Enhancing soil health and fruit yield through Tephrosia biomass mulching in rainfed guava (Psidium guajava L.) orchards

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Abstract

Tephrosia candida, a leguminous green manuring crop, exhibits superior biomass production and notably higher concentrations of carbon, nitrogen, phosphorus, potassium, and essential micronutrients. The research was undertaken to standardize the quantity of *Tephrosia candida* biomass for mulching in high density guava orchard. The experiment was initiated in the year 2019 comprising of four treatments *viz*. T_1 = 3.0 kg dry biomass per square meter of the plant basin, T_2 = 2.0 kg dry biomass per square meter of the plant basin, T_3 = 1.0 kg dry biomass per square meter of the plant basin and T_4 = control (No mulch). The treatments were imposed in the plant basin of a 12-year-old guava (cultivar: Allahabad Safeda) orchard planted at a spacing of 1.0m x 2.0m, accommodating 5000 plants per hectare. Each treatment was replicated five times. The present investigation recorded the data pertaining to the effects of the treatments during the third year of experimentation. Mulching with 3 kg of biomass per m^2 resulted in hastening of the winter bud stage by 29.17 days, increase in trunk diameter by 50.47%, fruit yield of winter crop by 42.25%, fruit weight by 11.00%, specific leaf area by 18% over the control. Moreover, there were notable increases in the levels of leaf total chlorophyll, total nitrogen, phosphorus, potassium, iron, zinc and manganese. Additionally, there was a marked reduction in total anthocyanin content of the leaves during the winter dormancy. Biomass mulching at rates of 3.0 kg/m^2 or 2.0 kg/m^2 significantly improved soil properties, including EC, available nitrogen, available phosphorus, exchangeable potassium, DTPA extractable micronutrients (Fe, Zn, Cu, and Mn), and C_{tot}, C_{tot}, $C_{frac1,2,3,4}$, and microbial biomass carbon within 0 to 15cm and 15 to 30cm soil depths. The FDA and DHA peaked in April 2022 and reached minimum values in January 2022, in both soil depths.

1. Introduction

Guava (*Psidium guajava* L.) is an important fruit crop in tropical and subtropical regions of India. It is adaptable to various soil and climatic conditions, including clay, sand, gravel bars, limestone, and slightly acidic to alkaline soils (pH ranging from 5.5 to 7.5) (Singh et al., 2017). The plants also respond well to proper manuring and fertilization to achieve optimal growth and yield. The Eastern Plateau and Hill Region of India has been a traditional guava growing region in the country. However, guava orchards in this region face challenges such as poor soil fertility, low organic carbon content, limited water holding capacity, and nutrient deficiencies, resulting in lower yield as compared to other guava-growing regions (Das et al., 2007). Improving soil organic carbon can be the most important step towards ameliorating the edaphic constraints under the Eastern Plateau and Hill Region. Although, application of farm yard manure is the most effective means for improving the soil health, its limited availability in the region combined with higher cost leads to its minimal application by the farmers particularly in fruit orchards.

The present scenario demands an economically feasible and environmentally friendly approach, particularly for the rainfed upland. Enriching the plant basins with leafy biomass can effectively improve soil organic matter and nutrient content. While green manuring with crops like *sesbania* or *crotalaria* is effective for plant-based organic carbon management, their annual nature and need for timely incorporation limit their widespread adoption in fruit production systems. To overcome this, integrating biomass-yielding perennial plants has proven successful in improving soil fertility. A number of perennial biomass yielding plants are being used in agroforestry systems worldwide for improving soil fertility through nutrient recycling. Subabul (*Leucaena leucocephala*) is the most commonly used plant for this purpose (Das et al., 2019). However, difficulties in its eradication and high seed dispersal rate hinder its integration into fruit based production systems in the region. On the other hand, *Tephrosia candida*, a perennial leguminous plant, has shown promising results in improving soil fertility when integrated into Bael (*Aegle marmelos* Corr.) based production systems in Eastern Plateau and Hill Region due to higher biomass yield and shorter lifespan of 5 to 6 years (Das et al., 2019). *Tephrosia candida* (Roxb) is native to the Himalayan tropical foothills of India and is naturalized in Southeast Asia. Being a leguminous species, it also has nitrogen fixation ability. According to Das et al. (2021), *Tephrosia candida* leaves have nitrogen, phosphorus, potassium, zinc, and copper contents of 2.94 ± 0.38%, 0.16 ± 0.22%, 1.06 ± 0.18%, 35.35 ± 5.46 ppm, and 19.18 ± 3.14 ppm, respectively. Mulching of *Tephrosia* biomass in the plant basin of bael plants had resulted in significant improvement soil fertility and plant growth parameters.

Beneficial effects of biomass mulching have been reported in a number of fruit crops. The beneficial effects have been recorded mainly on soil physical properties *viz*. water holding capacity (Das et al., 2007), bulk density (Mishra et al., 2002), chemical properties *viz*. organic carbon (Das et al., 2021), available nutrients (Das et al., 2021) and biological properties *viz*. microbial biomass (You *et al*., 1994), enzymatic activities (Iqbal et al., 2021). etc. However, the different mulching material may differ with respect to their effects of soil and fruit plants. Similarly, quantity of biomass to be applied as mulch can also influence the effects of biomass mulching. Apart from the beneficial effects, excessive application of biomass in the plant basin may also have detrimental effects on the fruit plants including non-availability of fixed nutrients to the fruit plants. The absence of any literature on effect of *Tephrosia* mulching in guava, it was essential to standardize the quantity of *Tephrosia* biomass to be applied as mulch in guava orchards for widespread adoption of this practice. Keeping this in view, the investigation was undertaken to quantify the effect of different doses of *Tephrosia* biomass mulching on soil physical, chemical and biological properties as well as fruit yield of guava growing under rainfed conditions.

