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ORIGINAL ARTICLE

Residual impact of nonwoven jute agro-textile mulch on soil health and productivity of maize (*Zea mays* L.) in lateritic soil

Koushik Manna[1,2] · Manik Chandra Kundu[1] · Biplab Saha[2] · Goutam Kumar Ghosh[1]

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Abstract
The residual effect of different thicknesses of nonwoven jute agro-textile mulches (NJATM), rice straw, and black polythene on the yield of maize, soil fertility, soil moisture, microbial population, and weed suppression was studied in lateritic soil of eastern India after broccoli. Results indicated that residual 400 gsm (grams per square meter) NJATM showed highest plant height (212.43 cm), plant per m^2 (8.29), cobs per plant (2.00), cob length (22.63 cm), cob diameter (14.95 cm), test weight (235.6 g), grain yield (6.90 t ha^{-1}), biological yield (16.0 t ha^{-1}), and harvest index (43.11%) of maize. Residual NJATM decreased the density of weeds (broadleaved, grasses, sedges), and their significantly lower density was in 400 gsm NJATM. The population of bacteria, actinomycetes, and fungi was increased from their initial value in residual NJATM-treated plots. In post-harvest soil, the population of bacteria and actinomycetes (72.50×10^6 and 152.75×10^4 cfu per g) were highest with residual 400 gsm NJATM. Residual NJATM significantly increased the soil moisture content compared to the control, and its 400 gsm thickness showed its highest content of 13.18%, 18.98%, 17.12%, and 15.98% at 15, 30, 60, and 90 DAS, respectively. Again, residual NJATM improved soil fertility compared to other mulches, and residual 400 gsm NJATM recorded the highest available N, P, and K (145.98 kg ha^{-1}, 30.33 kg ha^{-1}, and 138.23 kg ha^{-1}) and organic C (0.70%). Thus, the residual 400 gsm NJATM proved the best in improving soil fertility and microbial population, conserving soil moisture, suppressing weeds, and increasing maize yield in lateritic soil.

Keywords Jute mulches · Residual impact · Soil health · Maize productivity · Lateritic soil

1 Introduction

Mulching is the method of covering the surface soil layer with organic or inorganic material for increasing crop productivity by improving the micro-environment of that soil. Mulching has been widely practiced for producing field crops and vegetables commercially [1]. This mulching has a favorable effect on optimizing soil temperature, improving pore spaces and infiltration rate, suppressing weeds, and controlling soil erosion [2–4]. Mulches provide different kinds of ecological niches in the subsystem of the crop environment. Mulching improves soil fertility status by encouraging the propagation of beneficial soil microorganisms like micro-arthopods and earthworms in the root rhizosphere [5]. Favorable effects of residue mulching on soil organic carbon (SOC), water retention, and percent water-stable aggregates have been reported for the surface layer [6, 7]. Organic mulching materials like rice and wheat straw, husk, grass, weeds, leaves, animal manures, compost, sawdust, and wood chips and inorganic mulching materials like plastic film, sand, gravel, and pebbles are frequently used for producing commercial vegetables like tomato and lettuce [1, 8–10]. Though low-density polyethylene (LDPE) and agro-textile mulches are of more or less similar cost, the former item is not environment-friendly [11]. The development of the root of the succeeding crop will be hampered if residual polyethene sheets used as mulch in the preceding crop are left in the field [12]. According to Durham [13] and Rice et al. [14], plastic mulch films increased the runoff of water after rainfall or irrigation. Straw mulches often contaminate the soil with weed seeds [15]. Bio-degradable mulches of natural fibers are preferred nowadays in view of

✉ Manik Chandra Kundu
mckundu@gmail.com

[1] Department of Soil Science and Agricultural Chemistry, Institute of Agriculture (Palli Siksha Bhavana), Visva-Bharati, Sriniketan, West Bengal 731 236 Sriniketan, India

[2] National Institute of Natural Fibre Engineering and Technology (NINFET), Indian Council of Agricultural Research, 12 Regent Park, Kolkata, West Bengal 700 040, India

the improvement of soil health and reduction of carbon footprint in horticultural production systems.

Thus, there is tremendous scope for using nonwoven jute agro-textile mulches (NJATM) in improving soil fertility, suppressing weeds, and increasing crop yield [16]. Jute fibers are usually processed through garneting cum cross lapping, followed by needle punching loom for preparing such nonwoven jute agro-textile mulches. Such agro-textile mulches can reduce soil erosion, control weeds, conserve soil moisture, and promote plant establishment [17] as well as can enhance the content of organic matter [18]. Advantages of using jute agro-textile mulches in increasing yield of capsicum and pointed gourd [19], mousumbi and turmeric [20], ramie fiber [21], banana [22], and green gram [23] have already been reported. However, most of these researchers have studied only the direct impact of jute agro-textile mulches on the yield of a crop along with only a limited number of other beneficial effects but hardly anybody attempted to study the direct effect of jute agrotxtile mulches on a crop as well as their residual effects on the succeeding crop along with all the beneficial aspects of jute agro-textile mulches in comparison with other types of mulches. Again, there is no integrated information on either direct or residual effects of various mulches including agro-textile mulches on increasing yield of maize (which is an important cereal crop of India) grown after preceding broccoli, weed suppression, moisture conservation, microbial population, and soil fertility of light textured and less fertile lateritic soil of eastern India which receives ~1250 mm average rainfall annually. With this background, the present research experiment was conducted with maize (*Zea mays* L.) as the succeeding test crop after broccoli in the summer season of 2016 and 2017 in the same field and fixed treatment-wise plot to study the residual effect of NJATM along with other mulches applied in the preceding crop (broccoli) on soil nutrient improvement, increment in the microbial population, moisture conservation, weed suppression, increasing growth, and productivity of maize in lateritic soil of West Bengal, India.

2 Materials and methods

2.1 About the experiment

2.1.1 Experimental site

A field experiment was performed during the summer season (March to June) of both 2016 and 2017 at the Bahadurpur Village, Sriniketan, Bolpur, Birbhum, West Bengal, in the same field and fixed plot of our previous study on broccoli [16]. The farmer's field where the experiment was carried out was situated between 23°39′47.69″ N latitude and 87°37′36.91″ E longitude with an attitude of 58.9 m above the mean sea level (Fig. 1) [16]. The experimental soil is Typic ochraqualf which was sandy loam in texture, acidic in soil pH, low in oxidizable organic carbon, available N, K, and medium in available P.

