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EVALUATION OF HERBICIDES FOR WEED CONTROL, PHYTOTOXICITY, AND YIELD IN DARK JUTE (*CORCHORUS OLITORIUS* L.) UNDER SUBTROPICAL CONDITIONS

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Abstract

Substantial infestation of weed is a key constraint in jute. Chemical weed management may confirm actual long- term weed kill and ensure optimum production although it has some residual impact in soil, natural community composition and environment. In this respect, a field experiment was carried out at the Jute Agriculture Experimental Station, Manikganj (latitudes:23°38' and 24°03' north, and longitudes: 89°41' and 90°08' east) during jute growing season (April-July) of 2021 and 2022 in Bangladesh to monitor suitable and effective herbicides for weed control in *C. olitorius* - jute. The study was designed with 18 treatments and tested in a randomized block design with 3 replications. The weed control approaches consisted of several doses of chemical herbicide, conventional practice and control. Results of the study revealed that twelve weed species represented the weed community under five families in *C. olitorius* field. *Cyperus rotundus, Echinochloa colonum, Digitaria sanguinalis, Eleosine indica* were more abundant among the weed species. Principal component analysis of dry matter exposed that Fluazifop-p-butyl 10% + Ethoxysulfuron 10%, Quizalofop-p-ethyl 5%+Ethoxysulfuron 15%, Fenoxaprop-p-ethyl 10%+Ethoxysulfuron 10% were effective against weeds of Cyperaceae and Poaceae family. Fenoxaprop-p-ethyl 10% + Ethoxysulfuron 10% (Sunjute Plus 20 WG) @ 300 g ha^{-1} sprayed 8 days after sowing (DAS) performed the best in fibre yield (2.50 t ha^{-1}), and stick yield (4.99 t ha^{-1}) apart from weed free treatment. Correlation matrix demonstrated that plant height had a constructive and strong correlation with fibre yield and stick yield. Economics revealed that, the maximum gross return (149767 Tk. ha^{-1}) and benefit-cost ratio (BCR) (1.64) was observed with Fenoxaprop-p-ethyl 10% + Ethoxysulfuron 10% (Sunjute Plus 20 WG) @ 300 g ha^{-1} sprayed 8 DAS. After evaluation of efficiency of herbicides, it allowed the development of real plant protection approaches and the improvement of yield in jute. The constraint of this study was only done in one location but multi-location trials can be conducted before recommending the package to the farmers.

Key words: Weed control rating, Herbicide selectivity, Summed dominance ratio, Fibre yield, Correlation matrix.

Introduction

Jute (*Corchorus* spp.) is regarded as the second highest significant bast fibre-yielding crop worldwide (Samira *et al*., 2010) and a major cash crop in Bangladesh (Akhter *et al*., 2020). According to Anon., (2022), Bangladesh is the top jute grower country and sharing about 58% of the total production of jute in the world. The total cultivated area under *Corchorus olitorius* in 2021 was around 0.73 million ha producing about 2 million tons fibre yield in Bangladesh (Anon., 2022). Bangladesh earned about 909 million US dollars in the year 2020-21 by exporting unprocessed jute fibre and fibre products which is currently generating about 2.36% of GDP to the country's economic growth (Anon., 2022). The significant features of *C. olitorius* is that it is free from health dangers and environmental contamination (Kazal *et al*., 2013). It is durable, reusable, economical, and superior to artificial fibre. The other main advantages of *C. olitorius* are that it is agro-based, produced yearly, and decomposable (Basu & Roy, 2008). *C. olitorius* is considered as the top natural substitute for nylon and polypropylene. It has been recognized as a solution to produce eco-friendly crops for the future in Bangladesh.

The *C. olitorius* is particularly vulnerable to pathogens, pests (insects and weeds), and any alterations in the atmosphere, habitat, and climate (Sarkar & Gawande, 2016) and among them, weeds are recognized as the major challenge, since their interference might result in overall yield loss in *C. olitorius* crop (Islam & Rahman, 2008). Fast-growing weed flora with enhanced adaptability to the changing surroundings as well as strong regeneration capability exerts a severe threat to crop plants (Swanton *et al*., 2015) and frequently, such rivalry throughout the initial phase of development (15- 45 days after sowing) due to improper weed management approaches exerted a substantial impact on *C. olitorius* yield decreasing by up to 70% (Ghorai *et al*., 2013; Singh *et al*., 2015). Losses continue to occur when expenditures in weed control rise, which increases the overall budget for cultivation by more than 35% in India and 30–40% in Bangladesh (Kumar *et al*., 2013; Islam, 2014). About 40% of the entire cultivation charge and up to 70% of fibre output decline under weedy control situation, but the comparatively more productivity can be obtained through providing weed free situation in early growth stages (Singh *et al*., 2004). This statement was supported by Hossain *et al.* (2023), who discovered that fields of *C. olitorius* should be kept weed-free during the critical time frame (from 19 to 59 days after sowing) to get the maximum yield. Generally, crop-weed rivalry arises throughout the plant growth period for various growth-restricting variables such as irradiance, air, moisture, land, and minerals (Ashiq & Aslam, 2014) and laterally, impacts crop profitability through serving as a harbor for insects and pathogens, disrupting water supply, lowering outputs and quality, and accordingly, rising processing expenses (Zimdahl, 2013).

Weeds can be controlled using a variety of techniques, including conventional as well as advanced approaches, both of which have their own drawbacks. For instance, manual or hand weeding is an efficient established practice in Bangladesh for controlling weeds in *C. olitorius* though it is expensive and difficult, especially, when weed species emerge before seeding because of precipitation. Moreover, insufficiency of manpower with high wage rate during peak period is also a hindrance to traditional weeding in *C. olitorius* (Ghorai, 2015), as marginal farmers have been flocking towards cities in recent years to seek higher wage and uplift their standard of living. So, herbicide-based weed control approaches are getting importance to overcome this issue by the crop growers (Mukherjee, 2013). Additionally, time limits and improvements in pest management technology along with constant 'enticement' from the present farming method have motivated crop growers to continue utilizing herbicides that have proven to be effective, time-efficient and economical (Rashid *et al*., 2007; Hussain *et al*., 2008).

Hand weeding by *nirani* is the common method for weed control of *C. olitorius* in Bangladesh. This method is very arduous and time consuming for *C. olitorius* cultivation. Moreover, accessibility of labor is become a crucial problem during peak period. On the other hand, hand weeding is a non-effective method because weed grows very fastly just after weeding. So subsequent weeding is necessary and it increases the cost of cultivation and reduce yield of *C. olitorius*. In this regard, chemical technique of weed control could be a substitute for maximum yield (Islam & Rahman, 2008). This exercise is now gaining acceptance all over the world because of its amazing results in crop production and fewer cost involvement compared to hand weeding (Ahmed *et al*., 2005).

In *C. olitorius*, chemical weed management by utilizing selective herbicides as pre-emergence or post-emergence herbicides is also a widespread technique together with other approaches (Kumar *et al*., 2013; Islam, 2014). For example, Quizalofop-Ethyl, a post-emergence herbicide successfully controls grassy weeds in *C. olitorius* field (Ghorai *et al*., 2004). Mandal & Mukherjee (2018) documented that the application of Quizalofop-Ethyl 5% EC @ 60 g ha^{-1} at 20 DAS and one manual weeding in 35 DAS was best in handling weed flora as well as contributing the greatest yield components, yield and economics of *C. olitorius*. However, numerous chemical substances have been developed in recent years and used as herbicides globally to manage weed population efficiently, but unconscious and the reckless use of these chemicals had exerted negative consequences on crop plants' phenology, physiological and biochemical attributes, leading to phytotoxicity and decreased yields (Hasanuzzaman, 2020; Blackshaw, 2005).

The selectivity and phytotoxicity of a herbicide reckon on several issues, comprising the chemical properties of the herbicides, the physiology of crops and weeds, the plant developmental phase, and the atmospheric states in which the herbicide is applied (Hasanuzzaman, 2020). As stated by Strange, (2012), foliage and shoot anomalies, reduced root and shoot growth, spots on leaf blade, leaf chlorosis (yellowing) and necrosis (death) are a few damage indicators on plants caused by herbicides. Application of pendimethalin on *Foeniculum vulgare* leaves (El-Awadi & Hasan, 2011), chevalier in *Triticum aestivum* cultivars (Nabiha *et al*., 2014) and metosulam in *Vicia faba* plants (Badr *et al*., 2013) were found to reduce photosynthetic pigments, leading to foliage chlorosis and necrosis. Herbicide toxicity may also lead to a prolonged or uneven crop emergence, which in turn has a detrimental influence on crop development and production. Earlier investigations exposed that Pendimethalin at 0.5-10 ppm decreased the sprouting rate of *Zea mays* (Rajashekhar *et al*., 2012), whereas isoproturon at 2.5 kg ha^{-1} substantially dwindled the root and shoot biomass of *Zea mays* seedling (Alla *et al*., 2008). Besides, glyphosate, when sprayed at 800, 1200, and 2400 g ha^{-1}, lowered leaf surface area and shoot dry matter content of *Glycine max* (Zobiole *et al*., 2012). Additionally, the fresh root-shoot biomass of *Oryza sativa* was reduced while treating with acetachlor at 3.2 mol L^{-1} and bensulfuron-methyl at 0.96 mol L^{-1} (Huang & Xiong, 2009), whereas the tillers number $plant^{-1}$ and grain production in *Triticum aestivum* went down when isoproturon with 1 kg ha^{-1} was sprayed (Singh *et al*., 2013).

