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ORIGINAL ARTICLE

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Experimental characterization of the hydraulic and thermal conductivity of organic rich sandy clay loam soil using organic amendment

M.C. Subha[1,*] | F. Jeyamangalam[1]

[1,2]Department of Physics and Research Centre, Sarah Tucker College (Autonomous), Tirunelveli-627007, Tamil Nadu, India. (Affiliated to Manonmanium Sundaranar University, Tirunelveli, Tamil Nadu, India)

***Corresponding Author:**
E-mail: subhamc86@gmail.com

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ABSTRACT

Soil infertility due to inorganic fertilizer is a serious problem in India, which would degrade soil health, nutrients and crop production. Implementing organic manure application in agricultural practice is the most efficient approach of enhancing soil fertility and productivity. This experimental study aimed to investigate the effect of farm yard manure (FYM), goat manure (GM) and charcoal manure (CM) rates on soil physical, chemical, thermal and hydraulic properties and also on the optimum yield of onion (*Allium cepa* L.). The field experiment was conducted during early *kharif* season in the year 2020 at Alangulam in Tenkasi district, Tamil Nadu, South India. The experiment comprised of 13 treatments laid out in a completely randomized block design (CRBD) with three replicates. Application of FYM, GM and CM rates showed a highly significant impact ($p < 0.05$) on the onion yield. Onion yield was significantly highest in the soil treated with CM+FYM+GM @16.5 t ha^{-1} (T_4C) as (4758 kg ha^{-1}) and CM+GM @12.5 t ha^{-1} (T_2 B) as (4700 kg ha^{-1}) compared to control (1500 kg ha^{-1}).The findings of this study revealed that incorporation of CM, FYM and GM increased soil structure, soil aeration through the pore space and decreased thermal conductivity. Application of CM along with FYM and GM @16.5 t ha^{-1} increased hydraulic conductivity (2.75 cm hr^{-1}) and permeability (0.07 cm s^{-1}) compared with the control as 1.05 cm hr^{-1} and 0.03 cm s^{-1} respectively. Thus the balanced use of organic amendments in combination is necessary for sustaining soil fertility and onion productivity. Based on the results of the study, combination of CM, FYM and GM at 16.5 t ha^{-1} is recommended as the most effective cultivation practice to produce high yield and good quality onions in Alangulam, Tenkasi district, Tamil Nadu, South India.

1 | INTRODUCTION

Worldwide, onion (*Allium cepa* L.) is a very important commercial vegetable crop and indispensable item in every kitchen as a condiment. It is one of the most significant, traditional and commonly farmed crops in India. Nowadays, many small hold farmers producing onion in most part of the country. Onion is notable for its productivity and its high economic value. Due to its strong flavor, it is frequently used as a seasoning or vegetable cum condiment throughout the world. In India, onion is an essential component of many foods, beauty products and medicines. In addition, it is a rich source of antioxidants, sulphur containing compounds. It is also high in carbohydrates, sugar, protein, fiber and fat. Organic farming system increases soil organic matter, which in turn maintains the physical, chemical and biological properties of soil thereby improves the crop yield. The incorporation of organic amendments with soil is a common agricultural practice that increases soil organic matter, fertility and improves soil structure and texture (Arshad *et al.,* 2024). Organic amendments application can significantly improves crop yield, soil physical properties and improves soil enzyme activities and hence benefits the producers. Application of amendments which reduced surface runoff (38%) and soil loss (52%) compared to control treatment in soybean crop (Rashmi *et al.,* 2024). Organic amendment improve soil fertility levels by increased soil carbon levels beside ameliorating the harmful effects of sodicity (Bandyopadhayay *et al.,* 2021).Soil hydraulic and thermal conductivity are critical properties influencing agricultural productivity, environmental management, and climate change mitigation. Hydraulic conductivity governs

