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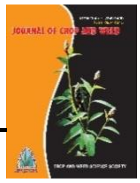

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Characterization of biochar produced from different agro-wastes

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ABSTRACT

An experiment was conducted with an aim to 'characterize biochar produced from different agro-wastes' during 2020-2021 at Onattukara Regional Agricultural Research Station, Kayamkulam, Alappuzha, Kerala. The experiment was laid out in completely randomized design, comprised with five treatments and replicated four times. The treatments were t_1 (biochar produced from rice stubbles), t_2 (biochar produced from rice husk), t_3 (biochar produced from tender coconut husk), t_4 (biochar produced from coir waste) and t_5 (biochar produced from banana waste). Among the biochar produced from different agro-wastes, recovery percentage (23.52%), pH (9.89), EC (0.013 dS m^{-1}), total N content (0.95%) and total Cu (0.32 mg ha^{-1}) were significantly higher in t_3. Water holding capacity was significantly higher in t_4 (235.74%) and was found to be on par with t_3 (232.34%). The CEC was significantly higher in t_1 (16.60 (cmol (+) kg^{-1}) and was on par with t_3 and t_5. The total K (1.54%) and total Ca (0.67%) content was found to be significantly higher in t_5. The total iron content was significantly higher in t_4 (108.83 mg kg^{-1}). The total Mn was superior in t_1 (10.42 mg kg^{-1} respectively). Based on the findings of the experiment, treatment t_3 (biochar produced from tender coconut husk) was identified as superior to the other biochars.

Keywords: Banana, biochar, coir, husk and tender coconut husk

In India, two to three crops are grown annually. The agricultural waste generated during these cropping seasons is much greater than that compared to other countries. After harvest, the farmers find less to no time to prepare their fields. The lack of suitable technology to dispose the left-over crop residues, force them to torch the residues as an easy way of clearing the field. About 43% of the total crop stubbles generated in India is burnt on the field (Singh and Kaskaoutis, 2014). This indiscriminate burning poses a threat to human and animal health as they are a significant source of gaseous and particulate pollutants. Biochar is made by pyrolysis of biomass where the substrates are burned with little or no oxygen. The biochar thus produced has low bulk density, high porosity, and water holding capacity (Punnoose and Anitha, 2015) which makes it a suitable alternate for crop residue burning. When applied to soil, these properties of biochar make it an ideal soil conditioner and improves the water and nutrient retention in soil, thereby improving the yield. Thus, converting the crop residues to biochar can serve as a potential technique to remediate the environmental problems caused by crop residue burning.

Rice cultivation leaves significant quantity of stubbles after harvest. At present, this is either ploughed along with soil at land preparation or burned out. This large quantity of agricultural waste can be converted to biochar and recycled back to use in agriculture. Similarly, the silica rich rice husk which is piled up during the first stage of milling is considered as an agricultural waste. The slow burning property of rice husk makes it an ideal candidate for producing biochar. Likewise, after the consumption of tender coconut, the coconut husk is now fast emerging as an agricultural waste. In Kerala, only a fraction of the tender coconut waste generated is effectively utilized by composting. The coconut husk has high potential to be converted to biochar after drying. Another agricultural waste is coir waste which is generated after the extraction of coir fibre. This is causing solid waste pollution. Coir waste can also be recycled back for agricultural use through production of biochar.

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Similarly, for every tonne of banana harvested, approximately 4 tonnes of banana waste including leaves, pseudostem, and bunch is generated. This waste can be routed back to enhance agricultural productivity by converting it to biochar. Hence, present investigation on 'characterization of biochar from different agro wastes' was undertaken.