In Bangladesh, herbicides usage for weed control in crops including *Oryza sativa, Triticum aestivum*, and *Glycine max*, among others, have been substantially increased, but farmers hardly ever apply herbicides in *C. olitorius* due to the fact that a handful of dark jute-specific selective herbicides are readily accessible in the market. Moreover, inadequate consciousness and technological expertise regarding the usage of herbicides among crop growers may cause phytotoxicity in crops. Consequently, the *C. olitorius* crop may or may not retrieve from the injury produced by herbicides based on the rate and intensity of harm and ultimately results in lower productivity. However, herbicidal weed control is now measured as a feasible alternative to conventional weeding (Anwar *et al*., 2012). Moreover, efficacy of an herbicide mostly depends on its capability to produce an anticipated effect on the target weeds. In addition, application time of herbicide is also very vital with respect to its efficacy. Some other researchers quantified that herbicide was effective weed control due to its fewer effects on non-target organism, and for sustainable crop production (Abbas *et al*., 2018). However, combination of more than one herbicide and its effect on weed control, efficacy and yield of jute is a time demanding research issue. Moreover, information regarding the selectivity and phytotoxicity of herbicides to *C. olitorius* crop is not available in Bangladesh. So, there is a dire demand to measure the specificity of numerous pre-and post-emergence herbicides due to their wide-spectrum actions in weeds and *C.*

olitorius as different herbicides may have different selectivity and phytotoxicity profiles. Therefore, this investigation was run to assess the selectivity and phytotoxicity of herbicides to *C. olitorius* and also to determine the yield of *C. olitorius* under the most cost-effective weed control practices in Bangladesh.

Material and Methods

Experimental site: The investigation was launched at Jute Agriculture Experimental Station (JAES), Bangladesh Jute Research Institute (BJRI), Manikganj (latitudes:23°38' and 24°03' north, and longitudes: 89°41' and 90°08' east) throughout fibre producing season (April-July) in 2021 and 2022. The study site was located at an altitude of 15 m from mean sea level having its place to non-calcareous dark grey floodplain soil in Young Brahmaputra Floodplain Agro-ecological zone “AEZ-8” (Anon. 1988). (Fig. 1) depicts monthly meteorological information on the mean highest and lowest temperature, relative humidity, and total precipitation during the study period which was received from the nearest weather station in Dhaka, approximately 55 km from the Jute Research Station Manikganj. Prior to conducting the trial, the soil in the research region was tested, and the physicochemical values are listed in (Table 1).

Table 1. Physico-chemical attributes of soil (0 - 15 cm) of the studied area

Soil properties	Analytical value
Land type	Medium high
Textural class	Silt loam
P^H	6.7
Organic Matter (%)	1.65
Total Nitrogen (%)	0.09
Available Phosphorus (ppm)	9.55
Exchangeable Potassium (meq/100 gm soil)	0.24
Available Sulphur (ppm)	12.88
Available Zinc (ppm)	7.56
Calcium (meq/100 gm soil))	9.12

Treatment and design: The experimentation was organized in a randomized complete block design (RCBD) with three repetitions. This design was used because in case of field experiment, it is more appropriate than other designs. The experiment was conducted with 16 herbicidal treatments, three hand weeding at 15, 30 and 45 days after sowing (DAS), and season-long weedy check (control). The detail information of different herbicides is presented in (Table 2). Herbicidal and other weed control approaches were administered as per experimental treatment. The one pre-emergence and other 15 early post-emergence herbicides were sprayed on 1 DAS and 8 DAS; accordingly, those were collected from the local market of Manikganj. Eight different herbicides were applied using a single dose per the manufacturer's instructions; however, another four herbicides were treated twice in the field to set the rate (Table 3). Herbicides were administered via a knapsack sprayer having a water capacity of 500 L water ha^{-1}.

General protocol: The variety O-9897 of *C. olitorius* was employed as research material @ 5 kg seed ha^{-1}. The experimental plots were dry farmed and harrowed during land preparation and one supplemental irrigation was applied at 15 DAS. After that no irrigation was required as rainy season started and continued during whole growing season. As per the standard prescription of BJRI, each plot (plot dimension: 4 m × 2.5 m) was nourished with urea, triple super phosphate, muriate of potash, gypsum, and zinc Sulphate at the following rates: 200, 50, 60, 95, and 110 kg ha^{-1}, correspondingly 50% urea and entire rate of other fertilizers were applied during the period of final plot preparation as basal dosage and another 50% urea i.e., 100 kg ha^{-1} broadcasted at 45 DAS. Jute Hairy Caterpillar infested the research plot and it was controlled by application of Karate 2.5 EC at the rate of 1 ml L^{-1} for 3 times at 10 days interval.

Data collection

Weed density, dry matter and Summed dominance ratio: In the experiment, weeds were sampled (at 30 and 50 DAS) randomly by lengthwise placing of quadrates (0.5 m x 0.5 m) at 4 spots of every single plot. Weed species were cut by sickle at the base level, cleaned, identified and numbered separately and expressed as weed density (WD, m^{-2}). In true sense, weed population of a field is generally determined by the soil seed bank, weed management in preceding crops and the cropping pattern was maintained. The separated weed species were oven-dried at 70ºC for 72 hours and balanced for estimating weed dry matter (WDM) which was stated as g m^{-2}. The summed dominance ratio suggested by Janiya & Moody (1989) was employed to estimate the predominant weed species of the experimental site. The following formula was chosen because it was widely used throughout the world.

$$\text{SDR of a weed species} = \frac{\text{Relative density (RD)} + \text{Relative dry matter (RDM)}}{2}$$

$$\text{Where, RD (\%)} = \frac{\text{Density of a specific weed species}}{\text{Total weed density}} \times 100$$

$$\text{RDM (\%)} = \frac{\text{Dry matter of a specific weed species}}{\text{Total weed dry matter}} \times 100$$

Weed control rating: Weed control rating of every herbicide was performed visually at 22 days after herbicide application (DAA) with a measure of 1 to 5 (Okafor, 1986).

Crop phytotoxicity rating: Crop phytotoxicity rating of several herbicidal treatments were judged visually at 30 days after sowing of each plot with a scale of 1 to 5 (Okafor, 1986).

Weed control efficiency: Weed control efficiency (WCE) of several herbicidal treatments were estimated following the equation advocated by Hasnauzzaman *et al.*, (2008).

$$\text{WCE (\%)} = \frac{(\text{DWC} - \text{DWT})}{\text{DWC}} \times 100$$

Here, DWC-Weed dry weight under season long weedy condition, DWT-Weed dry weight under herbicidal-treated plots.

Yield data: At harvest time, $1m^2$ quadrates were deliberately positioned lengthwise at three spots in each plot and the number of plants was counted and averaged to express plant density (PD) as m^{-2}. The length of ten arbitrarily identified *C. olitorius* plants from the base to their apex by meter scale was averaged to determine plant height (PH) in cm. After the *C. olitorius* plants were cut by sickle, the base diameter (BD) of 10 arbitrarily chosen plants was determined with the help of slide calipers, and the average diameter was represented as BD (mm). Following the harvest of *C. olitorius*, the fibre and stick were separated, washed and thoroughly dried under direct sunlight. The fibre (FY) and stick yield (SY) were then weighed and noted as kg $plot^{-1}$, which was subsequently equated to t ha^{-1}.

Economic analysis: An economic assessment was executed to compute the cost-effectiveness of several herbicidal approaches using the methods suggested by Hussain *et al*., (2008) and Parvez *et al*., (2013). It was thought that six hand-weeding sessions (about 106 labours) would be enough to maintain the plots weed free during the crop-growing period. The daily wage of one labor was 400 Tk and the price of per kilogram *C. olitorius* fibre and sticks was considered as 50 Tk. And 4 Tk., respectively. The net return (NR) was estimated by subtracting the total cost (fixed cost + weed management cost) from the gross income (GI). The BCR was determined with the following equation (Hasan *et al*., 2002). It was expressed as returns $Tk.^{-1}$ invested.

$$BCR = \frac{\text{Gross return}}{\text{Total cost}}$$

Statistical analysis

Statistical Analysis System (SAS 9.1) software was utilized for mean and comparing analysis of variance (ANOVA) with a protected LSD technique at 5% level of probability (Anon., 2003). The ANOVA for weed dry weight and density were carried out followed by square root conversion to standardize the data. PCA analysis was of weed dry matter and weed management methods were conducted with 'FactoMineR' and 'factoextra' packages under R.

Results

Weed species diversity and dominance at 30 DAS in *Corchorus olitorious*: At 30 DAS, 12 weed species (9 annuals against 3 perennials) were identified in the *Corchorus olitorius* field, including 4 broadleaves, 7 grasses and one sedge. Of these, seven weeds belonged to the Poaceae family, two to the Euphorbiaceae family, and one to each of the Cyperaceae, Solanaceae, and Asteraceae family (Table 4). The study documented that *Cyperus rotundus* had the highest RD (57.55%) and RDM (52.97%) followed by *Echinochloa colonum*. Though the occurrence of *Physalis heterophylla* was very low (RD1.39%) but it produced the second highest RDM (8.50%) (Figs. 2 & 3). Depending on SDR, *C. rotundus* ranked as the most dominant species (55.26%), whereas *E. colonum* appeared as the second most prevalent weed in the field (8.93%). The five other dominant weed species next to *E. colonum* were *Digitaria sanguinalis* (8.67%), *Eleosine indica* (7.87%), *Physalis heterophylla* (4.94%), *Paspalum distichum* (3.69%) and *Cynodon dactylon* (2.56%), respectively (Fig. 4). The results also revealed that *Euphorbia hirta* (0.99%) was noted as the least predominant weed in the experimental field. Further analysis showed that the sedges (SDR 55.26%) were dominant over grasses (SDR 34.84%) and broadleaves (SDR 9.90%) (Fig. 5).