the movement of water through the soil matrix, affecting plant water availability, irrigation efficiency, and groundwater recharge (Abdelhafeez *et al.,* 2022). On the other hand, thermal conductivity controls heat transfer in soils, playing a pivotal role in soil temperature regulation, microbial activity, and root development (Savin *et al.,* 2021). These properties are particularly significant in organic-rich soils, which are essential for enhancing soil fertility, water retention, and thermal stability. Farm yard manure (FYM), goat manure (GM), and charcoal manure (CM) are widely used organic amendments due to their ability to enhance soil structure, porosity and organic carbon content (Zhang *et al.,* 2022). Addition of organic manures tended to improve physico-chemical properties of soil (Sharma *et al.,* 2023). Improved soil structure promotes soil moisture availability and physiological function (Lamptey *et al.,* 2020). FYM and GM contribute to nutrient cycling and microbial activity, while CM, owing to its porous structure, improves water retention and aeration (Lehmann *et al.,* 2020). Panchagavya used as a natural fertilizer and pest repellent, Panchagavya promotes soil fertility and reduces reliance on chemical inputs (Rajive Singh and Raman Jeet, 2024). The present study was conducted to investigate the effect of CM, FYM and GM alone and in combination on hydraulic and thermal conductivity of the soil and effect of manure on yield of onion and its effect on soil properties. Organic amendments can enhance soil properties, contributing to improved water use efficiency and soil thermal dynamics. The findings of this research can be instrumental in developing sustainable soil management strategies.

HIGHLIGHTS

- Application of organic amendments significantly enhance soil properties.
- Treatments T_4 C (4758 kg ha^{-1}) and T_2 B (4700 kg ha^{-1}) produced 68 % highest onion yield compared to the control (1500 kg ha^{-1}).
- Organic amendments increase water holding capacity, hydraulic conductivity and soil permeability.
- Organic amendments reduce soil thermal conductivity, improving soil aeration and structure.
- Combination of CM, FYM, and GM at 16.5 t ha^{-1} was the most effective for sustainable onion production.

2 | MATERIALS AND METHODS

2.1 | Study area

The field experiment was conducted at farmer's land at Alangulam in Tenkasi district, Tamil Nadu, South India (latitude 8.87° N, longitude 77.5° E, altitude 127 m) in 2020 during early *kharif* season. *Fig. 3* shows the location map of alangulam. The experimental site has an average annual rainfall of 889 mm and a mean annual temperature of 28.5 °C. The maximum temperature was of 30^0 C with a mean of 25^o C while the minimum temperature was 20^o C. The mean relative humidity was 63.3%. The average wind speed was 2.53 km hr^{-1}. The soil moisture and temperature was 14.7% and 32.5^o C. The atmospheric pressure was 1015 h pa. The mean rainfall received during cultivation was 1.7 mm. The soils of experimental site had red sandy clay loam texture. The red color in soil is due to high iron content. It is moderately permeable and well-drained soil and high amounts of soil moisture.

2.2 | Experimental details

The experiment was laid out in a complete randomized block design (CRBD) with three replicates. The plot sizes were 8 m x 5 m. The crop chosen for this experimental study was Onion (*Allium cepa* L.) variety Nasik red N-53.The organic amendments chosen for the field experiment were CM, GM and FYM at three different doses such as 8.5, 12.5 and 16.5 t ha^{-1} respectively and it is noted as A, B and C (Table 1). Control does not receive any manure. All the treatments were replicated three times except control. The field area was completely ploughed twice to get tilth using tractor. Soil was deep turned through ploughing, to kill weeds and aerate the soil. Soil clumps were breaked and land was completely well levelled by collecting the weeds and stones. Experiment was laid out in a randomized block design (RBD) land was splitted into 13 plots. Organic manures such as CM, FYM and GM were measured, applied and mixed well with the soil manually 30 days before transplanting onion seedlings in the field. Sprinkler irrigation was used. About 45 days of onion seedlings were transplanted in the experimental field. Optimum spacing of 15 cm between rows and 10 cm between onion plants used. Irrigation was given at an interval of 3 days depending upon soil moisture. Hand weeding was carried out as per treatment. Weed free check was hand weeded regularly as and when the weeds emerged. In hand weeding practice three hand weeding were carried out at 20, 40 and 60 days. The vegetation period was from may to july in the year 2020. Soil samples were collected from all the 13 plots after 30 days of manure application from a depth of 0-15 cm from the study site. Onion was ready after 3 months of transplanting. Onion harvested after it reaches physiological maturity. Onion yield on every treatments were measured and also soil samples were collected for testing after harvesting.