MATERIALS AND METHODS

An experiment was undertaken during December 2020 to April 2021 at Onattukara Regional Agricultural Research Station, Kayamkulam, Alappuzha, Kerala to characterize biochars made from different agro-wastes. For this, different agro-wases from rice stubbles, rice husk, tender coconut husk, coir waste, and banana waste were collected and shade dried to render it free from moisture. These dried agro-wastes were subjected to controlled pyrolysis in a customized kiln having internal dimensions of 1.4 m x 1.5 m x 0.75 m (Plate 1). The biochars thus produced (plate 2 and plate 3) were powdered using pestle and mortar and was then sieved through a 0.2 mm sieve and stored for analysis. These powdered samples were then characterized for its physico-chemical properties by adopting appropriate methods (Table 1). The design used for analysis was completely randomized design which comprised of five treatments *viz*. t_1 (biochar produced from rice stubbles), t_2 (biochar produced from rice husk), t_3 (biochar produced from tender coconut husk), t_4 (biochar produced from coir waste) and t_5 (biochar produced from banana waste) and were replicated four times. The experiment was analysed statistically using GRAPES software developed by the Department of Agricultural Statistics, College of Agriculture, Vellayani (Gopinath *et al*., 2020).

RESULTS AND DISCUSSION

The agro-wastes *viz*., rice stubbles, rice husk, tender coconut husk, coir waste and banana waste were collected and processed to prepare biochar, separately. The biochar produced were characterized for physico-chemical parameters *viz*., recovery percentage, water holding capacity, bulk density, pH, electrical conductivity, cation exchange capacity, total organic carbon, and total nutrient content. The results obtained are discussed below and are depicted in Table 2, Table 3 and Table 4.

Recovery percentage

The recovery percentage of biochar from different agro-wastes were found to be significant (Table 2). Biochar produced from tender coconut husk (t_3) showed significantly higher recovery percentage (23.52%) and the lower recovery was recorded for biochar produced from coir waste (t_4) with 15.48%. There was an overall increase of 41.23% in t_3 compared to t_4. Similar results of higher recovery per cent (40% and 50%) were reported by Dainy (2015) and Nagula (2017) respectively, in biochar produced from tender coconut husk. Venkatesh *et al*. (2010) reported that biochar produced by gasification and pyrolysis yields between 2 and 35% by weight of biomass. The recovery percentage of biochar is depended on the type of kiln used for biochar production. This might be the reason for the difference in recovery percentage of tender coconut husk. The lower recovery percentage for biochar from coir waste might be due to its higher burning rate inside the customized kiln. The coir waste was converted to ash very quickly due to its fibrous nature.

Water holding capacity

The water holding capacity of different biochars produced from common agro-wastes is depicted in Table 2. All the biochars produced from different agro wastes had higher water holding capacity compared to its weight due to their porous nature and increased surface area. Punnoose (2015) has also reported an increase in water holding capacity in biochar due to a three-fold increase in porosity. Among the treatments, biochar produced from coir waste (t_4) was found to have significantly higher water holding capacity (235.74%). This was found to be on par with biochar produced from tender coconut husk (t_3) with 232.34%. This might be due to the elevated pore space in biochar produced from coir waste and tender coconut husk. Earlier, Rojith and Singh (2012) had suggested the effective utilization of coir waste biochar in improving the water retention capacity of the soil due to its ability to retain double the quantity of water compared to coir pith.

Bulk density

The bulk density of biochar produced from different sources were not found to be significant (Table 2).

pH

The treatments had a significant influence on pH (Table 2). Among the treatments, tender coconut husk biochar (t_3) recorded significantly higher pH of 9.89. All the biochars produced were alkaline in reaction (due to their higher pH) and hence, can be utilized as a soil amendment in acidic soils. Gaskin *et al*. (2008) has reported that biochar would turn alkaline due to hydrolysis of K, Ca and Mg salts in the biomass. Rajkumar (2019) observed the alkalinity in biochar might be due to the presence of alkali and alkaline earth metal carbonate. Similar report of a higher pH (9.13) was obtained by Dainy (2015) for biochar produced from tender coconut husk. Jabin (2022) also observed higher pH for biochars made from paddy husk (7.8) and coconut fronds (8.3).

Electrical conductivity (EC)

In general, a lower electrical conductivity was observed for the biochars produced. Among the treatments, biochar produced from tender coconut husk (t_3) registered a significantly higher EC of 0.013 dS m^{-1} (Table 2). This might be due to the lower level of phosphates, silica, heavy metals and carbonates of alkaline earth metals in Onattukara soils, from where the biomass for production of biochar was collected.