Effect of different weed control treatments on weed density (WD) in *Corchorus olitorius*: WD of all identified weed flora in *C. olitorius* field was statistically influenced by weed control approaches (Table 5). Among the tested herbicides, Fenoxaprop-p-ethyl 10% + Ethoxysulfuron 10% @ 300 ml ha^{-1} sprayed at 8 DAS exhibited the lowest WD for *C. rotundus* (20.67 m^{-2}) and *P. heterophylla* (3.36 m^{-2}). Whereas, Fluazifop-p-butyl @ 1 L ha^{-1} treatment produced the lowest WD for *E. colonum* (6.51 m^{-2}), *D. sanguinalis* (5.09 m^{-2}), *Eleusine indica* (4.45 m^{-2}), *P. distichum* (1.75 m^{-2}) and *C. dactylon* (1.15 m^{-2}). In the season long weedy situation, all the major weeds produced the highest WD. Pendimethalin produced the second highest WD for *C. rotundus*; *E. colonum, D. sanguinalis* and *Eleusine indica,* whereas Quizalofop-p-ethyl 9% + Ethoxysulfuron 12% @ 300 ml ha^{-1} produced the second highest WD for *P. heterophylla, C. dactylon* and *P. distichum* which directed that these herbicides were inefficient in managing the respective weed species.

Principal component analysis (PCA) of weed dry matter (WDM): Principal component analysis (PCA) was performed employing the trial dataset comprising 7 species of weed flora and 18 distinct factors to minimize the heterogeneity of the data and find probable associations between weed species and measured features (Fig. 6). The PCA found that the first two principal components (PCs) with Eigen scores greater than one described 94.9% of the overall heterogeneity. Because the first and second PCs generated 76.8% and 18.1% of the entire divergence, correspondingly, a PCA biplot was constructed with only the first two components. The PCA biplot revealed that the dry matter of *C. rotundus* (Cyperaceae) is favored by W_1, W_2, W_3, W_5, W_{15} and W_{16} treatments. In other words, these treatments were not effective for controlling *C. rotundus*. On the other hand, weeds of the Poaceae family were associated with PC1. Higher dry matter of these weeds was produced in W_4, W_{13} and W_{14} treatments. Therefore, these treatments were not effective against Poaceae weeds. Among the chemical treatments, W_7, W_8, W_9, W_{10}, W_{11} and W_{12} were effective against weeds of Cyperaceae and Poaceae family. The response of *P. heterophylla* could be neither explained with PC1 nor PC2.

Table 2. Trade name, active ingredient, chemical name, family and molecular formula, mode of action, manufacturers and target weeds of the herbicides used in the experiment.

Sl. No.	Trade name	Active ingredient	Family, Chemical name & Molecular formula	Mode of action	Manufacturer	Target weeds
1.	Whip Super 9 EC	Fenoxaprop-p-ethyl	Aryloxyphenoxypropionate (AOPP) $C_{18}H_{16}ClNO_5$ Ethyl (2R)-(+)-2-[4-(6-chlorobenzoxazol-2-yloxy) phenoxy] propionate	Fenoxaprop-p-ethyl is taken up by foliage and shoots of plants and is physiologically transported. It primarily suppresses the biosynthesis of fatty acids in the meristem tissues of grasses.	Bayer Crop Science	Grass
2.	Weednil 5 EC	Quizalofop-p-ethyl	Aryloxyphenoxypropionate (AOPP) $C_{19}H_{17}ClN_2O_4$ (QPE; ethyl(R)-2-[4-(6-chloroquinoxalin-2-yloxy) phenoxy] propionate)	Quizalofop-P-ethyl undergoes hydrolysis in plants to produce Quizalofop-P (an acid version of Quizalofop-P-ethyl), which has been confirmed to decrease fatty acid production by inhibiting acetyl-CoA carboxylase (ACCase).	ACI Formulation Ltd.	Grass
3.	Fusilade Max 12.5 EC	Fluazifop-p-butyl	Aryloxyphenoxypropionate (AOPP) $C_{19}H_{20}F_3NO_4$ butyl (2R)-2-[4-[5-(trifluoromethyl) pyridin-2-yl] oxyphenoxy] propanoate	Fluazifop-p-butyl blocks ACCase, a vital plant catalytic involved in fatty acid biosynthesis, and has selectivity because of the variation in enzymatic sensitivity between Gramineae and non-Gramineae plants.	Syngenta Bangladesh	Grass
4.	Sunrice 150 WG	Ethoxysulfuron	$C_{15}H_{18}N_4O_7S$ (2-ethoxyphenyl) N-[(4,6-dimethoxypyrimidin-2-yl) carbamoyl] sulfamate	Ethoxysulfuron is mostly absorbed by the foliage and then transported throughout the plant. Ethoxysulfuron acts as an suppressor of the acetolactate.	Bayer Crop Science	Sedge
5.	Pantera 4.41 EC	Quizalofop-p-tefuryl	Aryloxyphenoxypropionate (AOPP) $C_{22}H_{21}ClN_2O_5$	It is a systemic herbicide that is taken through the leaves and subsequently translocated within the plant, as well as an ACCase suppressor.	Hossain Enterpr. CC Ltd.	Grass
6.	Panida 33 EC	Pendimethalin	$C_{13}H_{19}N_3O_4$ [N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine]	Pendimethalin exhibits pre-emergence (prior to weeds emerge) and early post-emergence activity. It limits the development of roots and shoots.	Auto Crop Care Ltd.	Annual grasses, certain B road leaf
7.	Sunjute Plus 20 WG	(i) Fenoxaprop-p-ethyl (ii) Ethoxysulfuron)	(i) $C_{18}H_{16}ClNO_5$ *(R)*-2-[4-(6-chloro-1,3-benzoxazol-2-yloxy)phenoxy]propanoic acid (ii) $C_{15}H_{18}N_4O_7S$ 3-(4,6-dimethoxyoyrimidin-2-yl)-1-(2-ethoxyphenoxysulfonyl) urea	Fenoxaprop is a low-toxicity weed killing herbicide that corresponds to the heterocyclic oxy group phenoxy propionic acid category. Specifically, it prevents fatty acid synthesis by inhibiting the essential enzyme one acetyl-CoA carboxylase. Ethoxysulfuron blocks the biosynthesis of branched=chain amino acid synthase (ALS or AHAS), and prevents cell division and plant development by inhibiting the production of the key amino acids valine and isoleucine.	McDonald (BD) Pvt. Ltd.	Sedge, Grass

Table 2. (Cont'd.).

Sl. No.	Trade name	Active ingredient	Family, Chemical name & Molecular formula	Mode of action	Manufacturer	Target weeds
8.	Jute Guard 20 WDG	(i) Quizalofop-p-ethyl (ii) Ethoxysulfuron	(i) $C_{19}H_{17}ClN_2O_4$ (QPE; ethyl(R)-2-[4-(6-chloroquinoxalin-2-yloxy) phenoxy] propionate) (ii) $C_{15}H_{18}N_4O_7S$ 3-(4,6-dimethoxyoyrimidin-2-yl)-1-(2-ethoxyphenoxysulfonyl) urea	Quizalofop is a low-toxicity weed killing herbicide that corresponds to the heterocyclic oxy group phenoxy propionic acid category. Specifically, it prevents fatty acid synthesis by inhibiting the essential enzyme one acetyl-CoA carboxylase. Ethoxysulfuron blocks the biosynthesis of branched=chain amino acid synthase (ALS or AHAS), and prevents cell division and plant development by inhibiting the production of the key amino acids valine and isoleucine.	Haychem BD Ltd.	Sedge, Grass
9.	Viber 20 WG	(i) Fluazifop-p-butyl (ii) Ethoxysulfuron	(i) $C_{19}H_{20}F_3NO_4$ butyl (2R)-2-[4-[5-(trifluoromethyl)pyridin-2-yl]oxyphenoxy]propanoate (ii) $C_{15}H_{18}N_4O_7S$ 3-(4,6-dimethoxyoyrimidin-2-yl)-1-(2-ethoxyphenoxysulfonyl) urea	Fluazifop is a low-toxicity weed killing herbicide that corresponds to the heterocyclic oxy group phenoxy propionic acid category. Specifically, it prevents fatty acid synthesis by inhibiting the essential enzyme one acetyl-CoA carboxylase. Ethoxysulfuron blocks the biosynthesis of branched=chain amino acid synthase (ALS or AHAS), and prevents cell division and plant development by inhibiting the production of the key amino acids valine and isoleucine.	Valen Tech Ltd.)	Sedge, Grass
10.	Crusher 22 WP	(i) Fenoxaprop-p-ethyl (ii) Bensulfuran methyl	(i) $C_{18}H_{16}ClNO_5$ Ethyl (2R)-(+)-2-[4-(6-chlorobenzoxazol-2-yloxy)phenoxy]propionate (ii) $C_{16}H_{18}N_4O_7S$ methyl 2-[(4,6-dimethoxypyrimidin-2-yl)carbamoylsulfamoylmethyl]benzoate	Fenoxaprop is a low-toxicity weed killing herbicide that corresponds to the heterocyclic oxy group phenoxy propionic acid category. Specifically, it prevents fatty acid synthesis by inhibiting the essential enzyme one acetyl-CoA carboxylase. It inhibits the synthesis of enzymes like Acetolactate synthase (ALS) and acetohydroxy acid synthase (AHAS). Thus, suppress the production of brached-chain amino acids.	Eminence CIL	Sedge, Grass
11.	Pyzero 10EC	Metamifop	$C_{23}H_{18}ClFN_2O_4$ (2R)-2-[4-[(6-chloro-1,3-benzoxazol-2-yl)oxy]phenoxy]-N-(2-fluorophenyl)-N-methylpropanamide	It inhibits acetyl-coenzyme A carboxylase (ACCase) and it acts as post-emergence herbicide that reveals a greater control efficiency over specially *Echinochloa crus-galli* in rice fields. It functions as an EC 6.4.1.2 (acetyl-CoA carboxylase) antagonist.	Auto Crop Care Ltd.	