2.1.2 Experimental details

There were six treatments, each replicated four times and arranged in a randomized block design. The treatments comprised different thicknesses of agro-textile mulch along with other mulching materials viz., T_1 (control, i.e., no mulch), T_2 [300 gsm (grams per square meter) NJATM], T_3 (350 gsm NJATM), T_4 (400 gsm NJATM), T_5 (rice straw), and T_6 (black polythene mulch). Each of these treatments was practically imposed or applied on the surface of experimental plots at the time of preceding broccoli cultivation. Without destroying the plot, i.e., maintaining the fixed plot with the same experimental design and treatment arrangement, seeds of maize were sown, making holes according to crop spacing on the partially decomposed mulches. The size of each plot was 3.0 m × 6.0 m with row-to-row and plant-to-plant spacing of 1.0 m and 0.5 m, respectively. Maize seeds were sown in each experimental plot on March 6, 2016, and March 10, 2017, and the crop was harvested on June 16, 2016, and June 20, 2017. Recommended doses of nutrient application were N, P, and K at 120 kg/ha, 60 kg/ha, and 60 kg/ha, respectively, which were applied through urea, single super phosphate (SSP), and muriate of potash (MOP). Just before sowing of maize seeds cow dung @5 t/ha, full doses of P and K in the form of SSP and MOP and one-fourth of N in the form of urea were applied and incorporated into the soil. The rest amount of the N in the form of urea was top dressed at 20 days, 35 days, and 50 days after sowing (DAS) in three equal splits. Initially, one flood irrigation was applied at 5 DAS for quick establishment of plants, and after that, in every 15-day interval, the maize crop was irrigated up to 80 DAS.

2.1.3 Observation on growth and yield parameter of maize

The parameters like plant height (cm), numbers of plants per m^2, numbers of cob per plant, numbers of cob per m^2, cob length (cm), cob diameter (cm), and numbers of grains per cob, 1000 grain weight (g) were recorded. At the same time, grain yield (at ~12% moisture content) (t ha^{-1}), stover yield (t ha^{-1}), and biological yield (t ha^{-1}) of maize for each plot were noted. The harvest index for each treatment was also calculated by the following formula:

$$\text{Harvest Index (\%)} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

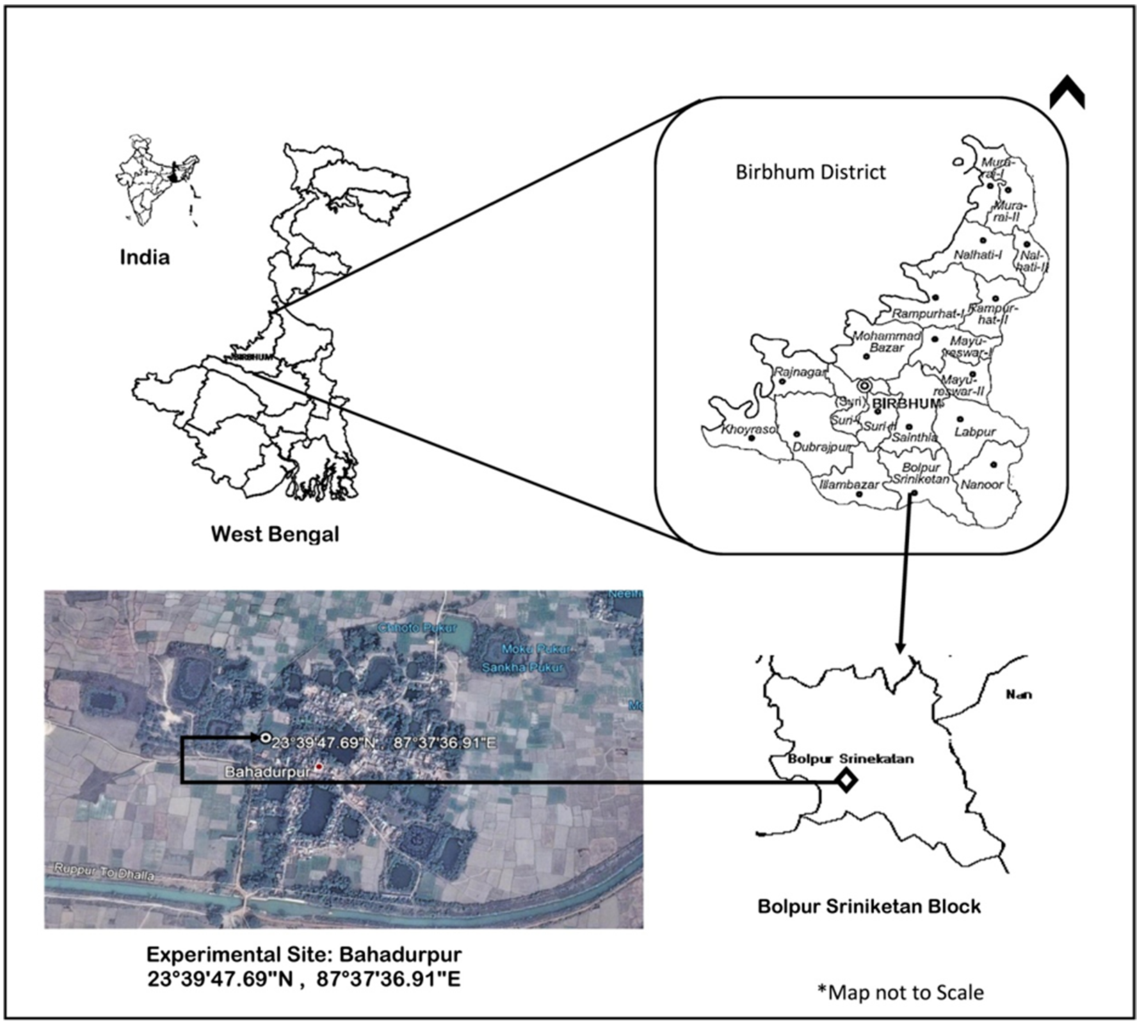

Fig. 1 Location map of the study area (adopted from Manna et al. [16])

2.1.4 Observation on weed population

Cynodon dactylon, *Tridex procumbens*, *Ludwigia parviflora, Cyperus rotundus*, and *Cyperus difformis* were the dominant weeds in the maize field. All the weeds were categorized into three groups like broad leaves weed, sedges, and grasses and counted at 30 and 60 DAS simply by randomly using a quadrant of 25 cm × 20 cm (0.05 m^2) in the sampling area. The weed population (per square meter area) was calculated from the observation.