Cation exchange capacity (CEC)

The data regarding the CEC of different biochars tested is provided in Table 2. The CEC was found to be significantly higher (16.50 cmol (+) kg^{-1}) for biochar produced from rice stubbles (t_1) and was on par with biochar produced from tender coconut husk (t_3) and banana waste (t_5) with 15.60 cmol (+) kg^{-1}. Biochar provides stronger adsorption capacity for mineral elements when applied to soil (Liang *et al*., 2006) due to the higher cation exchange capacity. The relative high cation exchange capacity might be due to their negative surface charge and resultant affinity for soil cations (Xie *et al*., 2015). Dainy (2015) and Nagula (2017) had also observed that the biochar produced from tender coconut husk acts as a cation exchanger to help nutrients retain in soil.

Total organic carbon

The results of the study revealed that there was significant effect for the treatments with respect to total organic carbon. Significantly higher total organic carbon (50.64%) was obtained for the treatment t_2 (Table 2). In general, all biochars produced had higher per cent of total organic carbon. This higher carbon in biochar is due to the carbonization of biomass during pyrolysis where the degradation of non-carbon atoms occurs, leading to an increase in the carbon content. Rice husk contains about 35-40% cellulose which when carbonized might have contributed to the higher carbon in t_2. Jabin (2022) had also reported 47% carbon content in biochar produced from paddy husk.

Total nitrogen

The data regarding the total nitrogen is presented in Table 3. The total nitrogen content (0.95%) was significantly higher for biochar produced from tender coconut husk (t_3) and was found to be on par with biochar produced from rice husk (t_2 - 0.89%). The difference in concentration might be due to the type of feed stock used. Similar results were also obtained by Dainy (2015) and Nagula (2017) who obtained 1.05% and 1.52% total nitrogen for biochar produced from tender coconut husk, respectively. Jabin (2022) also recorded a total N 0.84% in paddy husk biochar.

Total phosphorus

The total phosphorus for different biochar produced from different sources was not found significant (Table 3).

Total potassium

The effect of different agro-wastes with respect to total potassium in biochar is depicted in Table 3. The treatment t_5 (biochar produced from banana waste) was significantly superior regarding total potassium content with 1.54% of potassium. Ho *et al*. (2012) had reported a potassium content of 944.0 mg per 100 g dry pseudo stem. The higher potassium content in the initial agro waste compared to other biomass might be the reason for the higher values in t_5. Similar result of higher potassium content in biochar produced from banana peel waste was reported by Sial *et al.* (2019). Islam *et al*. (2019) also reported biochar from banana as a potassium rich amendment.

Total calcium

The total calcium content was found to be significant among the treatments (Table 3). The higher calcium content was recorded in t_5 with 0.67% in banana waste and was found on par with the treatment t_4 (0.55%). Ho *et al*. (2012) had reported a calcium content of 1335.30 mg per 100 g dry pseudo stem. This increased calcium content in the agro waste might be the reason for the higher calcium content in biochar produced from banana.

Total magnesium

The total magnesium content was not found significant (Table 4).

Total sulphur

The result of different biochar regarding the total sulphur content is provided in Table 4. The treatments were not found to be significant.

Total copper

The effect of different treatments on total copper content is depicted in Table 4. Copper, a heavy metal, in the biochars produced were analysed and was found below the threshold limit prescribed by IBI (2015). There were significant effects for the treatments. Among the treatments, tender coconut husk (t_3) recorded a higher copper content (0.32 mg kg^{-1}) and was found to be on par with $t_{1,}$ t_2 and t_5 (0.28 mg kg^{-1}, 0.27 mg kg^{-1} and 0.27 mg kg^{-1} respectively). Since the quantity of biochar is below the prescribed limit, its application as a soil conditioner is environmentally safe. Similar report of environmentally safer levels of total copper content (0.50 mg kg^{-1}) was observed by Nagula (2017) in tender coconut husk.

