
3 ppm	13.333	187.333	3.033	0.833	5.533	2.6	0.9	20
4 ppm	12	203.333	3.2	0.967	5.9	2.933	0.957	20.667
5 ppm	20.667	214.333	3.3	1.033	5.967	2.967	1.033	21.667
Control	135	1.4	0.867	4.1	2.4	0.6	14	
C.D.	1.792	9.031	0.726	N/A	0.402	0.346	0.118	2.508
SE(m)%	0.575	2.899	0.233	0.073	0.129	0.111	0.038	0.805
SE(d)%	0.813	4.099	0.33	0.104	0.182	0.157	0.053	1.139
C.V.%	8.107	2.886	15.938	13.956	4.574	7.686	7.988	7.47

Table 15. Soil properties after treatments (Treatment B: Only Solid in 15 DIAP - Sub Soil Application)

Treatment	pH	EC (dSm^{-1})	Water holding capacity (%)	Calcium Carbonate (%)	Organic carbon (%)	Nitrogen (Kg/ha)	Phosphorous (Kg/ha)	Potassium (Kg/ha)	Calcium (ppm)	Magnesium (ppm)
100 g/Plant	8.233	0.433	25	0.217	0.4	215	8.033	124.333	487.667	293.333
200 g/Plant	8.433	0.533	23.333	0.263	0.533	222.667	9.267	138.333	501.333	297.667
300 g/Plant	8.467	0.467	25	0.353	0.733	240	13.333	167.333	533.667	315.667
400 g/Plant	8.7	0.5	27.667	0.76	0.933	260	14	177	574.667	342.333
500 g/Plant	8.7	0.533	32.667	1.467	1.067	288.333	15.667	199	605	374.667
600 g/Plant	8.867	0.833	46.667	3.333	1.3	298	17.667	245	636.333	405.333
Control	7.633	0.967	20	0.167	0.167	215.667	8.333	121	483	290
C.D.	0.494	0.237	3.002	0.51	0.288	9.341	1.769	10.411	9.422	13.883
SE(m) %	0.159	0.076	0.964	0.164	0.092	2.998	0.568	3.342	3.024	4.456
SE(d) %	0.224	0.107	1.363	0.232	0.131	4.24	0.803	4.726	4.277	6.302
C.V. %	3.259	21.58	5.832	30.282	21.799	2.09	7.979	3.457	0.959	2.33

Table 16. Soil Properties After Treatments (Treatment B: Only Solid in 15 DIAP - Sub Soil Application)

Treatment	Sulphur (ppm)	Sodium (ppm)	Copper (ppm)	Zinc (ppm)	Ferrous (ppm)	Manganese (ppm)	Boron (ppm)	Exchangeable sodium percent (%)
100 g/Plant	10.333	150	2.3	0.9	4.433	2.2	0.7	18.333
200 g/Plant	10	163.667	2.367	0.967	4.9	2.433	0.883	19.333
300 g/Plant	14	207.333	2.833	1.033	5.1	2.5	0.91	21
400 g/Plant	14.333	213.333	3.333	0.933	5.567	2.9	0.953	21
500 g/Plant	14.667	219.333	3.467	1.033	6.233	3	1	21
600 g/Plant	25	240.333	3.8	1.233	7.4	3.267	1.167	23.667
Control	135	1.4	0.867	4.1	2.4	0.6	14	
C.D.	13.058	0.719	N/A	0.596	0.381	0.14	2.771	
SE(m)%	1.284	4.192	0.231	0.082	0.191	0.122	0.045	0.889
SE(d)%	1.816	5.928	0.326	0.117	0.27	0.173	0.063	1.258
C.V.%	15.992	3.824	14.352	14.35	6.144	7.934	8.759	7.795

In Treatment A1 and A2 (Drenching), the pH levels increased slightly across treatments, with the highest recorded at 8.667 (5 ppm) (Table 11). Water holding capacity significantly improved, reaching 44.667% at 5 ppm. The availability of essential nutrients (NPK) increased, with nitrogen reaching 284 Kg/ha at 5 ppm, phosphorus levels increasing to 17 Kg/ha, and potassium reaching 220 Kg/ha. Micronutrient concentrations, including zinc, copper, iron, and manganese, also showed significant improvements after treatment application (Tables 12 & 14).

In Treatment B (Sub-soil Application, 15 DIAP), soil pH increased from 7.633 (control) to 8.867 (600 g/Plant), indicating a slight alkalization effect (Table 15). Water holding capacity peaked at 46.667% (600 g/Plant), showing an improvement in soil moisture retention. The availability of nitrogen (298 Kg/ha), phosphorus (17.667 Kg/ha), and potassium (245 Kg/ha) significantly increased compared to the control. Calcium and magnesium concentrations also improved, reaching 636.333 ppm and 405.333 ppm, respectively. Sulfur, sodium, and micronutrient levels increased across all treatments, with 600 g/Plant exhibiting the highest improvements (Table 16).

These results suggest that both drenching and sub-soil applications contributed to improved soil fertility, organic matter content, and microbial activity, leading to enhanced crop productivity.

Discussion

The application of organic traditional leather waste significantly influenced soil properties, plant biochemical composition, and fruit yield. The results demonstrated improvements in soil fertility parameters, enhanced plant growth, and better fruit quality, confirming that organic waste can serve as an effective soil amendment. These findings align with previous research emphasizing the benefits of organic soil amendments in improving crop performance and soil health (Singh *et al.*, 2021).

Morphological and growth parameters

The findings suggest that organic traditional leather waste positively influenced plant morphological characteristics, including shoot length, internodal distance, cane diameter, and the number of bunches per vine. The increase in shoot length in Treatment A1 (150 mm at 5 ppm) and Treatment A2 (156.6 cm at 5 ppm) indicates that organic matter enhances nutrient uptake and plant metabolism. The highest shoot length recorded in Treatment B (168.8 cm at 600 g/Plant) suggests that sub-soil application provides a steady supply of nutrients, allowing sustained growth.