2. Material and method

2.1. Experiment description

The study was conducted at Farming System Research Centre for Hill and Plateau region of ICAR Research Complex for Eastern Region situated in Ranchi district of Jharkhand state in India. The study site was located at coordinates 23° 16' 50.4" N latitude and 85° 24' 39.4" E longitude, with an elevation of 620 m above sea level. The site features laterite soil with a sandy loam texture. The average temperature ranged from 19.30^{0}C to 30.55^{0}C, while the average rainfall during the experiment was approximately 115.57 cm. The experiment was conducted in a 12-year-old guava (cultivar: Allahabad Safeda) orchard planted at a spacing of 1.0 m x 2.0m accomodating 5000 plants per ha. Biomass of *Tephrosia candida*, was used for imposing the treatments on mulching in the present experiment. The biomass of *Tephrosia* was harvested from the top 30% of the plant height and utilized for mulching purposes. The fresh biomass of *Tephrosia*, weighing 2.5 kg, is equivalent to 1 kg of *Tephrosia* biomass that has been dried in an oven. The experiment consisted of a total of four treatments *viz*. T_1 (3.0 kg dry biomass of *Tephrosia candida* per m^2 of plant basin), T_2 (2.0 kg dry biomass of *Tephrosia candida* per m^2 of plant basin), T_3 (1 kg dry biomass of *Tephrosia candida* per m^2 of plant basin), and T_4 (control with no mulching). For ensuring uniformity among the treatments at the beginning of the experiment, all the plants were pruned up to 50% of their shoot length and mulches were laid out on the orchard floor in uniform thickenss in respective treatments. The mulching procedure was conducted during the month of August for two consecutive years (2020 and 2021). The experiment was undertaken under rainfed conditions with no additional application of chemical fertilizers or organic manures. Each treatment was replicated five times with five plants per replication and the trial was laid out in Randomized Block Design.

2.2. Plant material used in this study:

Tephrosia candida, (Accession No:13141). Herbarium at Janaki Ammal Herbarium (CSIR): https://iiim.res.in/herbarium/papilionaceae/tephrosia_candida.htm. We have used plant material available in the germplasm block of ICAR RCER which was already procured by earlier workers of this institute"

2.3. Observations recorded

2.3.1. Phenological behaviour of guava

After pruning, modified stages with different durations were identified, and each phenological stage was coded according to the BBCH scale. Twenty shoots from five randomly selected trees were tagged per replication in October 2021. Phenological data were recorded at four principal phenological stages viz. winter bud (00), bud swelling (01), leaves completely developed (19) and appearance of flower buds (51). Data on duration of each of the stage were recorded in days (Salazar et al., 2006).

2.3.2. Plant growth, fruit and leaf parameters

Plant growth parameters, such as trunk diameter (cm) was recorded in May 2022. Data on fruit weight and yield (kg/tree) were collected in December 2021 during the winter season after harvesting the fruits at colour break stage. Leaf parameters, including specific leaf area (SLA = leaf area (cm^2)/leaf dry mass (g)), leaves per shoot, total chlorophyll (measured according to Hiscox and Israelstam, 1979), total anthocyanin (measured following the method of Giusti and Wrolstad, 2001), total nitrogen (determined using the Kjeldahl method as described by Jackson, 1973), total phosphorus (measured using the Vanado molybdate method, as per Jackson, 1973), total potassium (determined by flame photometry, following Jackson, 1973), and total micronutrients (measured by Atomic Absorption Spectrophotometry, following the method described by Lindsay and Norvell, 1978), were recorded during April 2022, from randomly sampled 5th or 6th leaves of 6-month-old mature shoots after pruning, with the exception of anthocyanin data, which were collected in December 2021.

2.3.3. Soil parameters

*For studing the effect of the treatments on soil parameters, s*oil samples were collected at distance of 50 cm from the trunk and from two depths viz. 0 to15 cm and 15 to 30 cm. Soil moisture content was recorded gravimetrically from two depths viz. 0–15 cm and 15–30 cm at monthly interval from July 2021 to June 2022 and the moisture content (%) was calculated using the formula:

Moisture percentage = (Mw –Md) × 100/Md

Mw = Fresh weight of soil; Md = Dry weight of soil

With regard the soil chemical parameters, the samples were analyzed for electrical conductivity (Jackson, 1973), *available nitrogen (*Subbiah and Asija 1956), available phosphorus ((Tandon, 1999), exchangeable potassium (Hanway and Heidel,1952), available Zn, Cu, Mn and Fe (Lindsay and Norvell, 1978). Among the soil biological properties, total organic carbon (C_{tot}) was determined following the procedure by Heanes (1984). The soil organic carbon (C_{SOC}) fractions *viz*. very labile organic carbon fraction (%), labile organic carbon fraction (%), less labile organic carbon fraction (%) *and* non labile organic carbon fraction were determined following the procedure by Chan *et al.* (2001). The soil microbial biomass carbon was determined by the fumigation-extraction method (Vance et al., 1987). Soil samples were collected monthly from November 2021 to April 2022 to estimate soil dehydrogenase activity (DHA) using the method outlined by Casida et al. (1964) and Fluorescein Diacetate activity (FDA) using the procedure described by Green et al. (2006).

2.3 *Statistical analysis*

The experiment was laid out in Randomized Block Design with five replicates and five trees per replication. The data were subjected to DMRT analysis using OPSTAT software (CCSHAU, Hissar). Mean separation was conducted with a 5% significance level using OPSTAT software (Sheoran et al., 1998).

3. Results

3.1. Soil moisture dynamics

Soil moisture content varied significantly from July 2021 to June 2022 at 0 to 30cm. The soils with tephrosia biomass mulch had significantly higher soil *moisture* content even in the dryer months of January, March, and April 2022 (Figs. 1 and 2). From July 2021 to June 2022 at 0- 15cm, T3 had the least moisture reduction (45.46%), while control had the most (64.52%). Similarly, at 15–30 cm depth, T3 experienced the least reduction (55.14%), while control had the highest (63.56%).

3.2. Soil electrical conductivity and nutrients

Significant variation ($P \leq 0.05$) in soil electrical conductivity and soil nutrients (available nitrogen, available phosphorus, exchangeable potassium and DTPA extractable Mn, Zn, Fe and Cu) were observed among treatments at both the soil depths (Table: 1,2). As compared to control, mulching at 3.0 kg/m^2 significantly increased soil EC by 150% (0–15 cm) and 22% (15–30 cm), available nitrogen by 23–24%, and available phosphorus by 89.6% and 99.9% at 0 to 15 cm and 15 to 30 cm soil depths, respectively. *Tephrosia* mulching improved exchangeable potassium by 47.47% (0–15 cm) and 60.39% (15–30 cm) as compared to control. In case of DTPA extractable Mn, Zn, Fe and Cu, the highest values were recorded in case of mulching @ 3.0 kg/m^2.