Table 3. The herbicidal treatments with their respective dose used in experimental field.

Treatments		Dose (ha^{-1})
Fenoxapro-p-ethyl (Whip Super 9 EC, Bayer Crop Science)	(W_1)	650 ml
Quizalofop-p-ethyl (Weednil 5 EC, ACI Formulation Ltd.)	(W_2)	650 ml
Fluazifop-p-butyl (Fusilade Max 12.5 EC, Syngenta Bangladesh)	(W_3)	1 L
Ethoxysulfuron (Sunrice 150 WG, Bayer Crop Science)	(W_4)	200 g
Quizalofop-p-tefuryl (Pantera 4.41EC, Hossain Enter C.C. Ltd.)	(W_5)	650 ml
Pendimethalin (Panida 33 EC, Auto Crop Care Ltd.)	(W_6)	1 L
Fluazifop-p-butyl 10% + Ethoxysulfuron 10% (Viber 20 WG, Valen Tech Ltd.)	(W_7)	400 g
Fluazifop-p-butyl 10% + Ethoxysulfuron 10% (Viber 20 WG, Valen Tech Ltd.)	(W_8)	500 g
Quizalofop-p-ethyl 5%+Ethoxysulfuron 15% WDG (Jute Guard 20 WDG, Haychem BD Ltd.)	(W_9)	500 g
Quizalofop-p-ethyl 5%+Ethoxysulfuron 15% WDG (Jute Guard 20 WDG, Haychem BD Ltd.)	(W_{10})	400 g
Fenoxaprop-p-ethyl 10%+Ethoxysulfuron 10% (Sunjute Plus, McDonald (BD) Pvt Ltd)	(W_{11})	300 ml
Fenoxaprop-p-ethyl 10%+Ethoxysulfuron 10% (Sunjute Plus, McDonald (BD) Pvt Ltd)	(W_{12})	400 ml
Quizalofop-p-ethyl 9%+ Ethoxysulfuron 12% OD (Raker 21 OD, Roof CC)	(W_{13})	400 ml
Quizalofop-p-ethyl 9%+ Ethoxysulfuron 12% OD (Raker 21 OD, Roof CC)	(W_{14})	300 ml
Fenoxaprop-p-ethyl 7%+Bensulfuran methyl 15% (Crusher 22 WP, Eminence CIL)	(W_{15})	2 Kg
Metamifop (Pyzero 10EC, Auto Crop Care Ltd.)	(W_{16})	750 ml
Hand weeding at 15 DAS + 30 DAS + 45 DAS (weed free)	(W_{17})	-
Control (season long weedy)	(W_{18})	-

Table 4. Weed species with family, life cycle, types, density, dry matter identified at 30 DAS in *Corchorus olitorius* field.

Weeds with Scientific name	Family name	Weed type/ Life cycle	Density (m^{-2})	Dry matter ($g\ m^{-2}$)
Cyperus rotundus L.	Cyperaceae	SP	275.0	99.88
Echinochloa colonum L.	Poaceae	GA	52.2	13.09
Digitaria sanguinalis L.	Poaceae	GA	44.5	15.16
Eleosine indica L.	Poaceae	GA	39.87	13.93
Cynodon dactylon L.	Poaceae	GP	14.36	4.00
Paspalum distichum L.	Poaceae	GA	14.67	8.15
Physalis heterophylla Nees.	Solanaceae	BA	6.62	16.02
Enhydra fluctuans Lour.	Asteraceae	BA	5.29	6.39
Phyllanthus niruri L.	Euphorbiaceae	BP	6.60	3.89
Setaria viridis L.	Poaceae	GA	10.04	3.68
Paspalum comersoni Lam.	Poaceae	GA	4.98	2.15
Euphorbia hirta L.	Euphorbiaceae	BA	3.79	2.22
Total	-	-	477.82	188.56

Here, G- Grass, S-S edge, B- Broadleaf; P- Perennial, A- Annual

Weed control rating of herbicides in *Corchorus olitorius*: The treatments like Fluazifop-p-ethyl 10% + Ethoxysulfuron 10% @ 400 and 500 g ha^{-1}, Quizalofop-p-ethyl 5% + Ethoxysulfuron 15%@ 400 and 500 g ha^{-1}, Fenoxaprop-p-ethyl 10% + Ethoxysulfuron 10% @ 300 and 400 ml ha^{-1}ranked top due to producing excellent control over the sedge (*C. rotundus*) and grass weeds (*E. colonum* and *D. sanguinalis*) (Table 6). Excellent control (Rank 1) was found in handling *C. rotundus* by using Ethoxysulfuron @ 200 g ha^{-1} and Quizalofop-p-ethyl 9% + Ethoxysulfuron 12%@ 300 and 400 ml ha^{-1}, whereas these herbicides exhibited very poor (rank 5) to poor control (rank 4) over grass. Besides, Fenoxapro-p-ethyl @ 650 ml ha^{-1}; Quizalofop-p-ethyl @ 650 ml ha^{-1}; Fluazifop-p-@ 1 L ha^{-1}; Quizalofop-p-tefuryl @ 650 ml ha^{-1}; Fenoxaprop-p-ethyl 7% + Bensulfuran Methyl 15% @ 2 kg ha^{-1}; Metamifop @ 750 ml ha^{-1}ranked 4 as they poorly controlled the *C. rotundus*, but these herbicides produced excellent (rank 1) to good control (rank 2) to grass weeds like, *E. colonum, D. sanguinalis* in *C. olitorius*. Pendimethalin appeared as the last-ranked herbicide (Table 6). The above results showed that the ranking of herbicides varied depending on the weed species present in a field.

Phytotoxicity rating of herbicides on crop in *Corchorus olitorius*: Among the tested herbicides, no phytotoxicity was observed except Ethoxysulfuron, Quizalofop-p-ethyl 9% + Ethoxysulfuron 12% (under both doses); Fenoxaprop-p-ethyl 7% + Bensulfuran Methyl 15%. Plant growth of *C. olitorius* was found slightly stunted for a few days by the application of Ethoxysulfuron. This symptom could not sustain for a long time. However, after a certain period of growth *C. olitorius* plants easily recovered their injury. Regular crop monitoring revealed that phytotoxicity could not last till crop harvest (Table 6).

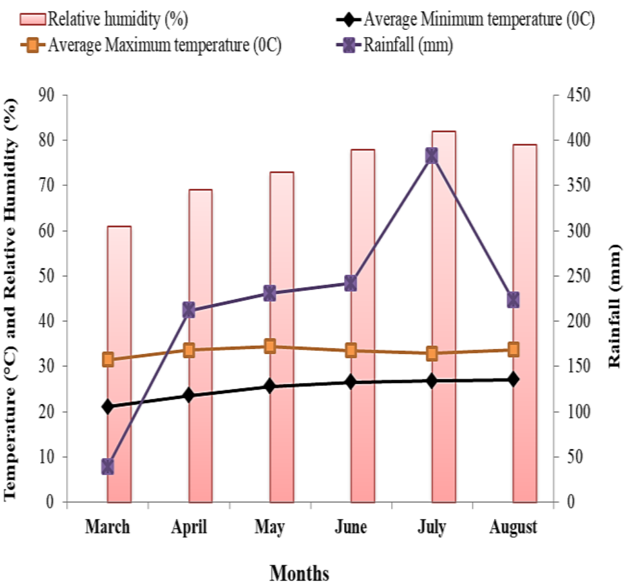

Fig. 1. Weather parameter during *Corchorus olitorius* experimental season in 2019.

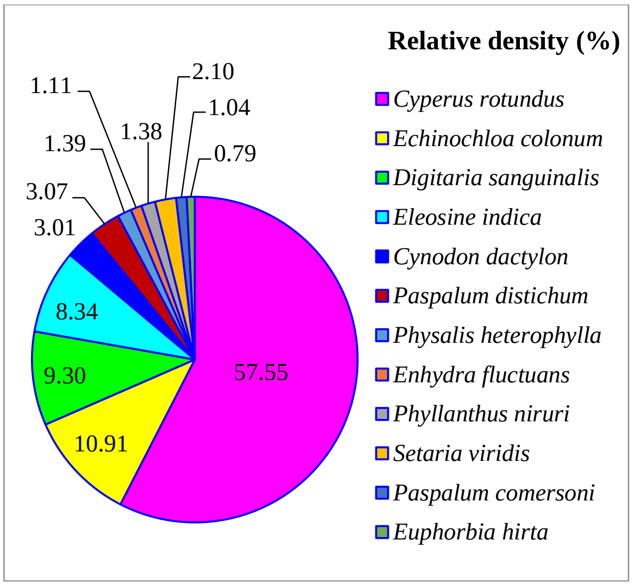

Fig. 2. RD of weeds grown in response to different herbicides at 30 DAS in *Corchorus olitorius* field (average of all plots).