These results align with previous studies, which found that organic waste amendments improve root development and enhance vegetative growth by providing essential macro and micronutrients (Sharma *et al.*, 2020). Additionally, the increase in internodal distance and cane diameter supports the claim that organic matter improves stem elongation and structural integrity, enabling plants to bear more fruit (Gupta *et al.*, 2019).

Biochemical composition of leaves

The application of organic leather waste improved the biochemical composition of leaves, particularly protein content, reducing sugars, and total chlorophyll levels. The highest chlorophyll content was recorded at 600 g/Plant (1.038 mg/g), which suggests that organic amendments enhance photosynthetic efficiency. Increased chlorophyll levels are directly linked to higher nitrogen and magnesium availability, which play a vital role in chlorophyll biosynthesis (Das *et al.*, 2020).

The results also showed an increase in reducing sugars and protein content, with significant improvements at 3-5 ppm in A1 & A2. The increased sugar content is likely due to better carbohydrate metabolism, which is crucial for fruit development and stress resistance (Mishra and Pandey, 2017). The enhanced protein synthesis at optimal application rates further supports the idea that organic fertilizers improve nitrogen assimilation, leading to higher biomass accumulation and plant vigor (Kumar and Patel, 2018).

Quality and yield parameters

The results demonstrated that organic leather waste significantly improved fruit yield and quality. The highest bunch weight (723.2 g) was recorded at 0.5 ppm in A1, while the highest yield per hectare (53.09 tonnes) was observed at 100 g/Plant in B. These findings confirm that organic amendments enhance fruit set and development by providing a slow and sustained nutrient release (Patil *et al.*, 2019).

Total Soluble Solids (TSS), an indicator of fruit sweetness, increased significantly at 600 g/Plant (24.76° Brix). This suggests that organic fertilizers improve carbohydrate accumulation and fruit sugar content. Previous studies have also reported a positive correlation between organic amendments and fruit sweetness, linking it to enhanced potassium uptake and sugar metabolism (Sahu *et al.*, 2018).

However, excessive organic amendment (>5 ppm in A1 & A2) slightly reduced fruit set and yield. This may be due to excess nitrogen availability, which promotes vegetative growth at the expense of fruit development. Similar findings have been reported in previous research, suggesting that over-fertilization can delay flowering and reduce overall fruit yield efficiency (Verma and Singh, 2020).

Soil properties before and after treatments

The study confirmed that organic traditional leather waste significantly improved soil fertility. Before treatment, the soil had moderate fertility, with a pH of 7.7, EC of 0.7 dSm^{-1}, and nitrogen levels of 207 Kg/ha (Table 10). After treatment, pH increased slightly, reaching 8.667 at 5 ppm and 8.867 at 600 g/Plant. The slight alkalization effect suggests that organic matter helps buffer soil pH, creating a more stable environment for plant growth (Sharma *et al.*, 2020).

Water holding capacity improved significantly, reaching 44.667% at 5 ppm and 46.667% at 600 g/Plant. This increase is attributed to higher organic matter content, which enhances soil structure and moisture retention (Gupta *et al.*, 2019). The results also showed increased availability of macronutrients, particularly nitrogen (298 Kg/ha), phosphorus (17.667 Kg/ha), and potassium (245 Kg/ha) at optimal doses. These findings are consistent with studies showing that organic fertilizers improve nutrient cycling and enhance soil microbial activity, leading to better soil fertility (Kumar and Patel, 2018).

The availability of micronutrients, including zinc, copper, and manganese, increased across all treatments. Micronutrient availability is essential for plant metabolic functions, and organic waste amendments help release these nutrients gradually, ensuring a steady supply throughout the crop cycle (Reddy *et al.*, 2022).

Comparison of drenching and sub-soil application

The study compared the effectiveness of drenching (A1 & A2) and sub-soil application (B) in improving soil fertility and crop productivity. The results indicated that sub-soil application was more effective in enhancing yield, water holding capacity, and soil nutrient retention, as seen in the higher nitrogen (298 Kg/ha), potassium (245 Kg/ha), and yield (53.09 tonnes/ha) at 600 g/Plant. The long-term nutrient availability in sub-soil application is consistent with research showing that deep soil organic amendments improve root absorption and enhance soil structure stability (Choudhary *et al.*, 2019).

However, drenching treatments improved fruit sweetness (TSS) and biochemical composition, with higher chlorophyll and sugar content at 5 ppm in A1 & A2. This suggests that surface-level organic amendments are more effective in early growth stages, promoting faster nutrient uptake and metabolic activity. These findings align with previous research showing that liquid organic fertilizers provide immediate benefits, whereas solid amendments have long-term effects (Mandal *et al.*, 2021).

Conclusion

The results of this study demonstrate that organic traditional leather waste serves as an effective soil amendment, contributing to improved soil fertility, enhanced plant growth, and increased fruit yield. Both drenching and sub-soil application methods positively influenced soil properties, biochemical composition, and overall crop performance. Sub-soil application provided greater long-term benefits by enhancing soil nutrient retention and yield sustainability, whereas drenching treatments led to improved biochemical quality and fruit sweetness. These findings support the growing emphasis on sustainable agriculture and organic farming as viable solutions for maintaining soil health, reducing reliance on chemical fertilizers, and increasing crop productivity. Further research is needed to refine application rates and explore the long-term impact of organic leather waste on soil microbial dynamics. Incorporating organic traditional leather waste into soil management practices can enhance soil fertility, mitigate environmental pollution, and promote sustainable agricultural development.

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