3.3. Soil organic carbon fractions

Significant variation ($P \leq 0.05$) in total organic carbon (C_{tot}), oxidisable organic carbon (C_{soc}) and fractions (C_{frac1}, C_{frac2} and C_{frac4}) were observed among treatments throughout soil depths (0-30cm) (Table: 3,4,5). C_{tot}, C_{soc}, C_{frac1} and C_{frac2} decreased with increasing the soil. The control recorded lowest C_{tot} (30.23 Mg/ha) at both the soil depths. The maximum C_{tot} was observed with the application of 3.0 kg *Tephrosia*, while application of 2.0 kg and 1.0 kg *Tephrosia* was found to be at par with each other. The C_{soc} varied from 24.14 to 30.85 Mg C/ha among different treatments under study. There was 27.79% increment of of oxidisable organic carbon by the application of *Tephrosia* biomass mulch @ 3.0 kg/m^2. The carbon fractions varied in the order of C_{frac1} > C_{frac2} > C_{frac4} > C_{frac3}, with greater values at 0–30 cm.

3.4. Soil biological properties

Mulching with biomass of Tephrosia resulted in significant improvement in soil microbial biomass carbon (C_{MBC}), soil fluorescein diacetate (FDA) and soil dehydrogense (DHA) over the control. In case of C_{MBC}, mulching @ 3.0 kg/m^2 *resulted in highest values at both the soil depths which were* 16.39% (0–15 cm) and 44.66% (15–30 cm) higher than the control (figure: 3). Significantly higher activities of DHA and FDA were recorded with biomass mulching during November 2021 to April 2022 (Table 6a, 6b). Dehydrogenase activity was significantly higher in the *Tephrosia* mulched at the rate of 3 kg per m^2 than in the soils with other treatments. The month of April 2022 witnessed the highest dehydrogenase activity, exhibiting 169% increase compared to the control, whereas the lowest activity was in January 2022, with a 152% increase over the control. Similar trend was recorded in case of FDA activity.

Table 1

Effect of Tephrosia biomass mulching on soil EC and content of available nitrogen, phosphorus and exchangeable potassium **(mean ± standard error).**

Treatments	**Soil EC (mS/cm)**		**Available nitrogen (kg/ha)**		**Available phosphorus (kg/ha)**		**Exchangeable potassium (kg/ha)**	
	0–15 cm	**15–30 cm**	**0–15 cm**	**15–30 cm**	**0–15 cm**	**15–30 cm**	**0–15 cm**	**15–30 cm**
T_1 (3.0 kg dry biomass/m^2)	0.25 ± 0.01^a	0.11 ± 0.00^a	246.96 ± 3.53^a	245.04 ± 3.47^a	33.85 ± 1.77^a	25.39 ± 1.79^a	372.19 ± 19.57^a	323.63 ± 13.35^a
T_2 (2.0 kg dry biomass/m^2)	0.16 ± 0.02^b	0.10 ± 0.00^b	226.59 ± 9.78^{ab}	226.06 ± 8.40^{ab}	27.05 ± 1.43^b	20.77 ± 1.74^a	293.53 ± 15.55^b	235.11 ± 21.45^b
T_3 (1.0 kg dry biomass/m^2)	0.15 ± 0.00^b	0.11 ± 0.00^b	226.33 ± 10.38^{ab}	224.45 ± 10.38^{ab}	24.64 ± 1.30^b	22.93 ± 1.29^a	256.25 ± 2.28^b	248.94 ± 5.67^c
T_4 (No mulching)	0.10 ± 0.00^c	0.09 ± 0.00^c	200.74 ± 13.23^b	198.70 ± 13.43^b	17.56 ± 2.08^c	12.70 ± 1.19^b	252.38 ± 6.04^b	201.77 ± 4.20^c

The value indicated with in the column by the same letters are not significantly different at 0.05 level of probability by DMR

Table 2

Effect of Tephrosia biomass mulching on soil available **Mn, Fe, Zn and Cu (mean ± standard error).**

Treatments	DTPA extractable Mn (ppm)		DTPA extractable Fe (ppm)		DTPA extractable Zn (ppm)		DTPA extractable Cu (ppm)	
	0–15 cm	15–30 cm	0–15 cm	15–30 cm	0–15 cm	15–30 cm	0–15 cm	15–30 cm
T_1 (3.0 kg dry biomass/m^2)	123.34 ± 3.63^a	117.85 ± 4.63^a	117.20 ± 3.21^a	109.67 ± 4.01^a	2.35 ± 0.14^a	2.03 ± 0.16^a	1.36 ± 0.15^a	1.25 ± 0.12^a
T_2 (2.0 kg dry biomass/m^2)	102.00 ± 4.19^b	103.88 ± 4.63^{ab}	111.30 ± 3.83^b	109.09 ± 3.86^a	2.24 ± 0.10^a	2.04 ± 0.09^a	0.95 ± 0.02^b	0.88 ± 0.04^b
T_3 (1.0 kg dry biomass/m^2)	108.28 ± 8.24^{bc}	99.72 ± 3.19^b	100.98 ± 3.21^{bc}	99.00 ± 3.20^b	2.20 ± 0.18^a	1.86 ± 0.18^a	0.77 ± 0.06^{bc}	0.74 ± 0.04^{bc}
T_4 (No mulching)	90.46 ± 2.63^c	90.23 ± 2.26^c	87.30 ± 1.61^c	85.30 ± 1.69^c	1.35 ± 0.06^b	1.12 ± 0.05^b	0.63 ± 0.03^c	0.59 ± 0.03^c

The values indicated with in the column by the same letters are not significantly different at 0.05 level of probability by DMRT

Table 3

Effect of Tephrosia biomass mulching on soil oxidizable and total organic **carbon fractions of guava orchard (mean ± standard error).**