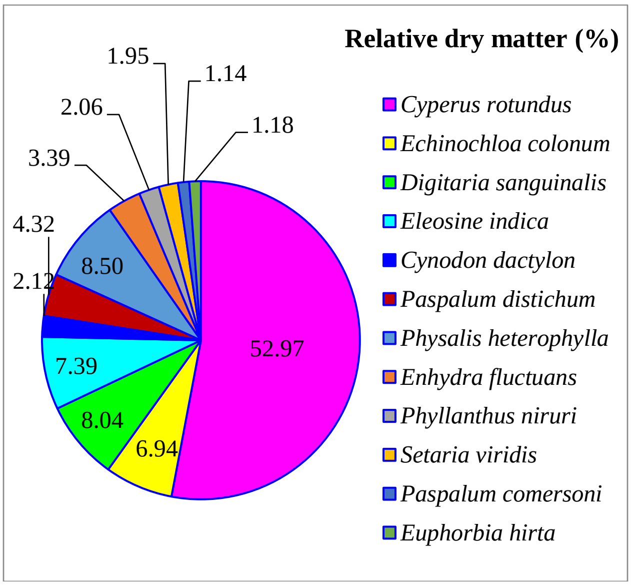

Fig. 3. RDM of weeds grown in response to different herbicides at 30 DAS in *Corchorus olitorius* field (average of all plots).

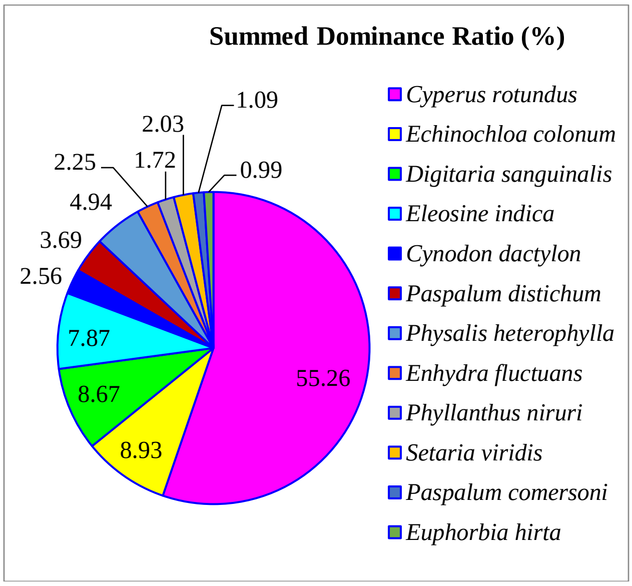

Fig. 4. SDR of weeds grown at *Corchorus olitorius* field at 30 DAS (average of all plots).

Effect of weed control treatments on weed control efficiency (WCE): The results also showed that Fenoxaprop-p-ethyl 10% + Ethoxysulfuran 10% @ 300 ml ha^{-1} over *C. rotundus*, and Fluazifop-p-butyl @ 1 L ha^{-1} over *E. colonum, D. sanguinalis, E. indica, P. distichum* and *C. dactylon* revealed as the best herbicides for producing the highest control next to weed free (Table 7). Ethoxysulfuron, Quizalofop-p-ethyl 9% + Ethoxysulfuron 12% @ 400 ml ha^{-1} and Quizalofop-p-ethyl 9% + Ethoxysulfuron 12% @ 300 ml ha^{-1}produced excellent control over *Cyperus rotundus* but very poor control over other weeds. In contrast, Fenoxaprop-p-ethyl, Quizalofop-p-ethyl, Fluazifop-p-butyl, Fenoxaprop-p-ethyl 7% + Bensulfuran Methyl, and Metamifop showed poor control over *C. rotundus* but excellent control over other weeds excluding *Physalis heterophylla*. Besides, the treatments like Fluazifop-p-ethyl 10% + Ethoxysulfuron 10% (@ 400 and 500 g ha^{-1}), Quizalofop-p-ethyl 5% + Ethoxysulfuron15% (@ 500 and 400 g ha^{-1}) and Fenoxaprop-p-ethyl 10% + Ethoxysulfuron 10% (@ 300 and 400 ml ha^{-1}) produced excellent control over *C. rotundus*, *E. colonum* and *D. sanguinalis, E.indica* (Table 7).

Impact of herbicidal weed control treatments on yield attributes and yield of *Corchorus olitorius*: Yield attributes of *C. olitorius* were statistically impacted by the studied weed control treatments (Table 8). The application of Fenoxaprop-p-ethyl 10% + Ethoxysulfuron 10% @ 300 ml ha^{-1} produced the statistically higher PH (2.78 m) and BD (14.02 mm) compared to other treatments except three hand weeding at 15 DAS +Weeding at 30 DAS +Weeding at 45 DAS. Similar to yield attributes, FY and SY of *C. olitorius* were also significantly affected due to weed control approaches (Table 8). Among these herbicides, Fenoxaprop-p-ethyl 10% + Ethoxysulfuron 10% @ 300 ml ha^{-1} produced the best results in terms of FY (2.50 t ha^{-1}) and SY (4.99 t ha^{-1}) followed by Quizalofop-p-ethyl 5% +

Ethoxysulfuron15% @ 500 g ha^{-1}. In contrast, the minimum yield attributes and yield was exhibited in the season long weedy situation.

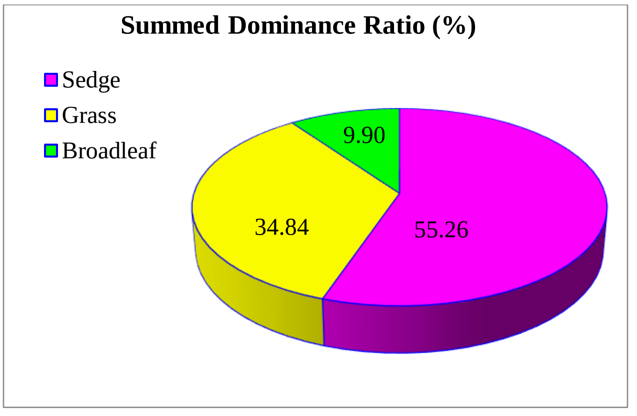

Fig. 5. SDR of weed types grown at *Corchorus olitorius* field at 30 DAS (average of all plots).

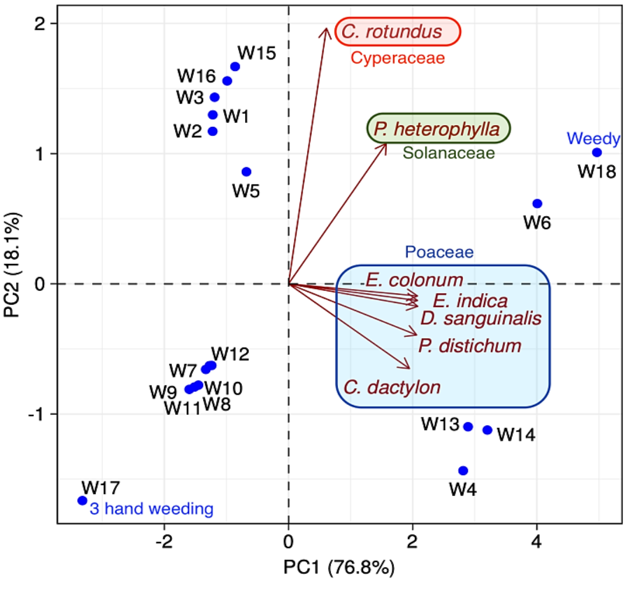

Fig. 6. Principal component analysis (PCA) biplot demonstrating the connection between the assessed parameters and the weed species. PC1 on the x-axis explained 76.8% of the overall variation, whilst PC2 on the y-axis explained 18.1% of the overall variation. The length of the arrows indicates the contribution of attributes to PC1 and PC2. The longer arrows represent components with greater contribution, while the darker shorter arrows represent components with a smaller contribution.

Here, W_1 - Fenoxapro-p-ethyl @ 650 ml ha^{-1}; W_2 - Quizalofop-p-ethyl @ 650 ml ha^{-1}; W_3 - Fluazifop-p-butyl @ 1 L ha^{-1}; W_4 - Ethoxysulfuron @ 200 g ha^{-1}; W_5 - Quizalofop-p-tefuryl @ 650 ml ha^{-1}; W_6 - Pendimethalin @ 1 L ha^{-1}; W_7 - Fluazifop-p-ethyl 10% + Ethoxysulfuron 10% @ 400 g ha^{-1} ; W_8 - Fluazifop-p-ethyl 10% + Ethoxysulfuron 10% @ 500 g ha^{-1}; W_9- Quizalofop-p-ethyl 5% + Ethoxysulfuron15% @ 500 g ha^{-1}; W_{10} - Quizalofop-p-ethyl 5% + Ethoxysulfuron15% @ 400 g ha^{-1}; W_{11} - Fenoxaprop-p-ethyl 10% + Ethoxysulfuron 10% @ 300 ml ha^{-1}; W_{12} - Fenoxaprop-p-ethyl 10% + Ethoxysulfuron 10% @ 400 ml ha^{-1}; W_{13} - Quizalofop-p-ethyl 9% + Ethoxysulfuron 12% @ 400 ml ha^{-1}; W_{14} - Quizalofop-p-ethyl 9% + Ethoxysulfuron 12% @ 300 ml ha^{-1}; W_{15} - Fenoxaprop-p-ethyl 7% + Bensulfuran Methyl 15% @ 2 kg ha^{-1}; W_{16} - Metamifop @ 750 ml ha^{-1}; W_{17} - Weeding at 15 DAS +Weeding at 30 DAS +Weeding at 45 DAS (weed free); W_{18} - Control (Season long weedy).