2.1.5 Counting soil microbial population

Composite soil samples from each treatment were collected during sowing, 60 DAS, and after harvesting maize for counting the microbial population of bacteria, fungi, and actinomycetes. The serial dilution technique and pour plate method were used for counting microbial populations as described by Agarwal and Hasija [24]. The number of bacteria, fungi, and actinomycetes was counted using nutrient agar, potato dextrose agar, and actinomycetes isolation agar media, respectively.

2.1.6 Estimating soil moisture content

The moisture content of composite soil samples collected from each treatment at 15, 30, 60, and 90 DAS was determined by the gravimetric method. The following formula was used to calculate gravimetric moisture content in soil:

$$\text{Gravimetric moisture content } (\%) = \frac{\text{Weight of wet soil–Weight of oven dry soil (at } 105^{\circ}\text{C)}}{\text{Weight of dry soil}} x\ 100$$

2.1.7 Chemical analysis of NJATM and soil

Using the established technique of the TAPPI Standard Method [25], the chemical elements such as hemicellulose, lignin, fat and wax, nitrogenous substance, and the amount of ash of various mulches utilized in previous broccoli crops were assessed. The cellulose content was measured using the updated method developed by Sarkar et al. [26], as described and presented in detail by Manna et al. [16], as again presented in Table 1. Besides the characteristics like nominal gsm as received, actual gsm, the apparent opening size (O95) in micron and thickness (mm) of NJATM materials used in the preceding broccoli crops is presented by Manna et al. [16], as again presented here in Table 2, as these are important for this residual study.

Initial and post-harvest soil samples collected from the experimental field were air-dried, crushed, and passed through a 2-mm sieve before laboratory analysis. Then some important soil properties of the processed soil samples were estimated like soil pH [soil: water = 1:2.5] by the method as described by Jackson [27], oxidizable organic carbon by the method of Walkley and Black [28], available nitrogen content by alkaline permanganate method of Subbaiah and Asija [29], available phosphorus by Bray's No. 1 method [30] using a spectrophotometer, available potassium extracted by neutral normal ammonium acetate (soil: extractant = 1:5), and estimated by flame photometer by the method as described by Jackson [27].

2.2 Statistical analysis

The data recorded for different parameters from laboratory and field experiments were analyzed with the help of Fisher's method of analysis of variance (ANOVA) technique as described by Gomez and Gomez [31] for randomized block design (RBD). The values of the standard error of means (SEm) and critical difference (CD) at a 5% level of significance were computed and used to assess the effect of treatments at a 5% level of significance ($p = 0.05$).

Table 2 Characteristics of different thicknesses of nonwoven jute agro-textile mulching (NJATM) material used in the experiment (adopted from Manna et al. [16])

Characteristics	Nonwoven jute agro-textile mulch (NJATM)		
Nominal gsm (grams per square meter) as received	300 gsm	350 gsm	400 gsm
Actual gsm	299.40	350.25	400.80
The apparent opening size (O_{95}) in microns	285	275	245
Thickness (mm)	2.72	3.10	3.58

3 Results and discussion

3.1 Residual effect of mulches on growth and yield of maize

Two-year pooled data indicated that the residue of different mulching materials influenced significantly the growth and yield of maize (Table 1), and it was noted that the growth and yield of maize was comparatively more in all nonwoven jute agro-textile mulch (NJATM)-treated plot than control as well as other mulches applied. Again, it was observed that the plot treated with 400 gsm NJATM showed the

Table 1 Physico-chemical properties of nonwoven jute agro-textile mulching (NJATM) material (adopted from Manna et al. [16])

Component	Mulching materials		
	Nonwoven jute agro-textile mulch (NJATM) (%)	Rice straw (%)	Black polythene
∞-Cellulose	59.91	36.80	Low-density polythene is a thermoplastic made from the monomer ethylene ranging in density from 0.915 to 0.925 g cm^{-3}. The thickness of the used black polythene was 50 µm.
Hemicellulose	23.45	25.60	
Lignin	12.56	10.30	
Fat and wax	1.10	5.42	
Nitrogenous matter	1.80	1.00	
Ash Content	0.70	7.20	

Table 3 Residual effects of different mulching materials on growth and yield attributes and yield of maize (2-year pooled data)

Treatments	Plant height (cm) at harvest	No. of plant/ m^2	No. of cob/ plant	No. of cob/ m^2	Cob length (cm)	Cob diameter (cm)	No. of grains/cob	1000 grain weight (g)	Grain yield (t/ha)	Stover yield (t/ha)	Biological yield (t/ ha)	Harvest index (%)
T1: no mulch	158.73	6.83	1.13	7.69	17.75	13.18	278.75	211.13	3.83	7.98	11.81	32.46
T2: 300 gsm NJATM	207.88	7.85	1.63	12.76	21.18	14.23	369.75	225.23	6.08	9.00	15.07	40.34
T3: 350 gsm NJATM	210.8	8.09	1.75	14.16	21.98	14.45	392.5	227.00	6.30	9.51	15.81	39.85
T4: 400 gsm NJATM	212.43	8.29	2.00	16.58	22.63	14.95	411.75	235.60	6.90	9.10	16.00	43.11
T5: rice straw	194.45	7.61	1.50	11.41	20.38	14.00	330.5	218.55	5.20	8.72	13.92	37.35
T6: black polythene	181.35	7.36	1.25	9.2	19.43	13.8	321.68	214.9	4.82	8.62	13.44	35.9
Sem (±)	1.80	0.05	0.12	0.92	0.19	0.11	5.96	1.048	0.05	0.13	0.10	0.51
CD (0.05)	5.24**	0.15**	0.35**	2.68**	0.55**	0.33**	17.39**	3.06**	0.14**	0.38**	0.30**	1.49**
CV (%)	1.85	1.34	15.48	15.37	1.83	1.58	3.40	0.94	1.70	2.92	1.43	2.67

NJATM, nonwoven jute agro-textile mulch; *gsm*, grams per square meter; *SEm*, standard error of the mean; *CD*, critical difference; *CV*, coefficient of variance