Treatments	Oxidizable organic carbon (Mg/ha) (Csoc)			Total organic carbon (Mg/ha) (C_{tot})		
	0–15 cm	15–30 cm	Total	0–15 cm	15–30 cm	Total
T_1 (3.0 kg dry biomass/m^2)	16.58 ± 0.25^a	14.26 ± 0.26^a	30.85 ± 0.47^a	21.73 ± 0.51^a	18.51 ± 0.43^a	40.25 ± 0.48^a
T_2 (2.0 kg dry biomass/m^2)	15.68 ± 0.26^a	13.68 ± 0.43^{ab}	29.37 ± 0.61^{ab}	19.94 ± 0.19^b	16.98 ± 0.37^b	36.92 ± 0.47^b
T_3 (1.0 kg dry biomass/m^2)	15.49 ± 0.39^b	12.85 ± 0.31^b	28.35 ± 0.68^b	19.23 ± 0.36^{bc}	16.24 ± 0.41^b	35.47 ± 0.49^b
T_4 (No mulching)	13.61 ± 0.42^c	10.53 ± 0.21^c	24.14 ± 0.43^c	17.91 ± 0.45^c	12.32 ± 0.32^c	30.23 ± 0.49^c

The values indicated with in the column by the same letters are not significantly different at 0.05 level of probability by DMRT

Table 4

Effect of Tephrosia biomass mulching on very labile and labile **soil organic carbon fractions of guava orchard (mean ± standard error).**

Treatments	Very labile (Mg/ha) (C_{frac1})			Labile (Mg/ha) (C_{frac2})		
	0–15 cm	15–30 cm	Total	0–15 cm	15–30 cm	Total
T_1 (3.0 kg dry biomass/m^2)	8.06 ± 0.24^a	6.85 ± 0.22^a	14.91 ± 0.36^a	5.57 ± 0.23^a	4.71 ± 0.41^a	10.28 ± 0.59^a
T_2 (2.0 kg dry biomass/m^2)	7.48 ± 0.24^a	6.69 ± 0.19^a	14.17 ± 0.31^{ab}	5.19 ± 0.20^a	4.00 ± 0.28^{ab}	9.19 ± 0.45^{ab}
T_3 (1.0 kg dry biomass/m^2)	7.31 ± 0.47^a	6.17 ± 0.23^a	13.49 ± 0.34^b	4.82 ± 0.15^a	3.54 ± 0.28^{bc}	8.37 ± 0.10^{bc}
T_4 (No mulching)	6.29 ± 0.30^b	4.99 ± 0.23^b	11.28 ± 0.42^c	3.98 ± 0.29^b	3.02 ± 0.09^c	7.00 ± 0.41^c

The values indicated with in the column by the same letters are not significantly different at 0.05 level of probability by DMRT

Table 5

Effect of Tephrosia biomass mulching on less labile and non-labile **soil organic carbon fractions of guava orchard (mean ± standard error).**

Treatments	Less labile (Mg/ha) (C_{frac3})			Non labile (Mg/ha) (C_{frac4})		
	0–15 cm	15–30 cm	Total	0–15 cm	15–30 cm	Total
T_1 (3.0 kg dry biomass/m^2)	2.94 ± 0.12	2.70 ± 0.22	5.64 ± 0.32	5.15 ± 0.51	4.24 ± 0.44^a	9.39 ± 0.47^a
T_2 (2.0 kg dry biomass/m^2)	3.00 ± 0.38	2.99 ± 0.29	5.99 ± 0.52	4.26 ± 0.38	3.29 ± 0.46^a	7.55 ± 0.79^{ab}
T_3 (1.0 kg dry biomass/m^2)	3.35 ± 0.43	3.13 ± 0.15	6.48 ± 0.55	3.74 ± 0.37	3.38 ± 0.23^a	7.12 ± 0.25^b
T_4 (No mulching)	3.34 ± 0.40	2.50 ± 0.21	5.85 ± 0.41	4.30 ± 0.82	1.78 ± 0.23^b	6.08 ± 0.69^b

The values indicated with in the column by the same letters are not significantly different at 0.05 level of probability by DMRT

Table 6

a. Effect of biomass mulching of *Tephrosia* bio-mulching on soil dehydrogenase activity in guava orchard

Treatments	Soil dehydrogenase activity (µg TPF day^{-1} g $soil^{-1}$)					
	Nov-21	Dec-21	Jan-22	Feb-22	Mar-22	Apr-22
T_1(3.0 kg dry biomass/m^2)	57.94 ± 2.55^a	51.76 ± 3.05^a	50.11 ± 3.28^a	57.87 ± 1.88^a	61.78 ± 1.28^a	65.35 ± 12.76^a
T_2 (2.0 kg dry biomass/m^2)	36.91 ± 3.73^b	36.38 ± 1.22^b	45.96 ± 2.79^a	36.87 ± 1.70^b	59.15 ± 1.49^a	55.44 ± 2.49^b
T_3(1.0 kg dry biomass/m^2)	43.49 ± 2.50^b	37.35 ± 2.71^b	43.89 ± 2.33^a	30.55 ± 1.22^c	40.84 ± 0.78^b	29.00 ± 1.55^c
T_4(No mulching)	20.00 ± 2.56^c	16.94 ± 1.64^c	19.87 ± 1.92^b	12.72 ± 0.99^d	23.68 ± 0.96^c	24.23 ± 1.82^c
#The values indicated with in the column by the same letters are not significantly different at 0.05 level of probability by DMRT						

Table 6

b. Effect of biomass mulching of *Tephrosia* bio-mulching on soil fluorescein diacetate activity in guava orchard

Treatments	Fluorescein diacetate (mg fluorescein kg $soil^{-1}$ hr^{-1})					
	Nov-21	Dec-21	Jan-22	Feb-22	Mar-22	Apr-22
T_1(3.0 kg dry biomass/m^2)	65.06 ± 5.57^a	54.83 ± 2.25^a	52.22 ± 4.21^a	93.41 ± 3.61^a	67.35 ± 2.17^a	95.16 ± 6.15^a
T_2 (2.0 kg dry biomass/m^2)	37.85 ± 2.28^b	28.30 ± 2.39^b	34.25 ± 3.85^b	79.56 ± 5.70^a	44.85 ± 3.44^b	63.92 ± 8.42^b
T_3(1.0 kg dry biomass/m^2)	35.18 ± 3.10^b	44.52 ± 1.39^c	54.94 ± 3.18^a	58.45 ± 5.83^b	38.03 ± 1.36^b	49.50 ± 8.31^{bc}
T_4(No mulching)	23.95 ± 1.71^c	16.81 ± 2.52^d	20.94 ± 3.26^c	21.78 ± 5.29^c	23.68 ± 3.65^c	34.00 ± 1.43^c
#The values indicated with in the column by the same letters are not significantly different at 0.05 level of probability by DMRT						

3.5. Phenological behaviour of guava plants (days)

During the study period, all the trees exhibited consistent pattern of sequential phenophases. The amount of mulch applied had a significant ($P \leq 0.05$) effect on duration of the phenological stages (Table 7). Application of mulch @ 3.0 kg/m^2 resulted in reduction in the duration of winter bud stage and leaves development stage while there was significant increase in the duration of bud swelling stage and appearance of flower bud stage. Plants with 3.0 kg dry biomass/m^2 of mulch had the earliest bud swelling (75.36 days), in contrast the non-mulched plants which had the longest duration of bud dormancy (104.53 days). The duration of bud swelling stage was recorded to be highest with 3.0 kg dry biomass/m^2 (24.54 days) while all other treatments were at par with control. The maximum duration of appearance of flower bud was in 3.0 kg dry biomass/m^2 of mulch (2.46 days) while all other treatments were at par with control.