Total zinc

The effect of treatments on the total zinc content was not significant (Table 4).

Total iron

The effect of treatments on total iron content was significant (Table 4). There was significant effect due to treatments on total iron content. Among the treatments, t_4 (biochar produced from coir waste) recorded a significantly higher iron content (108.83 mg kg^{-1}) and was found to be on a par with the treatment t_3 (107.58 mg kg^{-1}), t_1 (104.15 mg kg^{-1}) and t_2 (103.34 mg kg^{-1}). Dainy (2015) had also reported a total iron content of 123.04 mg kg^{-1} in biochar produced from tender coconut husk.

Total boron

The effect of treatments on different biochars on the total boron content (Table 4) was not found significant.

Total manganese

The significant effect of different biochars on total manganese content is depicted in Table 4. The highest manganese content was recorded for the treatment t_1 (biochar produced from rice stubbles) with 10.42 mg kg^{-1}.

Table 1. Standard analytical procedures used for the characterization of biochar

Sl. No.	Characters	Methods	
1.	Recovery percentage (%)	The quantity of biochar generated from each treatment was recorded on a fresh weight basis and recovery in terms of percentage was worked out. $\text{Recovery} = \frac{\text{Weight of the biochar}}{\text{Total weight of the agro waste}} \times 100$	
2.	Water holding capacity (%)	Core sample	Gupta and Dakshinamurthy (1980)
3.	Bulk density (Mg m^{-3})	Undisturbed core sample	
4.	pH	pH meter (1:2.5 sample water ratio)	Jackson (1958)
5.	Electrical Conductivity (dS m^{-1})	Conductivity meter (1:2.5 sample water ratio)	Jackson (1958)
6.	Cation Exchange Capacity (cmol (+) kg^{-1})	Ammonium saturation using neutral normal ammonium acetate and distillation	Jackson (1973)
7.	Total carbon (%)	Loss on ignition	Piper (1967)
8.	Nitrogen	Microkjeldahl distillation after digestion of H_2SO_4	Jackson (1973)
9.	Phosphorus	Nitric-perchloric (9:4) acid digestion and colorimetry using the vanado-molybdo phosphoric yellow colour method	Jackson (1973)
10.	Potassium	Nitric-perchloric (9:4) acid digestion and estimation using flame photometer	Jackson (1973)
11.	Calcium, Magnesium	Nitric-perchloric (9:4) acid digestion and versanate titration with standard EDTA	Piper (1966)
12.	Sulphur	Nitric-perchloric (9:4) acid digestion and turbidimetry	Massoumi and Cornfield (1963)
13.	Fe, Mn, Zn, and Cu	Nitric- perchloric (9:4) acid digestion and atomic absorption spectrophotometry	Lindsay and Norvel (1978) Jackson (1973)
14.	Boron	Estimation by spectrophotometry (Azomethine-H method)	Roig *et al.* (1988)

Table 2. Physico-chemical properties of biochar obtained from different agro-wastes

Treatments	Recovery (%)	WHC (%)	Bulk density (Mg m^{-3})	pH	EC (dS m^{-1})	CEC (cmol (+) kg^{-1})	TOC (%)
t_1- biochar produced from rice stubbles	19.55^{c}	219.51^{b}	0.29	9.63^{b}	0.008^{c}	16.50^{a}	29.56^{e}
t_2- biochar produced from rice husk	21.22^{b}	129.18^{d}	0.35	8.41^{d}	0.002^{d}	13.00^{c}	50.64^{a}
t_3- biochar produced from tender coconut husk	23.52^{a}	232.34^{a}	0.30	9.89^{a}	0.013^{a}	15.60^{ab}	48.14^{b}
t_4- biochar produced from coir waste	15.48^{d}	235.74^{a}	0.29	9.61^{b}	0.003^{d}	13.70^{bc}	45.11^{c}
t_5- biochar produced from banana waste	20.48^{bc}	176.53^{c}	0.33	9.33^{c}	0.011^{b}	15.60^{ab}	43.79^{d}
SEm (±)	0.322	3.280	0.016	0.07	0.001	0.650	0.311
LSD (0.05)	0.970	9.904	NS	0.212	0.002	0.196	0.936