**It indicates that the *F* value is significant at a 1% level of significance

highest plant growth characteristics of maize – plant height (212.43 cm), number of plant per m^2 (8.29), average number of cobs per plant (2.00), average number of cobs per m^2 (16.58), cob length (22.63 cm), and cob diameter (14.95 cm) as well as highest yield parameters of maize – average number of grains per cob (411.75), test weight (235.6 g), grain yield (6.90 t ha^{-1}), biological yield (16.0 t ha^{-1}), and harvest index (43.11%). All growth and yield parameters were observed as lowest in control. Only the stover yield of maize was highest (9.51 t ha^{-1}) in the 350 gsm NJATM-treated plot. The T_4 treatment (400 gsm NJATM) increased the maize yield by 80% as compared to the control. The 400 gsm bio-degradable NJATM was found to be most effective than others which might be due to the beneficial effect of increased moisture conservation, increased organic carbon, and nutrient status along with high weed control efficiency. Saha et al. [19] observed significantly higher yield over control in high-value crops of capsicum and pointed gourd in agro-textile mulched plots in the alluvial soil of Patna. Manna et al. [16] reported the highest broccoli yield (8.53 t ha^{-1}) in 350 gsm NJATM-treated plot over control in comparison to other mulches in the same experimental field of lateritic soil of West Bengal. However, green gram productivity was considerably raised with 800 gsm jute agro-textile mulches by enhancing the moisture conservation in the soil, as reported by Sarkar et al. [23]. Sarkar et al. [32] also documented that the application of 800 gsm jute agro-textile mulches can significantly boost up broccoli yield by supplying vital nutrients to plants via lignin degradation. In another study performed by Adhikari et al. [33], they documented maximum tomato yield with 600 gsm jute agro-textile mulches. According to Ialam et al. [34], the use of straw mulch in conjunction with three irrigations and minimal or conventional tillage may be an effective strategy for increasing maize yield in drought-prone areas of Bangladesh. However, Zhao et al. [35] confirmed that the application of maize straw mulches at shallow depths may substitute plastic mulches for producing maize in the irrigated condition of arid regions.

3.2 Residual effect of mulches on weed population

Residual mulching materials caused significant variations in weed density in maize (Table 3). At 30 DAS, the weed density was highest in the T_1 treatment (no mulch). Weed density was increased further at 60 DAS in all the treatments, and its density was again highest in T_1 (no mulch). At 30 DAS, both T_4 (400 gsm NJATM) and T_6 (black polythene mulch) suppressed the density of broad leaves weed to the lowest value of 1.00 per m^2. At 60 DAS, the density of broad leaves weed (2.75 per m^2) was again lowest in T_4 and T_6 treatments but statistically equal with T_3 treatment. The density of sedges was lowest at 30 DAS in T_6 (black polythene mulch) treatment but equal with T_2 (300 gsm NJATM), T_3 (350 gsm NJATM), and T_4 (400 gsm NJATM). In spite of the increased density of sedges in 60 DAS, its density (2.75 per m^2) was recorded lowest in T_6 (black polythene mulch). The density of grasses at 30 DAS was lowest (1.00 per m^2) in T_6 (black polythene mulch) which was statistically at par with T_3 (350 gsm NJATM) and T_4 (400 gsm NJATM). The increased density of grasses at 60 DAS was suppressed to its lowest value (4.50 per m^2) in T_6 (black polythene mulch) treatment. It was thus found that the weed population was reduced significantly through the application of mulches due to reduced light which caused stress situations to existing weeds and prevented the germination of many small-seeded weed species. According to Ahmad et al. [36], weed emergence is prevented temporarily by the

Table 3 Residual effects of different mulching materials on the density of weed (2-year pooled data)

Treatments	Weed density (numbers m^{-2})					
	BLWs 30 DAS	BLWs 60 DAS	Sedges 30 DAS	Sedges 60 DAS	Grasses 30 DAS	Grasses 60 DAS
T1: no mulch	8.50	17.25	4.00	20.75	15.75	47.50
T2: 300 gsm NJATM	2.00	5.25	1.00	5.75	2.25	8.75
T3: 350 gsm NJATM	1.25	3.75	0.75	4.00	1.50	6.25
T4: 400 gsm NJATM	1.00	2.75	0.75	3.00	1.25	4.75
T5: rice straw	5.00	13.75	2.50	13.75	8.75	22.00
T6: black polythene	1.00	2.75	0.50	2.75	1.00	4.50
SEm (±)	0.287	0.387	0.247	0.707	0.346	0.565
CD (0.05)	0.839**	1.130**	0.721**	2.064**	1.009**	1.648**
CV (%)	18.398	10.214	31.226	16.971	13.598	7.227

BLWs, broad-leaved weeds; *DAS*, days after sowing; *NJATM*, nonwoven jute agro-textile mulch; *gsm*, grams per square meter; *SEm*, standard error of the mean; *CD*, critical difference; *CV*, coefficient of variance

**It indicates that the *F* value is significant at a 1% level of significance

physical barrier created by mulches, but after the decomposition of mulches, the barrier disappears. A similar observation was registered by Wilen et al. [37], Datta et al. [38], and Manna et al. [16]. However, in a different set of experiments conducted by Minhas et al. [39], wheat grown with plastic mulches alone had the least incidence of weeds and their biomass, then came sorghum mulches and the interaction effect of sorghum mulches with conventional tillage also showed the lowest value of weed density and biomass.

3.3 Residual effect of mulches on rhizosphere microbial population

Residue of all the mulching materials increased the population of bacteria, fungi, and actinomycetes from their initial values (Table 4). The population of bacteria in the initial soil was ranged from 15×10^6 to 24.5×10^6 cfu per g (Table 4) which was increased thereafter up to 60 DAS and decreased drastically at post-harvest soil in each treatment. However, such decreased population of bacteria in each treatment was more compared to their initial value indicating that residual mulches increased the bacterial population. The population of bacteria was highest in T_4 (400 gsm NJATM), followed by T_3 (350 gsm NJATM) at 60 DAS. Favorable temperature and moisture content of soil at root depth may be the key factors in increasing bacterial population by NJATM-treated plots. Such a positive impact of NJATM on the bacterial population was also reported by Subba [40] and Manna et al. [16]. However, Sarkar et al. [22] conveyed the highest bacterial population with 1000 gsm (25.4×10^6 cfu) woven jute agro-textile mulches which was statistically very close with 800 gsm thickness (24.9×10^6 cfu).

The initial fungi population (39.75×10^3 to 54.0×10^3 cfu per g) was decreased at 60 DAS and gradually increased thereafter at harvest time (Table 4). At 60 DAS, the fungal population was highest (49.50×10^3 cfu per g) in T_3 (400 gsm NJATM) which was statistically equal with T_4 and T_2. The residual effect of T_3 recorded the highest fungal population (55.53×10^3 cfu per g) at harvest. Subba [40] and Manna et al. [16] in their study also reported the beneficial effect of NJATM on fungal populations. However, Sarkar et al. [22] conveyed the highest fungal population with 1000 gsm (45.3×10^4 cfu) woven jute agro-textile mulches which was again statistically equal to 800 gsm thickness (44.7×10^4 cfu).