2.3 | Soil sampling and analysis

Soil samples were analyzed to find the soil chemical and physical properties. The soil physical properties such as bulk density (BD), particle density (PD), porosity (PO), pore space (PS), water holding capacity (WHC) and saturated moisture (SM) were analyzed by keen raczkowski (KR) box method (Keen Raczkowski, 1921). The soil physical

TABLE 1 Dosage of organic manure used in different treatments

S.No.	Manure	Dosage (t ha^{-1})	Plots	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
1	CM	8.5	T1-A	190	95	465
2	CM	12.5	T1-B	175	73	543
3	CM	16.5	T1-C	168	110	518
4	CM+GM	8.5	T2-A	165	120	555
5	CM+GM	12.5	T2-B	190	88	543
6	CM+GM	16.5	T2-C	148	110	465
7	CM+FYM	8.5	T3-A	138	123	555
8	CM+FYM	12.5	T3-B	150	80	390
9	CM+FYM	16.5	T3-C	130	123	593
10	CM+FYM+GM	8.5	T4-A	123	88	315
11	CM+FYM+GM	12.5	T4-B	140	98	743
12	CM+FYM+GM	16.5	T4-C	105	80	440
13	CONTROL	No manure	T5	105	70	240

CM - Charcoal Manure; FYM - Farm Yard Manure; GM - Goat Manure; A - 8.5 t ha^{-1}; B - 12.5 t ha^{-1}; C - 16.5 t ha^{-1}

properties were determined by the KR box method after drying a defined volume of soil in an oven-dried at 105°C for 24 hr. To estimate the selected chemical properties of soil, soil pH value by Blackman's glass electrode pH meter, organic carbon (OC), by walkey and black wet (1934) oxidation method, available nitrogen (N) by the kjeldahl method, carbon ratio to nitrogen (C/N), available phosphorous (P) by spectrophotometric method and potassium (K) were analyzed using flame photometer. Hydraulic conductivity of soils was determined using falling head permeameter method (Israelson and Hansen, 1962). Thermal conductivity of soil samples were determined using Lee's Disc method (Lee and Charlton's, 2009). Experimental set up of hydraulic and thermal conductivity were given in *Fig.1* and *Fig. 2*. Minerals, micro and macro pores present in the samples were identified using scanning electron microscope coupled with energy dispersive x-ray spectrum (Tripti Pachauri *et al.,* 2013). SEM is the versatile technique, quickly used for quantification of macro elements in soil. SEM is an important analytical tool for the morphological and micro characterization of soil .EDX used to obtain qualitative and quantitative information about the elemental composition of the sample.

2.4 | Statistical analysis

Treatment effects were analyzed by one-way analysis of variance (ANOVA) using SPSS 19.0 (SPSS Inc.). The least significant difference test was employed to assess statistical differences between treatments at $p = 0.05$.

3 | RESULTS AND DISCUSSION

3.1 | Soil properties

Enhancement of soil chemical properties after the incorporation of organic amendments following onion harvesting are presented in Table 2. Findings revealed that organically treated soil increased with available nitrogen (105 -190 kg ha^{-1}), available phosphorous (70-123 kg ha^{-1}) and available potassium (240-743 kg ha^{-1}) compared to control. Onion bulb yield increased almost 50 % compared to control as the level of nitrogen and phosphorous were increased. No significant differences in soil EC (0.26-0.31 dS m^{-1}) and pH