NS- Not significant

Table 3. Primary and secondary nutrient content of biochar obtained from different agro-wastes

Treatments	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)
t_1- biochar produced from rice stubbles	0.60^{b}	0.24	0.23^{c}	0.41^{bc}	0.13	0.09
t_2- biochar produced from rice husk	0.89^{a}	0.27	0.33^{c}	0.09^{d}	0.13	0.10
t_3- biochar produced from tender coconut husk	0.95^{a}	0.25	0.93^{b}	0.21^{cd}	0.13	0.11
t_4- biochar produced from coir waste	0.69^{b}	0.24	0.24^{c}	0.55^{ab}	0.14	0.11
t_5- biochar produced from banana waste	0.65^{b}	0.26	1.54^{a}	0.67^{a}	0.15	0.10
SEm (±)	0.040	0.010	0.047	0.067	0.040	0.010
LSD (0.05)	0.120	NS	0.141	0.202	NS	NS

NS- Not significant

Table 4. Micronutrient content of biochar obtained from different agro-wastes

Treatments	Cu (mg kg^{-1})	Zn (mg kg^{-1})	Fe (mg kg^{-1})	B (mg kg^{-1})	Mn (mg kg^{-1})
t_1- biochar produced from rice stubbles	0.28^{a}	29.33	104.15^{a}	9.80	10.42^{a}
t_2- biochar produced from rice husk	0.27^{a}	24.88	103.34^{ab}	10.87	7.27^{c}
t_3- biochar produced from tender coconut husk	0.32^{a}	28.80	107.58^{a}	13.55	5.47^{d}
t_4- biochar produced from coir waste	0.17^{b}	27.15	108.83^{a}	10.07	8.39^{b}
t_5- biochar produced from banana waste	0.27^{a}	28.48	95.99^{b}	13.29	5.47^{d}
SEm (±)	0.021	1.086	2.575	1.145	0.31
LSD (0.05)	0.064	NS	7.761	NS	0.935

NS- Not significant

CONCLUSION

After characterization of biochar produced from different agro wastes, it could be concluded that biochar produced from tender coconut husk had higher recovery percentage, water holding capacity, pH, EC, CEC and total N. Higher organic carbon content was observed in biochar produced from rice husk, and higher total potassium and total calcium content were observed for biochar produced from banana waste. Thus, there is a great potential to convert different agro-wastes like tender coconut husk, coir waste and banana waste to biochar. The biochar thus produced can be used as a potential soil conditioner especially in the sandy soils for raising crops, thus enabling a safe disposal of agro-wastes through agro-waste utilization.

Plate 1. Customized biochar kiln used for the production of biochar

Plate 2. Different steps in biochar production

Rice stubbles

Rice stubbles biochar

Rice husk

Rice husk biochar

Tender coconut husk waste

Tender coconut husk biochar

Coir waste

Coir waste biochar

Banana waste

Banana waste biochar

Plate 3. Biochar produced from different agro-wastes

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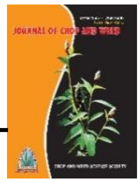

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Weed management in soybean using early post emergence herbicide in lateritic soil and residual effects of herbicide in succeeding crops

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ABSTRACT

A study was conducted to establish an appropriate weed management strategy through ready-mix early post-emergence herbicides for soybean production in lateritic belt of West Bengal (India). The experiment was conducted for two consecutive years i.e., 2017-18 and 2018-19 in a field located at Agricultural Farm of Palli Siksha Bhavana (Institute of Agriculture), Sriniketan, Birbhum, West Bengal (N $23^0$39.823', E $87^0$37.972'). The early post-emergence application of fomesafen 12.5% + fenoxaprop 10% + chlorimuron ethyl 0.9% ME at 10 days after soybean sowing recorded minimum weed population and dry weight as well as showed good weed control efficacy, higher yield with good soybean safety. However, weed-free treatment produced tallest plant, greater yield attributing characters, and yield that was comparable to fomesafen 12.5% + fenoxaprop 10% + Chlorimuron ethyl 0.9% ME at 280 g ha^{-1} which was again at par with fomesafen 12.5% + fenoxaprop 10% + chlorimuron ethyl 0.9% ME at 234 g ha^{-1} The application of ready-mix formulation of early post emergence herbicide may be incorporated into the weed management programme for sustainable soybean production, and there wouldn't be any residual effects on succeeding crops.