The population of actinomycetes was within the range of 89.50×10^4 to 134.75×10^4 cfu per g (Table 4) which was increased at 60 DAS and again further increased at harvesting. The influence of NJATM on the population of actinomycetes was comparatively more than other mulches. The population of actinomycetes was highest in T_4 (400 gsm NJATM) in all three sampling times, i.e., at initial, 60 DAS, and harvest. The result was in good agreement with the findings of Pal et al. [41], reporting an increased population of actinomycetes in soil toward soyabean maturity because of the higher availability of carbon at the maturity stage due to leaf fall. However, there was no significant change in the actinomycetes population in the control plot from its initial value to post-harvest value because of exposure of soils to light. Manna et al. [16] also reported a significant increase in the actinomycetes population in the rhizosphere soil of broccoli due to the application of NJATM. However, Sarkar et al. [22] conveyed the highest actinomycetes population with 1000 gsm (33.8×10^5 cfu) woven jute agro-textile mulches which was again statistically at par with 800 gsm thickness (33.7×10^5 cfu).

Table 4 Residual effects of different mulching materials on the populations of bacteria, fungi and actinomycets in soil (2-year pooled data)

Treatments	Population (cfu g^{-1})								
	Bacteria ($\times 10^6$)			Fungi ($\times 10^3$)			Actinomycetes ($\times 10^4$)		
	At sowing	At 60 DAS	At harvesting	At sowing	At 60 DAS	At harvesting	At sowing	At 60 DAS	At harvesting
T1: no mulch	15.00	45.00	21.00	39.75	37.50	41.75	89.50	89.75	92.50
T2: 300 gsm NJATM	18.50	54.50	36.00	53.00	46.75	55.00	121.50	131.05	140.98
T3: 350 gsm NJATM	24.50	67.50	39.50	54.00	49.50	55.53	131.0	136.40	147.40
T4: 400 gsm NJATM	21.50	72.50	46.50	48.50	46.25	51.00	134.75	148.95	152.75
T5: rice straw	16.00	46.25	24.50	41.50	37.75	43.25	102.50	115.85	123.50
T6: black polythene	18.00	46	21.50	40.75	37.00	41.03	110.50	116.67	129.53
SEm (±)	0.838	1.192	1.143	1.449	1.347	1.114	0.778	12.554	0.953
CD (0.05)	2.447**	3.480**	3.335**	4.229**	3.930**	3.252**	2.270**	36.597**	2.780**
CV (%)	8.863	4.313	7.255	6.267	6.343	4.650	1.353	20.325	1.453

cfu, colony forming unit; *DAS*, days after sowing; *NJATM*, nonwoven jute agro-textile mulch; *gsm*, grams per square meter; *SEm*, standard error of the mean; *CD*, critical difference; *CV*, coefficient of variance

**It indicates that the *F* value is significant at a 1% level of significance

3.4 Residual effect of mulches on soil moisture content

Activities of microorganisms in soil and growth parameters of maize are influenced by soil moisture content in the rhizosphere which was influenced by residual mulches applied in preceding broccoli. The soil moisture content was lowest at 15 DAS, followed by 90 DAS < 60 DAS < 30 DAS in decreasing order in all the treatments compared (Table 5). The average soil moisture content at 15, 30, 60, and 90 DAS was lowest in T_1 (control) and decreased in the order: T_4 (400 gsm NJATM) > T_3 (350 gsm NJATM) > T_2 (300 gsm NJATM) > T_6 (black polythene) > T_5 (rice straw) (Table 5). The highest moisture content in T_4 (400 gsm NJATM, having less porosity) plot was because of reduced evaporation and reduced weed population [16]. In the control plot without mulching materials, soil moisture content was lowest because of bare soil surface exposed to heat and wind reduced the moisture content through evaporation. Again, the moisture content in the plot where the residue of various thicknesses of NJATM mulches was comparatively higher because of their higher moisture retentive capacity than other mulches. In broccoli crops where fresh NJATM were applied, there was more moisture content compared to other mulches as well as control [16]. According to Sarkar et al. [23], jute agro-textile mulches can enhance water utilization by crops and can thus be employed in water-stressed areas, whereby improving the micro-environment in soil and optimizing the proper supply of nutrients to the crop, the higher crop productivity can be achieved. Adhikari et al. [33] also opined that the application of jute agro-textile mulches conserves soil moisture and also increases its use efficiency in the tomato field, resulting in maximum soil moisture use efficiency with 600 gsm jute agro-textile mulches compared to other thickness. Ahmad et al. [36] established that by storing moisture in the soil, mulching can help crop plants demand less irrigation.

Table 5 Residual effects of different mulching materials on soil moisture content (2-year pooled data)

Treatments	Moisture content (%)			
	15 DAS	30 DAS	60 DAS	90 DAS
T1: no mulch	6.80	7.55	7.20	6.82
T2: 300 gsm NJATM	9.28	14.84	13.67	13.39
T3: 350 gsm NJATM	12.41	16.40	15.71	14.89
T4: 400 gsm NJATM	13.18	18.98	17.12	15.98
T5: rice straw	7.44	10.07	9.77	9.66
T6: black polythene	8.60	12.26	11.17	10.74
SEm (±)	0.193	0.197	0.165	0.161
CD (0.05)	0.564**	0.575**	0.481**	0.470**
CV (%)	4.019	2.953	2.648	2.704

DAS, days after sowing; *NJATM*, nonwoven jute agro-textile mulch; *gsm*, grams per square meter; *SEm*, standard error of the mean; *CD*, critical difference; *CV*, coefficient of variance

**It indicates that the *F* value is significant at a 1% level of significance

3.5 Residual effect of mulches on post-harvest soil properties

All the studied soil properties except soil pH and EC varied significantly in the soil after the harvest of maize due to the residual effects of different mulching materials applied (Table 6). Soil organic carbon (OC) was increased significantly in all residual mulch-treated plots over control, and its content was noted highest (0.70%) in T_4 (400 gsm NJATM)-treated plots. Again, such an increase in soil OC was more in residual

Table 6 Physico-chemical properties of initial and post-harvest experimental soil (2-year pooled data)

Properties		pH	EC (mmhos cm^{-1})	Organic C (%)	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})
Initial soil		4.90	0.08	0.39	125.00	15.2	100.8
Post-harvest soil	T1: no mulch	4.90	0.08	0.38	123.78	16.33	101.65
	T2: 300 gsm NJATM	4.90	0.08	0.53	130.93	21.05	115.07
	T3: 350 gsm NJATM	4.88	0.09	0.67	140.08	23.00	121.02
	T4: 400 gsm NJATM	5.00	0.09	0.70	145.98	30.33	138.23
	T5: rice straw	4.88	0.08	0.47	128.51	20.35	108.10
	T6: black polythene	4.90	0.08	0.46	126.73	18.58	106.27
	Sem	0.04	0.00	0.01	1.500	1.084	0.6
	CD (0.05)	0.12 NS	0.01NS	0.017**	4.378**	3.164**	1.765**
	CV (%)	1.74	8.28	2.13	2.261	1.884	1.072