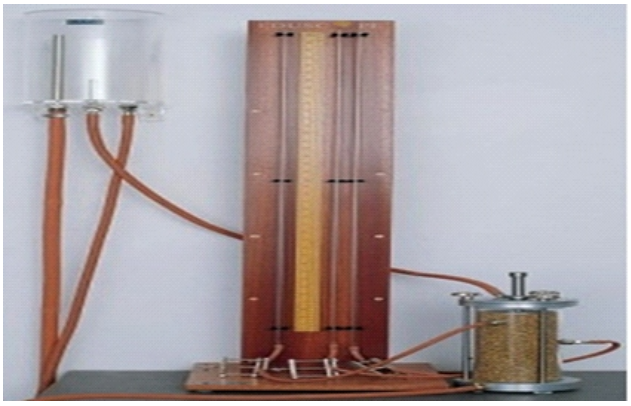

FIGURE 1 Hydraulic conductivity - Falling head permeameter experimental setup

FIGURE 2 Thermal conductivity - Lee's Disc apparatus experimental setup

TABLE 2 Effect of organic manure on soil chemical properties

S.No.	Manure	Plots	EC (dS m^{-1})	pH	SOC (%)	SOM (%)	C/N	Yield (kg ha^{-1})
1	CM	T1 A	0.31	7.8	0.76	1.31	0.40	3003
2	CM	T1 B	0.25	7.7	0.38	0.65	0.21	3575
3	CM	T1 C	0.24	7.8	0.82	1.41	0.49	2473
4	CM+GM	T2 A	0.33	7.8	0.65	1.12	0.39	4363
5	CM+GM	T2 B	0.3	7.7	0.43	0.74	0.22	4700
6	CM+GM	T2 C	0.3	7.6	0.33	0.56	0.22	3073
7	CM+FYM	T3 A	0.24	7.9	0.71	1.22	0.51	4129
8	CM+FYM	T3 B	0.27	7.8	0.49	0.84	0.32	3550
9	CM+FYM	T3 C	0.36	7.8	0.44	0.75	0.33	4548
10	CM+FYM+GM	T4 A	0.35	7.7	0.38	0.65	0.31	2553
11	CM+FYM+GM	T4 B	0.35	7.8	0.76	1.31	0.54	4335
12	CM+FYM+GM	T4 C	0.29	7.9	0.44	0.75	0.41	4758
13	CONTROL	T5	0.38	7.9	0.3	0.51	0.19	1500
		CD	0.02	0.07475	0.14	0.23	0.08	838.24

CM - Charcoal Manure; FYM - Farm Yard Manure; GM - Goat Manure; N - Nitrogen; P - Phosphorous; K - Potassium; EC - Electrical conductivity; OC - Organic carbon; OM - Organic matter; A - 8.5 t ha^{-1}; B - 12.5 t ha^{-1}; C - 16.5 t ha^{-1}.

For treatment details see Table no. 1.

(7.6-7.9) were detected among the organic-amended soils and the control. Organic amendments have been recognized as effective means to improve soil physical properties. FYM, GM and CM has many beneficial effects on soil physical conditions over a wide range of climates, soils, and cropping systems. Soil organic carbon (SOC) increased from 0.3 % to 0.82 % with an increase in the application rate of organic manure. These findings are in line with Pragya Kurmi *et al.* (2024) who reported that addition of organic manure increased the organic carbon content of soil which helped to reduce the mass of soil per unit volume. It was observed that charcoal manure @16.5 t ha^{-1} significantly improved the organic carbon content by 0.82 % .Combined use of CM+FYM+GM @12.5 t ha^{-1} and CM @8.5 t ha^{-1} having the OC value as 0.76 % which was 14% greater than CM+GM added plot @ 8.5 t ha^{-1} concentration (0.65%) and 6.5 % larger than CM+FYM added plot @8.5 t ha^{-1} concentration. The order of increase of organic carbon was CM(C) >CM (A)>CM+FYM (A)>CM+GM (A)>CONTROL. SOM also slightly increased from 0.52% to 1.4% with the addition of organic amendments relative to control (0.52%). Highest SOM value observed in CM @16.5 t ha^{-1} plot as 1.41 % and CM+FYM+GM @12.5 t ha^{-1} and CM @8.5 t ha^{-1} as 1.31 %.Soil moisture content mainly depends on Soil organic matter and bulk density. Data in Table 3 depicts that soil bulk density and particle density decreased significantly with the incorporation of organic amendments compared to the control. The rate of movement of water down into the soil is called the hydraulic conductivity (HC) of the soil. The rate of movement of water and air in the soil is called permeability of the soil. Soil hydraulic conductivity influencing water infiltration and aeration in soils. Table 4 shows the effect of organic manure on soil hydraulic and thermal conductivity. Application of CM, GM and FYM increased HC and permeability of soil. HC ranged from 1.05 to 2.75 cm hr^{-1}. Present study revealed that organic manure treated soil had more macro pores and these pores hold water which leads to increase hydraulic conductivity compared to control.