Relationship among yield and yield attributes of *Corchorus olitorius*: (Fig. 7) depicted the correlation plot of the measured attributes, allowing us to investigate the relationships between them. Fibre yield exerted a strong and significant positive connection to plant height followed by stem diameter and plant density. Stick yield had a strong and positive correlation with fibre yield followed by plant height, stem diameter and plant density. Plant height also showed a positive and strong correlation with fibre yield, stick yield and plant density followed by stem diameter. Stem diameter had weak correlation with plant height and plant density. Finally, plant density had strong correlation with stick yield but relatively weak correlation with fibre yield and stem diameter.

Economic assessment of several herbicidal weed control treatments in *Corchorus olitorius*: The results showed that Fenoxaprop-p-ethyl 10% + Ethoxysulfuron 10% @ 300 ml ha^{-1} revealed as the most profitable treatment among these herbicidal treatments due to producing the highest GI (149767 Tk ha^{-1}) and NR (58771 Tk ha^{-1}) and BCR (1.64). The second highest GI, NR and BCR were produced by the Quizalofop-p-ethyl 5% + Ethoxysulfuron15% @ 500 g ha^{-1} treatment followed by Fluazifop-p-ethyl 10% + Ethoxysulfuron 10% @ 500 g ha^{-1}. The treatment like Fenoxaprop-p-ethyl 7% + Bensulfuran Methyl, Metamifop, weeding at 15 DAS +Weeding at 30 DAS +Weeding at 45 DAS and Season long weedy condition appeared as the non-profitable treatment (Table 9).

Discussion

Weeds are the major constraint in *C. olitorious* production and fiercely compete with crop plants owing to their rapid growth, strong capacity to adapt to new surroundings and prolific seed production (Swanton *et al*., 2015). The earlier investigation documented that *E. colonum* appeared as the predominant weed flora in *C. olitorious* while broadleaves weed consisted of *Physalis minima* and *Phyllanthus niruri* (Sarkar, 2006). The present study revealed that among 12 weed species *C. rotundus* ranked as the most dominant species followed by *E. colonum* in *C. Olitorius* field of Bangladesh. This finding is confirmed by Hossain *et al*., (2012); Islam & Ali (2017), who mentioned *C. rotundus* as the most abundant weed in *C. olitorious* fields at Manikganj as well as at Faridpur and Rangpur, respectively. So, it is crucial to note that following the elimination of grasses, *C. rotundus* (sedge weed) and several broadleaf weed species, particularly *Trianthema portulacastrum* and *Ludwigia parviflora*, emerged as a threat to these fibre plants (Mandal &Mukherjee, 2018). Furthermore, Hossain *et al*., (2012) also documented that during 2009 to 2011, sedge weed (*C. rotundus*) accounted for 68% of the total weed density in Manikganj, Kishoreganj, and Cumilla, followed by grassy (26%), and broad-leaf weed species (6%), which is consistent with the current findings. The hot (20°C to 40°C) and humid (70% to 90%) climate together with sporadic precipitation during *C. olitorious* production encourages sedge weeds such as *C. rotundus* for their vigorous growth and development (Islam, 2011).

The results also showed that Fenoxaprop-p-ethyl 10% + Ethoxysulfuron 10% @ 300 ml ha^{-1}over *C. rotundus*, and Fluazifop-p-butyl @ 1 L ha^{-1} over all other grasses were the best herbicides next to weed free in terms of producing the minimum weed biomass and highest WCE. Overall, Fenoxaprop-p-ethyl 10% + Ethoxysulfuron 10% @ 300 ml ha^{-1} produced the lowest value of total WD and WDM which resulted in the highest WCE. Sarkar (2006) also reported an identical result that Fenoxaprop-p-ethyl showed the highest WCE. Even if pendimethalin is widely used in South Asia to suppress *E. colonum* in paddy (Mahajan *et al*., 2013; Mahajan & Chauhan, 2013), it produced the lowest WCE for weeds in *C. olitorius*. The primary cause of this manifestation was presumably heterogeneous absorption due to distinct types and intensities of selectivity against different weeds (Islam, 2014). During the critical crop-weed competition period, it was found that quizalofop-ethyl followed by hand weeding documented 23–53% lowest biomass than pretilachlor (Singh *et al*., 2015). In another research, quizalofop-ethyl with hand weeding exhibited well weeds control than pre-emergence herbicide (Jena *et al*., 2017). Ethoxysulfuron was described as a broad-spectrum herbicide, that controlled grass, sedge and broad-leaf weeds successfully in jute (Kumar *et al*., 2015).

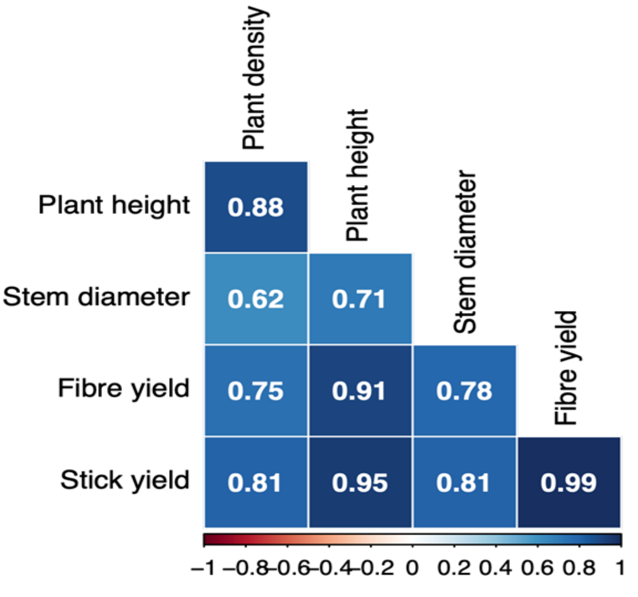

Fig. 7. Correlation matrix of assessed traits. The range between highest and lowest value is 1 to -1. Blue and red ellipses represent positive and negative associations, correspondingly. The greater color intensity reflects stronger co-efficient, whilst lower coefficient is reflected by lower color intensity.

Phytotoxicity refers to the delayed sprouting of seeds, hindrance in crop development or any undesired change in crops triggered by particular chemicals (phytochemicals) or growing conditions (WRAP, 2002). Schnelle & Cole (2017) identified various phytotoxic effects, including leaf yellowing, chlorosis, spotting on the leaves, abnormal leaf curvature, symptoms caused by herbicides that caused the death of the entire plant. The present study found that Ethoxysulfuron, Quizalofop-p-ethyl 9% + Ethoxysulfuron 12% (under both doses); Fenoxaprop-p-ethyl 7% + Bensulfuron Methyl 15% produced phytotoxic effect in *C. olitorius* stunting the plants growth which was recovered by plants within a few days. At higher doses Bensulfuron ethyl (Khaliq &Matloob, 2012) and ethoxsulfuron ethyl (Bhuiyan *et al*., 2018) reported temporary yellowing of rice leaves and minimum rice seedling mortality (≈4%) as phytotoxic effect, respectively, whereas quizalafop-p-ethyl at higher doses decreased the yield of *Vigna mungo* (Mahakavi *et al*., 2014) due to phytotoxic effect. The Fenoxyprop-p-ethyl 10% + Ethoxysulfuron 10% WP (both doses) and pendimethaline appeared as non-phytotoxic herbicides in *Corchorus olitorius* which showed toxicity to rice plants. Mahbub & Bhuiyan (2021) stated that Fenoxyprop-p-ethyl 10% + Ethoxysulfuron 10% WP @ 125 g ha^{-1} showed temporary yellowing of leaves in paddy, whereas Pendimethalin @ 1137 a.i. ha^{-1}showed its detrimental effects by causing yellowing and chlorosis of the leaves along with by reducing the root-shoot length and dry matter deposition in the respective parts of paddy plants (Khaliq & Matloob, 2012). Indeed, the specificity of herbicides depends on the rate, application period, plant growth phase, and prevailing environment (Das, 2008), therefore, the selective nature of different herbicides can be altered (Susha *et al*., 2018).

Weed control strategy is a prerequisite for farming activities in order to reach expected food productivity targets (Morsy & Tantawy, 2018) linked to the improvements in crop growth attributes (Abdelaal *et al*., 2019). According to results, the treatment Fenoxaprop-p-ethyl 10% Ethoxysulfuron 10% @ 300 ml ha^{-1} produced the greatest PD, PH and BD in *C. olitorius* next to weed-free condition followed by Quizalofop-p-ethyl 5% + Ethoxysulfuron15% @ 500 g ha^{-1}compared to other treatments. Generally, the morphological profile of *Corchorus olitorius* crop with tiny, narrow lanceolate leaf shape, fewer leaves with reduced leaf angle, proper petiole, smooth upright and cylindrical stem having optimal height indicated ideal plant density (Ngomuo *et al*., 2017). Additionally, the risk posed by weeds as manifested owing to competition with the *C. olitorius* crop for numerous basic growth-promoting resources, when reduced due to the application of Fenoxaprop-p-ethyl 10% + Ethoxysulfuron 10% @ 300 ml ha^{-1}, increases the PD, PH (Riaz *et al*., 2006), and favors the development of stem dimensions and subsequently the BD of crops (Mandal & Mukherjee, 2018). This is consistent with the assessment of Sarkar (2006).