Table 7

Effect of biomass mulching of *Tephrosia* on duration of phenological stages in guava

Phenology (days)	Winter bud stage (00)	Bud swelling stage (01)	Leaves completely developed stage (19)	Appearance of flower bud stage (51)
T_1(3.0 kg dry biomass/m^2)	75.36 ± 5.26^c	24.54 ± 1.89^a	10.94 ± 0.44^b	2.46 ± 0.07^a
T_2 (2.0 kg dry biomass/m^2)	86.53 ± 1.02^b	19.74 ± 0.53^b	10.76 ± 0.28^b	1.90 ± 0.27^b
T_3(1.0 kg dry biomass/m^2)	92.46 ± 1.94^b	18.08 ± 0.43^b	12.46 ± 0.47^a	1.62 ± 0.11^b
T_4(No mulching)	104.53 ± 1.08^a	17.80 ± 1.10^b	11.44 ± 0.29^a	1.80 ± 0.07^b

#The values indicated with in the column by the same letters are not significantly different at 0.05 level of probability by DMRT

3.6. Guava plant growth, fruit and leaf parameters

The guava plants treated with varying quantity of *Tephrosia* mulch showed significant variation in terms of trunk diameter (cm), fruit yield (Kg/ tree and t/ha), fruit weight (g), number of leaves per shoot, specific leaf area (cm^2g^{-1}), total chlorophyll content (mg g^{-1} fresh weight) and total anthocyanin content in leaves (mg/100g) (Table 8).

Table 8
Effect of mulching of *Tephrosia* biomass on guava plant, fruit and leaf

Treatments	Trunk Diameter (cm)	Yield per tree (kg/tree) (winter crop 2021)	Fruit weight (kg)	Leaves per shoot	Specific leaf area (cm^2g^{-1})	Total Chlorophyll	Total Anthocyanin (mg/100g)
T_1(3.0 kg dry biomass/ m^2)	9.48 ± 0.48^a	4.04 ± 0.12^a	111.34 ± 2.70^a	56.04 ± 2.21^a	109.13 ± 2.69^a	1.68 ± 0.04^a	7.34 ± 0.21^d
T_2 (2.0 kg dry biomass/ m^2)	8.01 ± 0.47^{ab}	3.01 ± 0.20^b	105.06 ± 5.13^{ab}	47.88 ± 2.75^b	103.79 ± 1.45^{ab}	1.65 ± 0.03^a	18.12 ± 0.32^c
T_3(1.0 kg dry biomass/ m^2)	7.38 ± 0.84^b	2.18 ± 0.28^{bc}	104.98 ± 4.13^{ab}	36.52 ± 1.94^c	96.20 ± 2.74^{bc}	1.39 ± 0.02^b	35.27 ± 0.59^b
T_4(No mulching)	6.30 ± 0.27^b	2.84 ± 0.25^c	100.30 ± 4.61^b	15.16 ± 1.52^d	91.98 ± 2.69^c	1.37 ± 0.04^b	45.45 ± 0.95^a
#The values indicated with in the column by the same letters are not significantly different at 0.05 level of probability by DMRT							

The highest values of trunk diameter (cm), fruit yield (Kg/ tree and t/ha), fruit weight (g), number of leaves per shoot, specific leaf area (cm^2g^{-1}), total chlorophyll content (mg g^{-1} fresh weight) were found in case of the treatment with biomass mulching @ 3.0 kg/m^2. However it was interesting to note the reduction in leaf anthocyanin content in the order $T_4 > T_3 > T_2 > T_1$.

3.7. Guava leaf nutrient content

The concentration of total nitrogen, total phosphorus, total potassium and total micronutrients like Mn, Zn and Fe) are presented in the Table 9. In case of nitrogen, potassium, total Mn, total Zn and total Fe the maximum value was recorded in case of application of mulch @ 3.0 kg/m^2. In case of total phosphorus, all the treatments resulted in significant increase over that of control and were at par with each other. There was an overall improvement of 35.6% in total nitrogen, 27.6% in total phosphorus, 111.1% in total potassium, 72.3% in total iron, 51.5% in total zinc, 75.4% in total manganese, and 66.6% in total copper.

Table 9
Effect of mulching of *Tephrosia* biomass on guava leaf nutrient content

Treatments	Total nitrogen %	Total phosphorus %	Total potassium %	Fe ppm	Zn ppm	Mn ppm
T_1(3.0 kg dry biomass/m^2)	1.60 ± 0.06^a	0.37 ± 0.02^a	2.28 ± 0.06^a	150.30 ± 5.07^a	36.98 ± 2.09^a	166.00 ± 14.87^a
T_2 (2.0 kg dry biomass/m^2)	1.38 ± 0.04^b	0.37 ± 0.02^a	1.74 ± 0.08^b	115.80 ± 3.78^b	30.40 ± 1.74^b	121.40 ± 7.42^b
T_3(1.0 kg dry biomass/m^2)	1.35 ± 0.03^b	0.35 ± 0.03^a	1.61 ± 0.11^b	102.60 ± 4.78^c	27.40 ± 2.35^{bc}	150.40 ± 5.03^a
T_4(No mulching)	1.18 ± 0.06^c	0.29 ± 0.01^b	1.08 ± 0.15^c	87.20 ± 4.49^d	24.40 ± 0.77^c	94.60 ± 4.66^c
#The values indicated with in the column by the same letters are not significantly different at 0.05 level of probability by DMRT						

4. Discussion

4.1. Soil moisture dynamics

Tephrosia biomass consistently maintained soil moisture levels, particularly during dry months and quantity of biomass retained was directly proportional to the amount of moisture retention. Beneficial effects of *Tephrosia candida* in retaining soil moisture in bael orchard have also been reported by Das et al (2021). Hernández-Aranda et al. (2021) found that the utilization of similar mulching techniques had a twofold effect in retaining moisture and preventing light penetration, effectively suppressing weeds and promoting microbial growth, along with enhancing soil structure.