EC, electrical conductivity; *NJATM*, nonwoven jute agro-textile mulch; *gsm*, grams per square meter; *SEm*, standard error of the mean; *CD*, critical difference; *CV*, coefficient of variance

**It indicates that the *F* value is significant at a 1% level of significance, and NS indicates that the *F* value is nonsignificant

NJATM-treated plots compared to other mulches applied because of their higher contribution to root biomass and crop residues in soil. Additionally, NJATM with a higher C:N ratio and lignin content (12.56%) improved nutrient immobilization and degradation of NJATM materials causing organic matter addition in soil [16]. The enrichment of soil organic matter through the decomposition of organic mulches has already been reported by Youkhana and Idol [42]. Adhikari et al. [33] conveyed that organic C content in soil was maximum with 600 gsm jute agro-textile mulches in tomato. However, Sarkar et al. [22] documented the highest organic C content (0.46%) in soil treated with 1000 gsm woven jute agro-textile mulches which showed an increment of 84% over un-mulched soil.

The available N content in soil was enhanced after the harvest of maize in residual NJATM-treated plots over control as well as other mulches. The highest available N content (145.98 kg ha^{-1}) was recorded in T_4 treatment, i.e., plot treated with 400 gsm NJATM. Such enhancement of available N under NJATM-treated soils may be attributed due to higher mobility of nitrogen in increased moisture content and enhanced mineralization of soil organic N due to higher microbial activities [16, 43]. A separate investigation conducted by Zhou et al. [44] looked at the influence of nonwoven ramie fiber film on the surroundings of the roots of rice seedlings and discovered a substantially greater amount of soil nitrogen that ultimately resulted to improve rice seedling growth. However, Sarkar et al. [22] reported the highest available N content (79.4 kg ha^{-1}) in soil treated with 1000 gsm woven jute agro-textile mulches for bananas in the new alluvial soil of West Bengal, India. Again, according to Adhikari et al. [33], the available soil N content was highest due to the imposition of 600 gsm jute agro-textile mulches in tomatoes.

The available P content in post-harvest soil was enhanced in residual NJATM-treated plots over control as well as other mulches. Similar to available N, the available P content was highest (30.33 kg ha^{-1}) in T_4 (400 gsm NJATM), followed by T_3 (23.0 kg ha^{-1}) (350 gsm NJATM). Such a higher amount of available P in residual NJATM-treated plots was probably due to better hydrothermal regimes, higher root growth, and reduced weed density [16]. Production of organic acids due to the decomposition of NJATM along with the release of metal cations (Al, Fe) might enhance the native P solubilization and subsequent availability of P in soil [16, 45]. However, Sarkar et al. [22] reported the highest available P content (25.0 kg ha^{-1}) in soil treated with 1000 gsm (which was, however, statistically equal to 800 gsm) woven jute agro-textile mulches for bananas in the new alluvial soil of West Bengal, India. Again, the experiment conducted by Adhikari et al. [33] noted the highest available P content in soil treated with 600 gsm jute agro-textile mulches in tomato.

Again, there was an increase in available K content in post-harvest soil in residual NJATM-treated plots over control as well as other mulches. The plot treated with T4 (400 gsm NJATM-treated plot) showed the highest (138.23 kg ha^{-1}) available K which was, however, statistically equal to T3 (350 gsm NJATM-treated plot). Such improvement in available K content residual mulch-treated soils might be due to less weeds, better hydrothermal regime, and good amount of root biomass, as reported by Gupta and Acharya [43], Singh et al. [46], and Manna et al. [16]. Thus, enrichment in available N, P, and K in residual NJATM-treated plots compared to control and other mulches was might be due to microbial decomposition of NJATM under favorable temperature and moisture regime [16]. However, Sarkar et al. [22] reported the highest available K content (226.0 kg ha^{-1}) in soil treated with 1000 gsm woven jute agro-textile mulches for bananas in the new alluvial soil of West Bengal, India. Again, Adhikari et al. [33] reported the lowest (153 kg ha^{-1}) and highest (310.5 kg ha^{-1}) available P content in un-mulched and soil treated with 600 gsm jute agro-textile mulches, respectively, in tomatoes.

3.6 Efficacy of the residual NJATM over others

The results of the experiment revealed that residual nonwoven jute agro-textile mulches (NJATM) were more efficient in comparison to residual rice straw and polythene mulches for enhancement of growth and productivity of maize, enrichment of macro-nutrients in soil, suppression of weeds, and enhancement in water holding capacity and increase in the microbial population of the light-textured lateritic soil of West Bengal. The residue NJATM with higher porosity, higher permeability, higher carbon to nitrogen (C:N) ratio, higher water absorbing capacity (~500%), eco-friendliness, and biodegradability, its chemical composition like cellulose, lignin, fat, wax, and nitrogenous matter contents might be responsible for its superiority over other mulches like rice straw and plastic mulches. Consequently, overall soil health was improved, and the yield of maize was increased in NJATM-treated plots in comparison to other treatments. Manna et al. [16] reported similar observations in previous crop broccoli in the same experimental field. Considering biodegradability and strength loss, 250 gsm NJATM can be used well for boosting the yield of short-duration (75–100 days) horticultural crops, while 400 gsm NJATM can be utilized for long-duration crops [47]. Manna et al. [48] found that 350 gsm NJATM is superior to other mulches in terms of enhancing soil water, optimizing soil temperature, raising soil nutritional status, and consequently raising the yield of broccoli planted in lateritic soil. Sengupta et al. [49] and Sengupta [50] have earlier reported the outstanding potential of applying needle-punched NJATM compared to other mulches in crop yield in rainfed humid and semi-arid regions. Furthermore, considering the environment, Liu et al. [51] conveyed that bio-degradable nonwoven mulches fabricated from natural fibers have the potential in enhancing cotton productivity when compared to plastic mulches and simultaneously reduce plastic pollution.