Added amendments increased soil porosity and also increased HC (*Fig. 4*). A perusal of data revealed that, after harvesting onion crop significantly higher hydraulic conductivity (2.75cm hr^{-1}) was recorded for soil treated with triple manure CM+GM+FYM @ 16.5 t ha^{-1} which was 61.9 % greater than control. The lowest hydraulic conductivity was observed under control (1.04 cm hr^{-1}). The data regarding hydraulic conductivity of this study indicated that incorporation of organic manures improved drainability. Thermal conductivity is important for the transmission of heat in the soil. Thermal conductivity varied from 0.017 to 0.032 W m^{-1} K^{-1}. Lowest thermal conductivity (0.017 W m^{-1} K^{-1}) was obtained for combination of CM+GM+FYM plot @ 12.5 t ha^{-1} and highest value (0.03 W m^{-1} K^{-1}) obtained in control which was 46.8% greater than T_4B. Thermal conductivity of organically amended soils were decreased compared to control. Application of organic manure increases available water content AWC (Jeyamangalam *et al.,* 2012) due to that thermal conductivity of soil decreases (Mary Mwalechishala *et al.,* 2019). Effects of soil water content and dry density affects soil thermal conductivity. Organic manure increased organic matter in soil which improved soil structure, moisture and porosity. Organic manure promotes soil aggregation and increases pore space and also it acts as an insulator between soil particles to prevent heat transfer. Charcoal manure having high water absorption capacity that reduces thermal conductivity of soil. The changes in soil structure caused by organic amendment incorporation may be assessed through either the aggregate perspective or pore space perspective (Schlüter *et al.,* 2020). Addition of organic

TABLE 3 Effect of organic manure on soil physical properties

S.No.	Manure	Plots	BD (g cm^{-3})	PD (g cm^{-3})	WHC (%)	PS (%)	WC (%)	SM (%)	PO (%)	VR (%)
1	CM	T1 A	1.57	2.61	35.86	48.12	14.55	35.45	39.92	0.66
2	CM	T1 B	1.61	3.49	28.78	62.49	16.64	48.00	53.81	1.17
3	CM	T1 C	1.51	2.80	28.65	52.18	18.74	31.50	45.98	0.85
4	CM+GM	T2 A	1.56	2.61	34.80	47.03	15.61	34.26	40.08	0.67
5	CM+GM	T2 B	1.53	2.47	30.78	45.15	15.47	30.78	38.20	0.62
6	CM+GM	T2 C	1.48	2.67	40.02	51.56	18.15	40.02	44.53	0.80
7	CM+FYM	T3 A	1.42	2.98	38.17	57.18	23.16	40.02	52.36	1.10
8	CM+FYM	T3 B	1.59	2.47	33.00	43.90	13.02	34.19	35.73	0.56
9	CM+FYM	T3 C	1.51	2.57	29.93	48.43	16.32	32.81	41.08	0.70
10	CM+FYM+GM	T4 A	1.39	2.14	31.57	43.75	15.44	32.76	35.11	0.54
11	CM+FYM+GM	T4 B	1.55	2.65	33.54	47.03	17.36	35.31	41.53	0.71
12	CM+FYM+GM	T4 C	1.49	2.43	34.62	43.75	17.16	33.51	38.47	0.63
13	CONTROL	T5	1.70	2.72	23.66	45.15	12.77	27.18	37.69	0.60
		CD	0.07	0.27	3.62	4.70	2.22	4.31	4.85	0.16

CM - Charcoal Manure; FYM - Farm Yard Manure; GM - Goat Manure; BD-Bulk Density; PD - Particle Density; WHC - Water Holding Capacity; PS - Pore Space; SM - Saturated Moisture; A - 8.5 t ha^{-1}; B - 12.5 t ha^{-1}; C - 16.5 t ha^{-1}.