4.2. Soil electrical conductivity and soil nutrients

The study clearly indicated improvement in the soil chemical properties with mulching of *Tephrosia* biomass. The increment in soil electrical conductivity (EC) can be attributed to increased soil moisture (Grisso et al., 2005), nitrate nitrogen, or mineralizable nitrogen (Ju et al., 2007). According to Das et al. (2021) the *Tephrosia* biomass contains 2.94% nitrogen, 0.16% phosphorus, and 2.94% potassium. Accordingly the total quantity of nutrients per m^2 in the mulching material under the treatments 3.0 Kg/m^2, 2.0 Kg/m^2 and 1.0 Kg/m^2 can be calculated to be 88.2 g, 58.8 g, 29.4 g of nitrogen, 4.8 g, 3.2 g, and 1.6 g of phosphorus, and 31.8 g, 21.2 g, and 10.6 g of potassium, respectively. Hence, addition of nutrients in the plant basin through the mulching material was attributed to increase in the content of different nutrients in the plant basin. Apart from that organic mulch application reduces phosphorus movement and fixation, as organic acids released during decomposition minimize phosphorus fixation with aluminium (Mensah, 2015). Higher potassium content in the study may result from reduced leaching, increased soil moisture, electrical conductivity, and organic acid release during biomass decomposition, and easy movement potassium from plant tissues to soil. Organic acids released during decomposition form chelates with micronutrients, increasing their availability in soil and to plants. These chelates are more stable than the free micronutrients and, therefore, are more easily absorbed by the plants (Mackowiak et al., 2001).

4.3. Soil organic carbon and its fractions

Soil with high organic matter content promotes microbial proliferation, nutrient availability and soil structure (Liddle et al., 2020). Intercultural operations have been shown to reduce the soil carbon content by 30–50% (Six et al., 2002; Dinakaran et al., 2014). Application of *Tephrosia* in the guava orchard helped to improve soil organic carbon and its fractions. The higher C_{tot} and C_{soc} in the surface soil might be due the addition of biomass directly in to the surface soil and lack of biological nutrient recycling in the deeper layers (Naik et al., 2017), and this might contribute towards long term carbon sequestration.

Tephrosia treatments improved organic fractions, including highly labile, labile, and non-labile fractions, promoting nutrient cycling and crop productivity. Greater labile pool of organic carbon in the present study may be due to the higher C_{mic}, DHA, and FDA activity supplied readily decomposable carbon. *Tephrosia* litter had higher ash, polyphenol, and lignin can lead to organic carbon resistance and addition to the recalcitrant pool of soil organic carbon (Mafongoya et al., 2003). Therefore, increase in non-labile organic carbon in the *Tephrosia* treated soil may be due to the quality and quantity of leaf litter. Additionally, our present study also showed a 40% of carbon content in *Tephrosia candida* leaf litter which will apparently contribute towards addition of 1.2 kg carbon per m^2. Therefore, the direct application of *Tephrosia* as mulch might also have contributed towards the increment in soil organic carbon.

4.4. *Soil biological properties like microbial biomass carbon dehydrogenase activity and Soil fluorescein diacetate activity (FDA)*

C_{mic} generally accounts for 1–5% of C_{tot} (Mandal 2005; Naik et al., 2017) and microbial adaptation or community changes may increase carbon use efficiency (Allison et al., 2010). *Tephrosia* mulching increased C_{mic} due to the supply of oxidizable or mineralizable carbon, nutrients as substrate and created favourable microclimate for the growth and reproduction by maintaining favourable rhizospheric microclimate, while the lower value in the control might be due the unfavourable rhizospehric microclimate, leaching of available nutrients and lower biomass accelerates the carbon loss (Allison et al., 2010).

DHA measurement shows microbial oxidation (Nannipieri *et al*., 2002; Patra *et al*., 2006), and high dehydrogenase activity is a valid soil microbial activity metric affected by temperature, microbiota, moisture, vegetation, and aeration (Klein et al., 1971). Mulching with *Tephrosia* biomass reliably improved DHA over a 6-month period. Long-term effects are associated with increased oxidizable organic carbon, substrate availability (including soil nutrients and rhizospheric moisture), and soil temperature (Rastin et al., 1988). This can explain the peak in the activity of dehydrogenase during the month of April 2022 in the present investigation.

Similarly, mulching with *Tephrosia* biomass at 3.0 kg/m^2 enhanced FDA activity. Singh et al. (2018) and Kumawat et al. (2017) showed similar increases in soil FDA activity in the context of residue management. FDA activity in April 2022 was 179% greater than the control, whereas it was 149% higher in January. A rapid rise in FDA activity was found with mulch decomposition, similar to Tang et al. (2004), who reported a 60–120% increase in FDA activity from mulched treatments to controls. The monthly fluctuation in enzyme activity is affected by soil temperature, microbiota, moisture, vegetation, and aeration (Rastin et al., 1988). The increased FDA activity in our study implies greater microbiological activity in the mulched soil, improved biological stability of the mulched materials and improved plant nutrient availability. The decline in dehydrogenase and fluorescein diacetate (FDA) activities during the initial months upto January 2022 mainly due to reduced microbial decomposition of the newly applied mulch, because of the higher carbon-to-nitrogen (C:N) ratio, combined with lower temperatures, which collectively hinder microbial decomposition processes (Park and Kremer, 2009).

4.5. Guava leaf nutrient content

Mulching prevents root shrinkage, maintains optimal soil microclimates and soil temperature there by improves the absorption of N, P. K and micronutrients (Kozlowski, 1972; Russell, 1975; Dantas et al., 2007; Dutta, 2009). The increase in leaf nutrient content can be attributed to synergistic effect of applied nutrients (Tiwari et al., 2018) which might contributed towards more absorption and translocation. As the biomass mulching enriches the soil humus, which was the source of easily available nutrients for plant absorption (Bucki and Siwek, 2019).