4 Conclusion

Based on the results obtained from this experiment conducted in lateritic soil of eastern India, it can be summarized that the residue of nonwoven jute agro-textile mulches (NJATM) of different thicknesses as well as rice straw and black polythene mulch which were used in preceding broccoli increased all the growth characteristics and yield parameters of maize, soil fertility, soil moisture, microbial population, and weed suppression as compared to non-mulched plots. However, among all the mulches used, the residual 400 gsm NJATM showed the highest value of plant height, plant per m^2, cobs per plant, cob length, cob diameter, test weight, grain yield, biological yield, and harvest index of maize. Again, weed population (broadleaved, grasses, sedges) density was significantly decreased with the residue of NJATM of 400 gsm thickness. Similarly, the population of bacteria and actinomycetes in post-harvest soil was highest in residual 400 gsm NJATM. Likewise, residual NJATM significantly improved the moisture content and fertility status (available N, P, K and organic C) of soil compared to soil imposed with other mulches and not imposed with any mulching material. Among all the thicknesses of NJATM, 400 gsm thickness preserved the highest soil moisture and highest available N, P, K, and organic C. Thus, it can be concluded that residue of 400 gsm NJATM mulches is proven best in improving soil fertility, conserving soil moisture, increasing soil microbial population, suppressing weeds, and increasing summer maize yield in dry lateritic light-textured soil.

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Data Availability The data that support the findings of this study will be available from the corresponding author, Dr. Manik Chandra Kundu, upon reasonable request, and after all, derived papers from this research are published.

Declarations

Ethical approval Not applicable.

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References

1. Albert T, Karp K, Starast M, Paal T (2010) The effect of mulching and pruning on the vegetative growth and yield of the half-high blueberry. Agron Res 8:759–769
2. Bhatt R, Kheral KL (2006) Effect of tillage and mode of straw mulch application on soil erosion in submontaneous tract of Punjab, India. Soil Tillage Res 88:107–115
3. Anikwe MAN, Mbah CN, Ezeaku PI, Onyia VN (2007) Tillage and plastic mulch effects on soil properties and growth and yield of cocoyam (Colocasia esculenta) on an ultisol in South eastern Nigeria. Soil Tillage Res 93(2):264–273. https://doi.org/10.1016/j.still.2006.04.007
4. Sarkar S, Singh SR (2007) Interactive effect of tillage depth and mulch on soil temperature, productivity and water use pattern of rainfed barley (Hordium vulgare L.). Soil Tillage Res 92(1-2):79–86. https://doi.org/10.1016/j.still.2006.01.014
5. Yadav RL, Yadav DV, Duttamajumder SK (2008) Rhizospheric environment and crop productivity: a review. Indian J Agron 53(1):1–17
6. Duiker SW, Lal R (1999) Crop residue and tillage effects on carbon sequestration in a Luvisol in central Ohio. Soil Tillage Res 52:73–81
7. Havlin JL, Kissel DE, Maddus LD, Claasen MM, Long JH (1990) Crop rotation and tillage effects on soil organic carbon and nitrogen. Soil Sci Soc Am J 54:448–452
8. Khurshid K, Iqbal M, Arif MS, Nawaz A (2006) Effect of tillage and mulch on soil physical properties and growth of maize. Int J Agric Biol 8(5):593–596
9. Seyfi K, Rashidi M (2007) Effect of drip irrigation and plastic mulch on crop yield and yield components of cantaloupe. Int J Agric Biol 9:247–249
10. Quilty JR, Cattle SR (2011) Use and understanding of organic amendments in Australian agriculture: a review. Soil Res 49(1):1–26. https://doi.org/10.1071/SR10059
11. Subrahmaniyan K, Mathieu N (2012) Polyethylene and biodegradable mulches for agricultural applications: a review. Agron Sustain Dev 32(2):501–529
12. Schonbeck MW (1995) Mulching practices and innovations for warm scason vegetables in Virginia and neighboring states. 1. An informal survey of growers. Virginia Association for Biological Farming, Blacksburg, p 24
13. Durham S (2003) Plastic mulch: harmful or helpful? Agricultural Research. July 2003. http://www.ars.usda.gov/is/AR/archive/jul03/mulch0703.pdf. Accessed September 22, 2018
14. Rice PJ, McConnell LL, Heighton LP, Sadeghi AM, Isensee AR, Teasdale JR, Abdul Baki AA, Harman Fetcho JA, Hapeman CJ (2001) Runoff loss of pesticide and soil: a comparison between vegetative mulch and plastic mulch in vegetable production systems. J Environ Qual 30(5):1808–1821
15. Mooers CA, Wasko JB, Young JB (1948) Effects of wheat straw, Lespedeza sericea hay, and farmyard manure as soil mulches on the conservation of moisture and the production of nitrates. Soil Sci 66:307–315
16. Manna K, Kundu MC, Saha B, Ghosh GK (2018) Effect of nonwoven jute agrotextile mulch on soil health and productivity of broccoli (Brassica oleracea L.) in lateritic soil. Environ Monit Assess 190(2):1–10. https://doi.org/10.1007/s10661-017-6452-y
17. Bu L, Liu J, Zhu L, Luo S, Chen X, Li S, Hill RL, Zhao Y (2013) The effects of mulching on maize growth, yield and water use in a semi-arid region. Agric Water Manag 123:71–78. https://doi.org/10.1016/j.agwat.2013.03.015
18. Jordan A, Zavala LM, Muoz-Rojas M (2011) Mulching, effects on soil physical properties. Encyclopedia of Agro-physics Springer, Berlin, pp 492–496
19. Saha B, Prasad LK, Harris AA, Sikka AK, Batta RA (2006) Effect of geo-textile mulch on soil moisture, temperature and yield of