For treatment details see Table no. 1.

TABLE 4 Effect of organic manure on soil hydraulic and thermal conductivity

S.No.	Manure	Plots	HC (cm hr^{-1})	PE (cm s^{-1})	K (W m^{-1} K^{-1})	Thermal Diffusivity (10^{-5}) m^2 s^{-1}
1	CM	T1 A	2.615	0.07	0.023	1.81
2	CM	T1 B	1.17	0.03	0.024	1.85
3	CM	T1 C	1.25	0.03	0.024	1.97
4	CM+GM	T2 A	1.68	0.04	0.027	2.13
5	CM+GM	T2 B	1.86	0.05	0.023	1.90
6	CM+GM	T2 C	2.52	0.06	0.023	1.96
7	CM+FYM	T3 A	2.76	0.07	0.021	1.86
8	CM+FYM	T3 B	1.27	0.03	0.024	1.92
9	CM+FYM	T3 C	2.01	0.05	0.022	1.85
10	CM+FYM+GM	T4 A	1.18	0.03	0.026	2.33
11	CM+FYM+GM	T4 B	1.59	0.04	0.03	2.46
12	CM+FYM+GM	T4 C	2.76	0.07	0.018	1.46
13	CONTROL	T5	1.05	0.03	0.033	2.42
		CD	0.54	0.02	0.003	0

HC - Hydraulic conductivity; PE - Permeability; K - Thermal conductivity; A - 8.5 t ha^{-1}; B - 12.5 t ha^{-1}; C - 16.5 t ha^{-1}

manure increased macro and micro pores in the soil due to that the soil became well aerated that contains enough oxygen for respiration of plant roots. Improved aeration of air in soil and water retention leads to better onion growth and optimum yield. Permeability and hydraulic conductivity of soils depends mainly on the amount of macro pores in the soil. Multiple macro pores observed in amended soil using SEM images relative to control. *Fig. 5* shows the backs scattered image of the soil amended with CM+FYM+GM @16.5 t ha^{-1}. As seen in the image we can observe that amended soil seem to have many aggregates and macro pores which leads to greater HC. *Fig. 6* shows the bulk spectrum of control which has less number of macro pores.

3.2 | Yield

Generally, onion yield increased in the organic manure treated soil from the control. It was ranged from 1500 to 4758 kg ha^{-1}.Significantly highest yield (4758 kg ha^{-1}) was recorded in the treatment CM+GM+FYM @12.5 t ha^{-1} which was 68.4% higher than the control. Significantly lowest yield (1500 kg ha^{-1}) was recorded in the control. The plots treated with CM+GM @12.5 t ha^{-1} and CM+FYM @16.5 t ha^{-1} also produced better onion yield 4700 and 4548 kg ha^{-1} respectively. At 8.5 t ha^{-1} CM+FYM and CM+GM combination produced onion yield 4129 and 4363 kg ha^{-1} respectively. The effects of CM,GM and FYM improved onion yield on the sandy clay loam soil was possible through the increased amount of nutrients and enhanced soil physical properties. Onion yield depends on the CM, GM and FYM and their concentration. The differences in yield in treated soil due to different combination and different level of nutrient levels in manure.