4.6. Phenological behaviour of guava

The phenological behavior of guava have been reported to be affected by climate conditions such as temperature (Normand and Robert Habib, 2001; Padilla-Ramirez et al., 2012), rainfall (Das et al., 2018), and the initial nutrient content of the soil (Normand and Robert Habib, 2001). The hastening of bud swelling by 29.17 days and a longer duration of bud swelling and appearance of the flower buds with respect to 3.0 kg/m^2 of biomass mulching compared to non-mulching might be due to the increase in nutrient in the leaf and soil. The duration of ‘leaves completely developed stage’ was reduced by 0.5 days with mulching @ 3.0 kg/m^2 compared to no mulching which can be attributed to the influence of degree-day accumulation and lower temperatures during vegetative flushing.

4.7. Guava plant growth, fruit and leaf parameters

Increased guava plant growth and fruit yield with biomass mulching have been reported by several researchers (Das et al., 2010; Bhattacharjee, 2020; Nandhini et al., 2021). The improvements in guava plant growth parameters with *Tephrosia* biomass mulching can be attributed to the improvement in soil fertility, as evidenced by increased soil nutrient and soil moisture regime. Das et al., (2021) also reported a better trunk diameter under *Tephrosia* treatments under bael orchard. The substantial enhancements in plant growth parameters during the second year of the study can be attributed to the cumulative effects of previous years' biomass mulching. There was in increment in fruit weight and yield of guava, similar study was also reported by Shukla et al., (2009) by the use of organic fertilizers and bio fertilizers. The increase in photosynthesis resulting from increase in number of leaves and total chlorophyll content might have contributed towards the increase in fruit weight and fruit yield. The higher leaf number recorded in the present study can be attributed to the increase in macro and micronutrient content in the soil due to biomass mulching.

Leaf anthocyanin pigmentation, an indicator of low temperature stress (Hao et al., 2009). This phenomenon is commonly observed across various guava genotypes. Interestingly, present study revealed that mulching played a significant role in reduction in leaf anthocyanin content which might have contributed towards shortening of the duration of the winter bud stage in our phenological study.

5. Conclusion

The study clearly demonstrated that mulching the guava plant basin with *Tephrosia* biomass at rates of 3.0 kg/m^2 or 2.0 kg/m^2 resulted in hastening of phenophases viz winter bud and leaf development, quicker bud swelling and the appearance of flower buds. Additionally, it resulted in higher trunk diameter, increased fruit yield, larger fruit size, and enhanced leaf parameters. Notably, it led to a significant reduction in leaf anthocyanin content. Furthermore, it effectively maintained higher soil moisture levels, even during dryer months, and significantly improved soil electrical conductivity, nutrient content (nitrogen, phosphorus, potassium, micronutrients), and organic carbon fractions. These improvements were particularly evident at the 0–15 cm depth. This study also demonstrated the positive influence of *Tephrosia* mulch on soil biological properties, such as microbial biomass carbon, dehydrogenase activity, and soil fluorescein diacetate activity. Consequently, adopting the technique of biological nutrient recycling using *Tephrosia candida* biomass mulching can be considered as a sustainable agricultural approach to improve guava productivity and soil quality, leading to potential benefits for farmers and the environment, even in regions with low fertility.

Declarations

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Credit authorship contribution statement

In the study, Abeer Ali served as the principal investigator and lead researcher, conducted the primary data collection, analysis, interpretation and contributed as the main author for the manuscript. Bikash Das is the main coordinator of the project and conceptualized the study. Execution of the study was conducted by Bikash Das, M.K. Dhakar, S.K. Naik, V.B. Patel, and G.P. Mishra. Bikash Das, M.K. Dhakar and S.K. Naik provided laboratory facilities. Bikash Das and M.K. Dhakar were involved in the preparation of manuscript

Data availability

Data will be made available on request to the main author Abeer Ali, abeerali8281@gmail.com.

Supplementary information: T*he plant collection and use was in accordance with all the relevant guidelines.*

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Figures

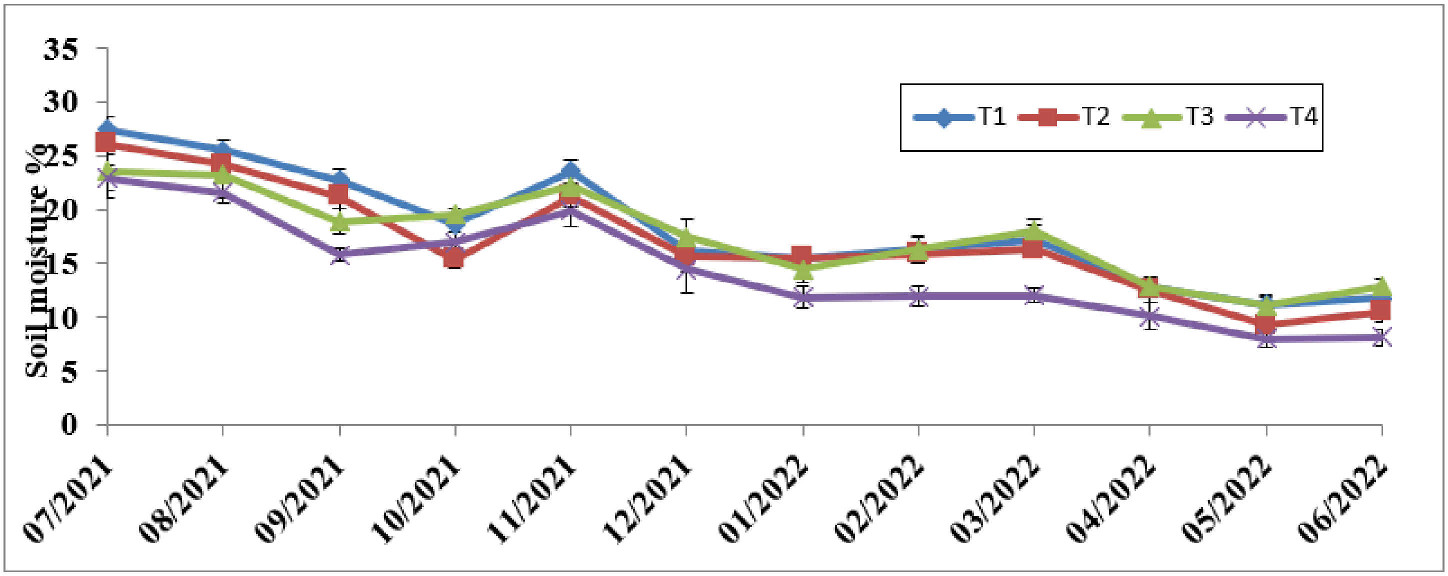

Figure 1

Effect of biomass mulching of *Tephrosia* on soil moisture (%) at 0 to 15 cm depth