Keywords: Chlorimuron-ethyl fenoxaprop, fomesafen, early post emergence and soybean

Soybean [*Glycine max* (L.) Merill], also known as 'wonder crop' possesses global importance. In India, it is cultivated in an 8.53 million ha area with an annual production of 9.43 million tonnes (FAOSTAT, 2021). However, soybean productivity in India is significantly less than that in USA. There are several reasons for low productivity. Out of these, weed has paramount importance. As soybean is a wet season crop, it must contend with fierce crop weed competition, while it is actively growing. Depending on the weed species and their density, inadequate weed control can reduce soybean yields as high as 43% in the untreated control (Reddy *et al*., 2013). Although weeds are an issue during the crop cycle, keeping a weed-free environment during the critical time (the first 45 days after planting) is crucial (Hosmath, 2014). The production potential of the crop cannot be realized fully, if weeds are not controlled within the critical period of crop-weed competition. Effective weed management in soybean cultivation is crucial to protect soybean growth and productivity from weed competition during the growing seasons. Soybean is susceptible to weed interference since the seeds are sown with wider spacing for encouraging to produce more branches and to allow the canopy to expand fully during the late growth stage (Hock *et al*., 2006). The late canopy closure permits weeds to be established more quickly in soybean field than in other crops (Harder *et al*., 2007). To efficiently manage weed infestations in soybean field, various weed management methods, including hand weeding, herbicide application, tillage practices, and crop rotation are used in combination (Vivian *et al*., 2013). Manual weeding and hoeing are typically used to control weeds in soybean fields. Hand weeding is the most popular weed management technique (Shukla *et al*., 2022). However, hand weeding becomes difficult due to shortage of labour,

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especially during the peak of crop weed competition and also now a days, it is not economically much viable due to high labour costs. Because of severe and persistent rain, weeding equipment and implements are exceptionally scarce during *kharif* season (Jadhav and Kashid, 2019). Due to the increased cost of cultivation and depletion of the resource base, manual weeding and mechanical weed control methods may not be efficient and effective (Kumar *et al*., 2018; Adigun *et al*., 2018). Hence, there is a need to evaluate the new herbicide molecules for successful control of annual grass and broadleaved weed flora in soybean. So, fomesafen 12.5% + fenoxaprop 10% + chlorimuron ethyl 0.9% ME is a new molecule that reportedly kills the post-emergence weeds in soybean. In context of all these information, the current study has been carried out by using post emergence herbicide with the goal of determining its impact on weed and growth of the soybean crop.

MATERIALS AND METHODS

The field experiments were conducted in 2017-18 and 2018-19 in soybean fields at Agricultural Farm of Palli Siksha Bhavana (Institute of Agriculture), Visva-Bharati, Sriniketan, Birbhum, West Bengal (N $23^0$39.823′, E $87^0$37.972′). During the entire growing season (*kharif*), soybean was grown in rainfed conditions. The respective total rainfall during the growing season was 751.4 mm in 2017-18 and 836.9 mm in 2018-19 (Indian Meteorological Department, Sriniketan). The soil of the experimental field was sandy loam (Ultisol) in texture with slightly acidic pH (6.07), organic carbon 0.48%, available nitrogen concentration of 167.1 kg ha^{-1} (Alkaline permanganate method by Subbiah and Asija, 1956), available phosphorus (P) concentration of 6.2 mg kg^{-1} (Olsen's calorimeter method by Olsen *et al*., 1954) and available potassium concentration of 83.4 mg kg^{-1} (0.1 N Ammonium acetate extractable K method; Jackson, 1973).