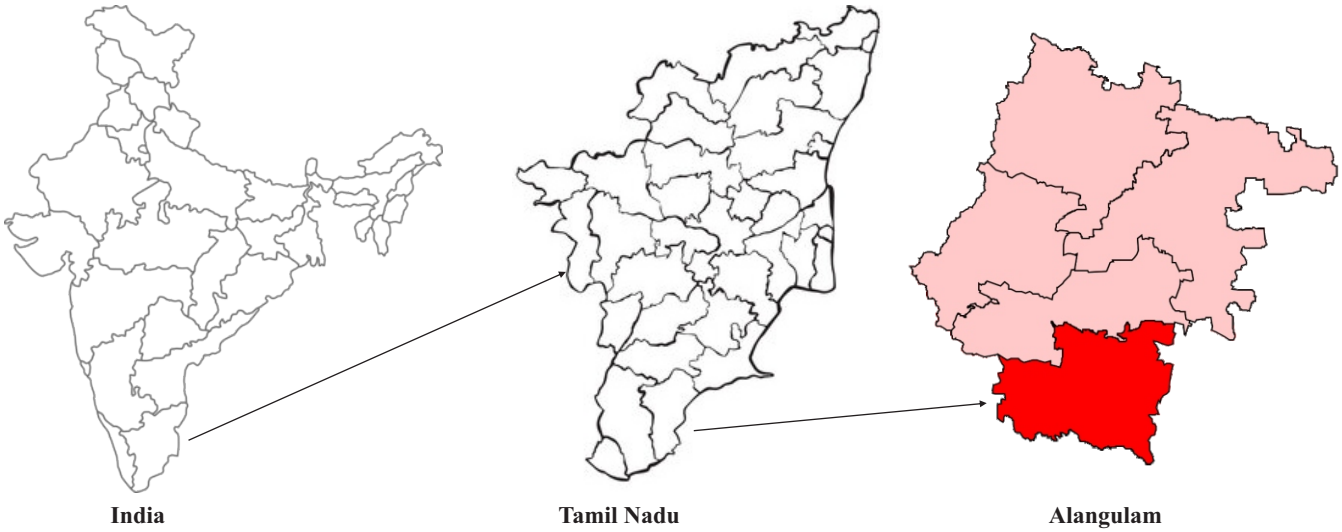

FIGURE 3 Location map of Alangulam, Tenkasi District, South Tamil Nadu Plateau, India