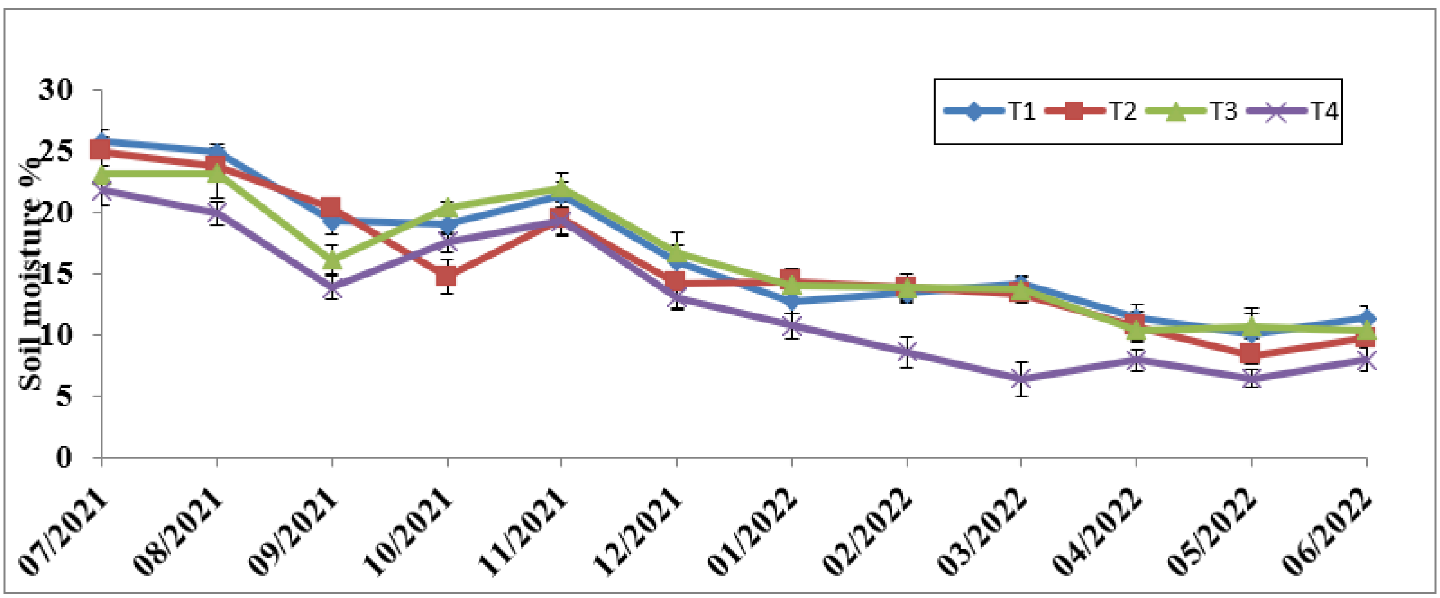

Figure 2

Effect of biomass mulching of *Tephrosia* on soil moisture % at 15 to 30 cm depth

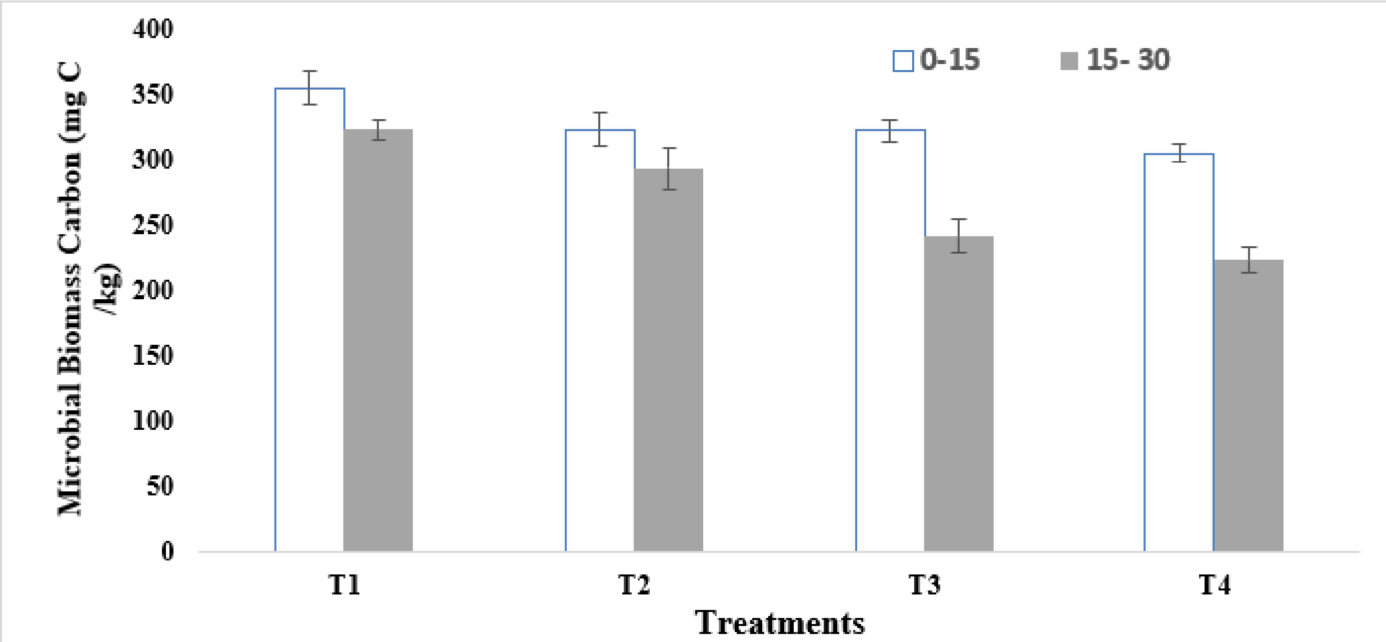

Figure 3

Effect of biomass mulching of *Tephrosia* on soil microbial biomass carbon (mean± standard error).