The experiment was designed in a Randomized Block Design with three replications. Soybean variety ‘Pusa 20’ was sown on June 8, 2017 for first year and on June 6, 2018 for second year maintaining the row to row spacing of 40 cm and plant to plant spacing 10 cm at 75 kg seed ha^{-1}. A total of 40 kg N through urea, 80 kg P_2O_5 through SSP and 25 kg K_2O through MOP were applied per hectare basis to the crop as basal. The ten treatments comprised of early post emergence herbicide formulation fomesafen 12.5% + fenoxaprop 10% + chlorimuron ethyl 0.9% ME in different doses (187, 234 and 280 g ha^{-1}) along with chlorimuron ethyl 25% WP at 9 g ha^{-1}, Fenoxaprop-p-ethyl 9.3% w/w EC at 103 g ha^{-1}, imazethapyr 10% SL at 100 g ha^{-1} and fluazifop-p-butyl 11.1% w/w + fomesafen 11.1% w/w SL at 222 g ha^{-1}. All the herbicides were sprayed as early-post emergence at 10 days after sowing (DAS). The herbicides were applied using a Knapsack sprayer with a flat-fan nozzle that was adjusted to deliver 500 L ha^{-1}. Hand weeding (15 and 30 DAS) was also included twice in the experiment besides the weed free and un-weeded control (weedy check). All the recommended improved package of practices of soybean was followed in this experiment including the general plant protection measures.

The efficacy of the tested herbicides was evaluated at 15 and 30 days after herbicide application (DAA). At each sampling period, three quadrates of 50 × 50 cm were placed randomly in each plot to determine the density and biomass of weeds. Weeds were uprooted manually, identified and counted into three groups viz., grasses, sedges, and broad-leaved. Weed samples were then sun-dried for 24 hours and then oven-dried at 70^oC for 72 hours. The dry weight of weeds was recorded separately with precise electronic balance to compare the efficacy of different herbicidal treatments in terms of weed control efficiency (Mani *et al*., 1973; Das, 2008) and weed index (Gill and Kumar, 1969)

Residual study of tested herbicides was done on succeeding rapeseed (cv. B9) during 2017-18 and lentil (cv. Subrata) during 2018-19. The crops were sown in the same experimental plot previously used for soybean crop without disturbing the previous field lay-out. Seeds were sown after treating with *Trichoderma viride* @ 4 g kg^{-1} (Liebigs Agro Chem Pvt. Ltd., Kolkata) at a spacing of 30 × 10 cm. All the recommended improved package of practices were followed in rapeseed and lentil. The germination percentage along with the yield was recorded for both the succeeding crops during harvesting and presented in Table 4.

All data were analyzed through analysis of variance (ANOVA) using standard variance techniques suggested by Gomez and Gomez (1984). Before statistical analysis, the data on density of weeds and dry weight of data were subjected to square root ($\sqrt{x+0.5}$) transformation to improve the homogeneity of the variance (ANOVA). The significant treatment effect was judged with the help of ‘F’ test at the 5% level of significance.

RESULTS AND DISCUSSION

Weed flora in experimental site

The experimental field was infested with weeds belonging to three different groups. There was a total of six major different species of weeds, including *Commelina benghalensis*, *Phyllanthus niruri*, and *Eclipta alba* among the broad-leaved weeds and major grassy weeds included *Dactyloctenium aegyptium*, *Cynodon dactylon* as well as *Cyperus sp*. among the sedge were the predominant weed floras during the cropping period.

Effect on weed density

Results revealed significant differences among the herbicidal treatments on weed density of various species at 15 DAA (Days after herbicide application) and 30 DAA (Table 1). Maximum weed density of all species was recorded in weedy check plots due to uninterrupted growth of weeds as no weed control measures were taken. The herbicide - fomesafen 12.5% + fenoxaprop 10% + chlorimuron ethyl 0.9% ME gave better result in controlling all the weed