Maximizing fibre production is one of the main objectives of *C. olitorius* plant (Majumder *et al*., 2020) and the present study revealed that Fenoxaprop-p-ethyl 10% + Ethoxysulfuron 10% @ 300 ml ha^{-1} produced the best results in terms of FY followed by Quizalofop-p-ethyl 5% + Ethoxysulfuron15% @ 500 g ha^{-1}. This result was in accordance with Mandal & Mukherjee (2018), who indicated an encouraged plant development, as evidenced by the advancements in plant height and basal diameter, a driving component behind total biomass accumulation and fibre output production by the plants. Mukul *et al.* (2021) also supported these findings that the fibre production in *C. olitorius* crop relied on its phonological attributes such as plant population, PH, BD and fresh weight. Weeds were permitted to fight against crops for growth-stimulating elements throughout the whole growing season, which resulted in the lowest yield attributes and yield in the season-long weedy condition.

According to results, Fenoxaprop-p-ethyl 10% + Ethoxysulfuron 10% @ 300 ml ha^{-1} appeared as the most profitable treatment (BCR: 1.64) compared to weed free condition (manual weeding) because of having the ability to manage the weed infestation at an early growing stage and minimal labor cost involvement. Parvez *et al*., (2013) noted that herbicidal weed control practices in rice were more profitable over weed free condition. Application of pre-and post-emergence herbicides reduced the production cost and augmented economic return and BCR (Chakraborty *et al*., 2020). In reality, maintaining a season-long weed-free environment via traditional hand weeding is challenging and discouraged.

Table 5. Effect of weed control treatments on weed density (m^{-2}) of different weed species grown in *Corchorus olitorius.*

Treatment	*Cyperus rotundus*	*Echinochloa colonum*	*Digitaria sanguinalis*	*Eleusine indica*	*Physalis heterophylla*	*Paspalum distichum*	*Cynodon dactylon*
W_1	218.33 e	6.64 d	5.29 d	4.83 e	5.04 f	1.95 ef	1.20 f-h
W_2	211.33 f	6.92 d	5.51 d	4.98 de	4.85 fg	2.04 ef	1.39 e-h
W_3	222.00 e	6.51 d	5.09 d	4.45 e	5.36 e	1.75 f	1.15 gh
W_4	32.33 hi	30.22 c	27.54 c	27.12 c	5.36 e	13.56 ab	12.97 b
W_5	202.00 g	11.53 d	8.02 d	7.50 d	4.70 g	3.74 d	3.03 d
W_6	264.00 b	46.33 a	38.67 b	33.54 b	6.14bc	12.42 bc	11.03 c
W_7	28.33 ij	8.16 d	7.13 d	6.69 de	4.04 h	3.18 de	2.78 de
W_8	22.67 j-l	7.82 d	6.61 d	5.90 de	3.55 i	2.91 d-f	2.45 d-g
W_9	21.38 kl	7.76 d	6.42 d	5.67 de	3.47 i	2.73 d-f	2.30 d-g
W_{10}	25.33 j-l	8.00 d	6.79 d	6.19 de	3.93 h	3.01 d-f	2.57 d-f
W_{11}	20.67 l	7.63 d	6.22 d	5.47 de	3.36 i	2.33 ef	2.23 d-g
W_{12}	28.24 i-k	8.49 d	6.87 d	6.50 de	4.00 h	3.07 de	2.68 de
W_{13}	36.67 h	33.96 bc	28.13 c	25.54 c	6.16bc	12.08 c	12.62 b
W_{14}	38.36 h	37.11 b	29.30 c	27.27 c	6.28 b	12.70 bc	13.13 ab
W_{15}	241.67 c	7.40 d	5.99 d	5.28 de	5.91cd	2.18 ef	2.00 d-g
W_{16}	230.67 d	7.10 d	5.74 d	5.08 de	5.71 d	2.10 ef	1.52 e-g
W_{17}	0.00 m	0.00 e	0.00 e	0.00 f	0.00 j	0.00 g	0.00 h
W_{18}	275.00 a	52.15 a	44.45 a	39.87 a	6.62 a	14.67 a	14.36 a
LSD at 5%	6.911	5.106	4.708	2.669	0.303	1.263	1.393
CV (%)	3.54	18.64	20.95	13.05	3.89	14.21	16.91

Here, statistics with the same letter in a column do not differ considerably. LSD = Least Significant Differences at 5% level of probability. CV = Coefficient of Variance; W_1 - Fenoxapro-p-ethyl @ 650 ml ha^{-1}; W_2- Quizalofop-p-ethyl @ 650 ml ha^{-1}; W_3- Fluazifop-p-butyl @ 1 L ha^{-1}; W_4- Ethoxysulfuron @ 200 g ha^{-1}; W_5- Quizalofop-p-tefuryl @ 650 ml ha^{-1}; W_6- Pendimethalin @ 1 L ha^{-1}; W_7- Fluazifop-p-ethyl 10% + Ethoxysulfuron 10% @ 400 g ha^{-1}; W_8- Fluazifop-p-ethyl 10% + Ethoxysulfuron 10% @ 500 g ha^{-1}; W_9- Quizalofop-p-ethyl 5% + Ethoxysulfuron15% @ 500 g ha^{-1}; W_{10} - Quizalofop-p-ethyl 5% + Ethoxysulfuron15% @ 400 g ha^{-1} ; W_{11} - Fenoxaprop-p-ethyl 10% + Ethoxysulfuron 10% @ 300 ml ha^{-1}; W_{12} -Fenoxaprop-p-ethyl 10% + Ethoxysulfuron 10% @ 400 ml ha^{-1} ; W_{13} - Quizalofop-p-ethyl 9% + Ethoxysulfuron 12% @ 400 ml ha^{-1} ; W_{14} - Quizalofop-p-ethyl 9% + Ethoxysulfuron 12% @ 300 ml ha^{-1} ; W_{15} - Fenoxaprop-p-ethyl 7% + Bensulfuran Methyl 15% @ 2 kg ha^{-1} ; W_{16} - Metamifop @ 750 ml ha^{-1} ; W_{17} - Weeding at 15 DAS +Weeding at 30 DAS +Weeding at 45 DAS (weed free); W_{18} - Control (Season long weedy).

Table 6. Weed control rating and phytotoxicity rating of different herbicides in *Corchorus olitorius* at 30 DAS using 1 to 5 scales (Okafor, 1986).

Herbicides as treatment	Dose (ha^{-1})	Weed control rating on			Phytotoxicity rating
		Cyperus rotundus	*Echinochloa colonum*	*Digitaria sanguinalis*	
Fenoxapro-p-ethyl (Whip Super 9 EC)	650 ml	5	1	1	1
Quizalofop-p-ethyl (Weednil 5 EC)	650 ml	5	1	1	1
Fluazifop-p-butyl (Fusilade Max 12.5 EC)	1 L	5	1	1	1
Ethoxysulfuron (Sunrice 150 WG)	200 g	1	4	5	2
Quizalofop-p-tefuryl (Pantera 4.41EC)	650 ml	5	2	1	1
Pendimethalin (Panida 33 EC)	1 L	5	5	5	1
Fluazifop-p-ethyl 10% + Ethoxysulfuron 10% (Viber 20 WG)	400 g	1	1	1	1
Fluazifop-p-ethyl 10% + Ethoxysulfuron 10% (Viber 20 WG)	500 g	1	1	1	1
Quizalofop-p-ethyl 5% + Ethoxysulfuron 15% (Jute Guard 20 WDG)	500 g	1	1	1	1
Quizalofop-p-ethyl 5% + Ethoxysulfuron 15% (Jute Guard 20 WDG)	400 g	1	1	1	1
Fenoxaprop-p-ethyl 10% + Ethoxysulfuron 10% (Sun Jute Plus 20 WG)	300 g	1	1	1	1
Fenoxaprop-p-ethyl 10% + Ethoxysulfuron 10% (Sun Jute Plus 20 WG)	400 g	1	1	1	1
Quizalofop-p-ethyl 9% + Ethoxysulfuron 12% (Raker 21 OD)	400 ml	1	5	5	2
Quizalofop-p-ethyl 9% + Ethoxysulfuron 12% (Raker 21 OD)	300 ml	1	5	5	2
Fenoxaprop-p-ethyl 7 %+Bensulfuran Methyl 15% (Crusher 22 WP)	1 Kg	5	1	1	2
Metamifop (Pyzero 10EC)	750 ml	5	1	1	1

Here,
Weed control rating: 1 (80-100%) = Excellent; 2 (70-79%) = Good; 3 (60-69%) = Fair; 4 (40-59%) = Poor; 5 (0-39%) = Very poor control
Phytotoxicity rating: 1 = No; 2 = Slight injury; 3 = Phytotoxic; 4 = Severely phytotoxic; 5 = Crop 100% killed

Table 7. Weed control efficacy (%) of different herbicides on the dominant weeds grown in *Corchorus olitorius*.