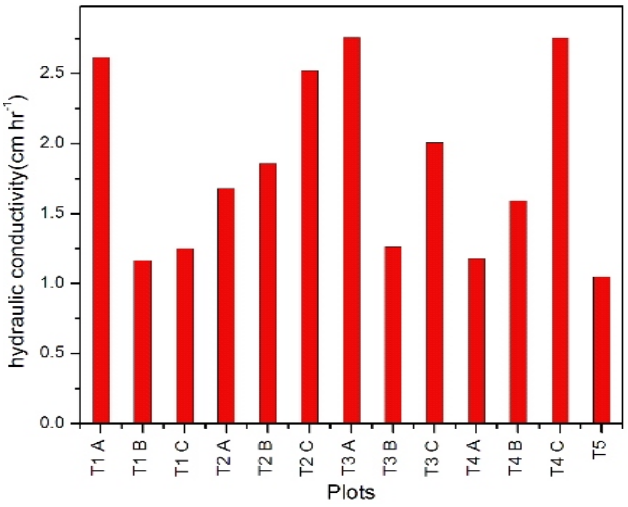

FIGURE 4 (a) Plots vs HC

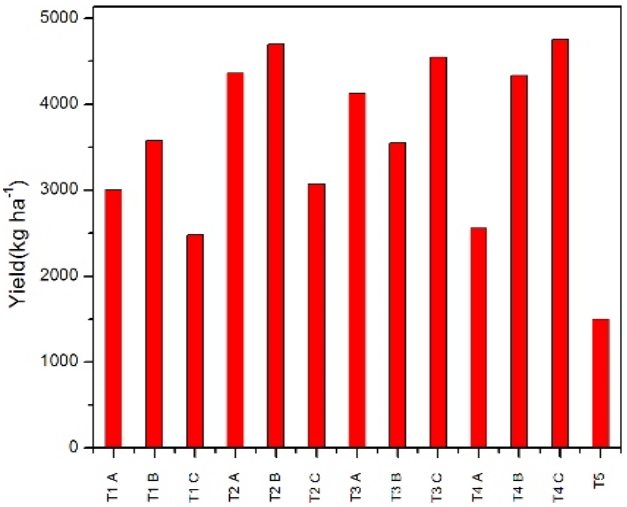

FIGURE 4(c) Yield

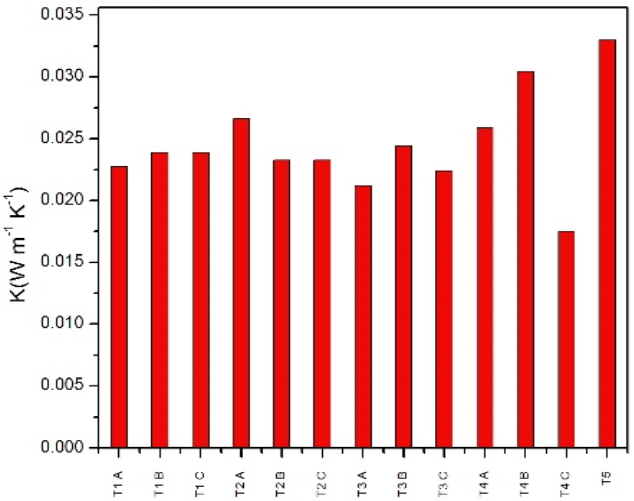

FIGURE 4 (b) Plots vs K

4 | CONCLUSIONS

The study revealed a significant difference in the yield of onion in all the treatments added with organic amendments related to control. This finding revealed that combined use of charcoal manure (22 kg cent^{-1}), goat manure (22 kg cent^{-1}) and farmyard manure (22 kg cent^{-1}) @16.5 t ha^{-1} improved onion growth and yield compared to other combination and control. This could be the result of improved soil properties, nutrient accessibility in organic amendments and the facilitation of soil characteristics in charcoal manure, goat manure and farmyard manure application. Incorporation of organic manure increased soil physical properties significantly. Improvement in soil organic matter enhanced porosity thereby increased hydraulic conductivity of soil treated with manure due to large macro pores present in soil. Organic amendments also reduced soil thermal conductivity and provides the essential nutrients for the soil thereby

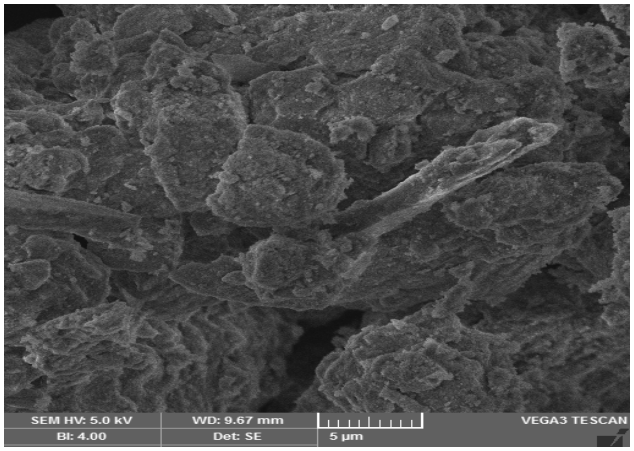

FIGURE 5 SEM images of amended soil (T_4C)

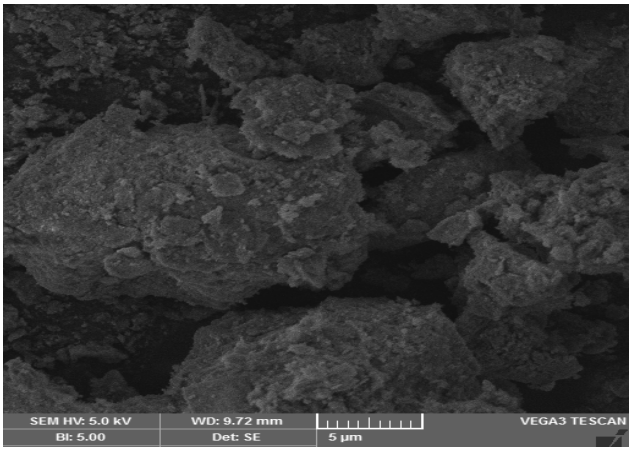

FIGURE 6 SEM images of control (T_5)

recovers the soil from severe damage .The result revealed that organic amendments addition to soil is more economical and cost effective to obtain better onion yield by farmers in the study area.

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CONFLICT OF INTEREST

The author has no conflict of interest

DATA AVAILABILITY STATEMENT

Data presented in the study are available with the corresponding author.

AUTHOR'S CONTRIBUTION

MCS: Performed the experiments, analysed the data, prepared figures, tables and written the manuscript. FJ: Supervision.

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