vegetable crops grown in planes of Bihar. Int J Tropical Agric 24(1–2):153–157

20. Nag D, Choudhury TK, Debnath S, Ganguly PK, Ghosh SK (2008) Efficient management of soil moisture with jute non-woven asmulch for cultivation of sweetlime and turmeric in red lateritic zone. J Agric Engg 45(3):59–62
21. Hu L, Wang Z, Peng D, Liao G (2000) Study of the effect of jute geotextiles on ramie growth. Sci Agric Sinica 33(3):103–105
22. Sarkar A, Tarafdar PK, De SK (2020) Effect of woven jute agro textile mulch on soil health and productivity of banana (Musa domestica L.) in new alluvial soil. Int Res J Pure Appl Chem 21(3):1–7
23. Sarkar A, Barui S, Tarafdar PK, De SK (2018) Jute agro textile as a mulching tool for improving yield of green gram. Int J Curr Microbiol App Sci 7(05):3604–3611. https://doi.org/10.20546/ijcmas.2018.705.416
24. Agarwal GP, Hasija SK (1986) Microorganisms in laboratory. Print House India Ltd., Lucknow, p 155
25. TAPPI Standard and suggested methods (1971) Technical Association of the Pulp and Paper Industry, New York
26. Sarkar PB, Mazumdar AK, Pal KB (1948) The hemicelluloses of jute fibre. J Text Inst 39(T44):44–58
27. Jackson ML (1973) Soil chemical analysis. Prentice Hall of India Pvt. Ltd, New Delhi, India
28. Walkley A, Black IA (1934) An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci 37(1):29–37. https://doi.org/10.1097/00010694-193401000-00003
29. Subbaiah BV, Asija GL (1956) A rapid procedure for the estimation of available nitrogen in soil. Curr Sci 25:259–260
30. Bray RH, Kurtz LT (1945) Determination of total organic and available forms of phosphorus in soil. Soil Sci 59(1):39–45. https://doi.org/10.1097/00010694-194501000-00006
31. Gomez KA, Gomez AA (1984) Statistical procedures for agricultural research, 2nd edn. John Wiley and Sons, New York
32. Sarkar A, Swain N, Tarafdar PK, De SK (2018) Influence of jute agro textiles on improvement of broccoli productivity in inceptisols. J Pharmacogn Phytochem 7:1451–1454
33. Adhikari N, Saha A, Bandopadhyay P, Mukharjee S, Tarafdar PK, De SK (2018) Efficient use of jute agro textiles as soil conditioner to increase tomato productivity. J Crop Weed 14(1):122–125
34. Islam MS, Alam MK, Salahin N, Alam MJ, Hussen MAM, Mondol ATMAI (2022) Effects of tillage, mulch and irrigation on maize (Zea mays L.) yield in drought prone area. Bangladesh J. Agri. 47(1):27-38. https://doi.org/10.3329/bjagri.v47i1.60591
35. Zhao ZY, Wang PY, Xiong XB, Zhou R, Zhu Y, Wang YB, Wang N, Wesly K, Xue W, Cao J, Zhang JL, Tao HY, Xiong YC (2023) Can shallow-incorporated organic mulching replace plastic film mulching for irrigated maize production systems in arid environments? Field Crop Res 297:108931. https://doi.org/10.1016/j.fcr.2023.108931
36. Ahmad S, Raza MAS, Saleem MF, Zaheer MS, Iqbal R, Haider I, Aslam MU, Ali M, Khan IH (2020) Significance of partial root zone drying and mulches for water saving and weed suppression in wheat. J Anim Plant Sci 30:154–162
37. Wilen CA, Schuch UK, Elmore CL (1999) Mulches and subirrigation control weeds in container production. J Environ Hort 17:174–180
38. Datta M, Singh NP, Choudhury PK, Mitra S (2005) Jute agro-textiles—its uses in agriculture. Resource documents. ICAR Research Complex for NEH Region, Tripura Centre, Lembucherra-779 210 Tripura http://tripuraicar.nic.in/publication/agriculture%2002/jute%20agrotextile.pdf. Accessed 10 Mar 2017
39. Minhas WA, Mehboob N, Yahya M, Rehman HU, Farooq S, Hussain M (2023) The influence of different crop mulches on weed infestation, soil properties, and productivity of wheat under conventional and conservation production systems. Plants 12:9. https://doi.org/10.3390/plants12010009
40. Subba R (2015) Study on microbial population in rhizosphere under different agro-textile mulches in vegetable production system. In: M. Sc. Thesis, Integrated Rural Development and Management Faculty Centre. Ramakrishna Mission Vivekananda University, Narendrapur, West Bengal, India, p 46
41. Pal D, Bera S, Ghosh RK (2013) Influence of herbicides on soyabean yield, soil microflora and urease enzyme activity. Indian J Weed Sci 45(1):34–38
42. Youkhana A, Idol TW (2009) Tree pruning mulch increases soil carbon and nitrogen in shade and full sun coffee agroecosystems in Hawaii. Soil Biol Biochem 41(12):2527–2534. https://doi.org/10.1016/jsoilbio.2009.09.011
43. Gupta R, Acharya CL (1993) Effect of mulch induced hydrothermal regimes on root growth, water use efficiency, yield and quality of strawberries. J Indian Soc Soil Sci 41(1):17–25
44. Zhou W, Chen J, Qi Z, Wang C, Tan Z, Wang H, Yi Z (2020) Effects of applying ramie fiber nonwoven films on root-zone soil nutrient and bacterial community of rice seedlings for mechanical transplanting. Sci Rep 10:3440. https://doi.org/10.1038/s41598-020-60434-3
45. Dahiya R, Malik RS (2002) Trash and green mulch effects on soil N and P availability. Resource documents. Chaudhary Charan Singh Haryana Agricultural University, Hisar, India https://www.citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.497.3368/rep=rep1/type=pdf. Accessed 10 Mar 2017
46. Singh AK, Singh S, Rao VVA, Bagle BG, More TA (2010) Efficiency of organic mulches on soil properties, earthworm population, growth and yield of aonla cv. NA7 in semi-arid ecosystem. Indian J Hort 67:124–128
47. Saha B (2021) Non-woven jute agro-textiles for improvement of soil quality and horticultural production: example from coastal ecosystem. In: Souvenir, International Symposium on Coastal Agriculture: Transforming Coastal Zone for Sustainable Food and Income Security. Eds. Mandal, U.K. et al. Indian Society of Coastal Agricultural Research, ICAR-Central Soil Salinity Research Institute, Regional Research Station, Canning Town - 743 329, West Bengal, India. pp 45-57
48. Manna K, Saha B, Kundu MC (2022) Study of non-woven jute agro-textile mulches on soil water, temperature and nutrient status in root zone in broccoli (*Brassica oleracea* L.) cultivation. Int J Bio-resour Stress Manag 13(4):348–356
49. Sengupta S, Debnath S, Bhowmick M (2022) Sustainable agrotextile: jute needle-punched nonwoven preparation, properties and use in Indian perspective. In: Muthu SS (ed) Sustainable Approaches in Textiles and Fashion. Sustainable Textiles: Production, Processing, Manufacturing & Chemistry. Springer, Singapore, pp 41–80. https://doi.org/10.1007/978-981-19-0878-1_3
50. Sengupta S (2020) Potential of jute based needle-punched nonwoven: properties and applications. In: Elise R (ed) Nonwoven fabric: manufacturing and applications. Nova Science Publishers, Inc., pp 37–100
51. Liu X, Chen C, Sun X, Wang X (2022) Multicriteria optimization of a novel degradable nonwoven mulch fabricated from recycled natural fibers using CV-TOPSIS technique. Text Res J 92(15–16):2784–2791. https://doi.org/10.1177/00405175211014236