Treatments	*Cyperus rotundus*	*Echinochloa colonum*	*Digitaria sanguinalis*	*Eleosine indica*	*Physalis heterophylla*	*Paspalum distichum*	*Cynodon dactylon*
W_1	20.58 gh	87.27 b	87.75 b	87.91 b	23.73 ef	86.48 b	91.50 a-b
W_2	23.11 g	86.60 bc	87.22 b	87.49 bc	26.62 de	85.82 b	90.01 b-d
W_3	19.28 h	87.55 b	88.36 b	88.85 b	18.89 f	87.77 b	91.88 ab
W_4	88.24 de	41.94 d	37.00 c	31.99 d	19.02 f	5.55 de	8.12 gh
W_5	26.51 f	77.90 c	81.70 b	81.17 c	28.93 d	73.97 c	78.54 e
W_6	3.97 k	4.87 f	10.99 d	15.89 e	7.18 hi	13.05 d	22.30 f
W_7	89.69 cd	84.33 bc	83.95 b	83.26 bc	38.97 c	77.88 bc	80.30 de
W_8	91.76 bc	84.89 bc	84.65 b	85.18 bc	46.32 b	79.72 bc	82.63 b-e
W_9	92.22 bc	85.13 bc	85.05 b	85.79 bc	47.55 b	80.93 bc	83.71 b-e
W_{10}	90.78 b-d	84.54 bc	84.27 b	84.44 bc	40.59 c	79.05 bc	81.75 c-e
W_{11}	92.50 b	85.37 bc	85.93 b	86.27 bc	49.20 b	83.85 bc	84.11 b-e
W_{12}	89.74 cd	83.70 bc	84.51 b	83.66 bc	39.58 c	78.57 bc	80.99 de
W_{13}	86.67 e	34.88 de	36.17 c	35.94 d	6.81 hi	15.38 d	10.10 g
W_{14}	86.04 e	28.66 e	33.70 c	31.59 d	5.04 i	12.50 d	8.42 gh
W_{15}	12.09 j	85.74 bc	86.42 b	86.73 bc	10.65gh	84.82 bc	85.71 b-e
W_{16}	16.12 i	86.37 bc	86.66 b	87.24 bc	13.75 g	85.36 b	89.28 b-d
W_{17}	100 a	100 a	100 a	100 a	100 a	100 a	100 a
W_{18}	0 l	0 g	0 e	0 f	0 j	0 e	0 h
LSD at 5%	2.746	8.956	10.577	6.612	4.906	11.350	9.855
CV (%)	2.89	7.86	9.22	5.77	10.18	10.89	9.14

Here, statistics with the same letter in a column do not differ considerably. LSD = Least Significant Differences at 5% level of probability. CV = Coefficient of Variance; W_1 - Fenoxapro-p-ethyl @ 650 ml ha^{-1}; W_2 - Quizalofop-p-ethyl @ 650 ml ha^{-1}; W_3 - Fluazifop-p-butyl @ 1 L ha^{-1}; W_4 - Ethoxysulfuron @ 200 g ha^{-1}; W_5 - Quizalofop-p-tefuryl @ 650 ml ha^{-1}; W_6 - Pendimethalin @ 1 L ha^{-1}; W_7 - Fluazifop-p-ethyl 10% + Ethoxysulfuron 10% @ 400 g ha^{-1} ; W_8 - Fluazifop-p-ethyl 10% + Ethoxysulfuron 10% @ 500 g ha^{-1} ; W_9- Quizalofop-p-ethyl 5% + Ethoxysulfuron15% @ 500 g ha^{-1} ; W_{10} - Quizalofop-p-ethyl 5% + Ethoxysulfuron15% @ 400 g ha^{-1} ; W_{11} - Fenoxaprop-p-ethyl 10% + Ethoxysulfuron 10% @ 300 ml ha^{-1}; W_{12} - Fenoxaprop-p-ethyl 10% + Ethoxysulfuron 10% @ 400 ml ha^{-1} ; W_{13} - Quizalofop-p-ethyl 9% + Ethoxysulfuron 12% @ 400 ml ha^{-1} ; W_{14} - Quizalofop-p-ethyl 9% + Ethoxysulfuron 12% @ 300 ml ha^{-1} ; W_{15} - Fenoxaprop-p-ethyl 7% + Bensulfuran Methyl 15% @ 2 kg ha^{-1} ; W_{16} - Metamifop @ 750 ml ha^{-1} ; W_{17} - Weeding at 15 DAS +Weeding at 30 DAS +Weeding at 45 DAS (weed free); W_{18} - Control (Season long weedy)

Table 8. Impact of several weed control treatments on yield and yield attributes of *Corchorus olitorius.*

Treatments	PD (m^{-2})	PH (m)	BD (mm)	FY (t ha^{-1})	SY (t ha^{-1})
W_1	41.15 fg	2.39 cd	11.60 c	1.76 fg	3.53 g
W_2	41.55 f	2.36 de	11.44 c	1.83 f	3.61 g
W_3	39.75 g	2.27 de	11.49 c	1.62 hi	3.23 hi
W_4	44.12 c-e	2.63 b	13.77 b	2.21 d	4.40 de
W_5	40.15 fg	2.33 de	7.46 e	1.68 gh	3.35 gh
W_6	29.33 h	1.63 fg	13.70 b	1.49 j	2.94 j
W_7	45.07 b-d	2.67 b	13.85 b	2.24 d	4.46 d
W_8	43.89 c-e	2.74 b	13.91 b	2.42 b	4.82 bc
W_9	46.30 ab	2.75 b	13.94 b	2.47 b	4.90 b
W_{10}	46.00 ab	2.72 b	13.83 b	2.38 bc	4.75 bc
W_{11}	46.23 ab	2.78 b	14.02 b	2.50 b	4.99 b
W_{12}	45.21 bc	2.70 b	13.79 b	2.29 cd	4.59 cd
W_{13}	43.54 de	2.61 b	13.58 b	2.09 e	4.14 ef
W_{14}	43.26 e	2.59 bc	9.48 d	2.06 e	4.08 f
W_{15}	28.33 h	1.76 f	9.59 d	1.51 ij	2.50 k
W_{16}	26.67 i	2.17 e	10.09 d	1.55 ij	2.98 ij
W_{17}	46.97 a	3.51 a	17.31 a	3.61 a	7.03 a
W_{18}	26.33 i	1.48 g	7.32 e	1.46 j	2.45 k
LSD at 5% level	1.536	0.214	1.061	0.124	0.287
CV (%)	2.30	5.26	5.23	3.62	4.29

Here, statistics with the same letter in a column do not differ considerably. LSD = Least Significant Differences at 5% level of probability. CV = Coefficient of Variance; W_1 - Fenoxapro-p-ethyl @ 650 ml ha^{-1}; W_2 - Quizalofop-p-ethyl @ 650 ml ha^{-1}; W_3 - Fluazifop-p-butyl @ 1 L ha^{-1}; W_4 - Ethoxysulfuron @ 200 g ha^{-1}; W_5 - Quizalofop-p-tefuryl @ 650 ml ha^{-1}; W_6 - Pendimethalin @ 1 L ha^{-1}; W_7 - Fluazifop-p-ethyl 10% + Ethoxysulfuron 10% @ 400 g ha^{-1} ; W_8 - Fluazifop-p-ethyl 10% + Ethoxysulfuron 10% @ 500 g ha^{-1} ; W_9- Quizalofop-p-ethyl 5% + Ethoxysulfuron15% @ 500 g ha^{-1} ; W_{10} - Quizalofop-p-ethyl 5% + Ethoxysulfuron15% @ 400 g ha^{-1} ; W_{11} - Fenoxaprop-p-ethyl 10% + Ethoxysulfuron 10% @ 300 ml ha^{-1}; W_{12} - Fenoxaprop-p-ethyl 10% + Ethoxysulfuron 10% @ 400 ml ha^{-1} ; W_{13} - Quizalofop-p-ethyl 9% + Ethoxysulfuron 12% @ 400 ml ha^{-1} ; W_{14} - Quizalofop-p-ethyl 9% + Ethoxysulfuron 12% @ 300 ml ha^{-1} ; W_{15} - Fenoxaprop-p-ethyl 7% + Bensulfuran Methyl 15% @ 2 kg ha^{-1} ; W_{16} - Metamifop @ 750 ml ha^{-1} ; W_{17} - Weeding at 15 DAS +Weeding at 30 DAS +Weeding at 45 DAS (weed free); W_{18} - Control (Season long weedy); PD-Plant density, PH-Plant height, BD-Base diameter, FY-Fibre yield, and SY-Stick yield.

Table 9. Economic assessment of several weed control treatments in *Corchorus olitorius*.

Treatment	FY (kg/ha)	FP Tk/ha	SY (kg/ha)	SP Tk/ha	GI (Tk ha^{-1})	TC (Tk ha^{-1})	NR (Tk ha^{-1})	BCR
	1	2	3	4	5 (2+4)	6	7 (5-6)	8(5/6)
W_1	1763	88167	3527	17633	105800	91279	14521	1.16
W_2	1827	91333	3613	18067	109400	90791	18609	1.20
W_3	1623	81167	3233	16167	97333	91846	5487	1.06
W_4	2213	110667	4403	22017	132683	92146	40537	1.44
W_5	1683	84167	3350	16750	100917	90856	10061	1.11
W_6	1487	74333	9337	14683	89017	90946	-1929	0.98
W_7	2237	111833	4457	22283	134117	91746	42371	1.46
W_8	2423	121167	4823	24117	145283	92196	53087	1.58
W_9	2470	123500	4900	24500	148000	91946	56054	1.61
W_{10}	2377	118833	4747	23733	142567	91546	51021	1.56
W_{11}	2497	124833	4987	24933	149767	90996	58771	1.64
W_{12}	2290	114500	4593	22967	137467	91346	46121	1.50
W_{13}	2087	104333	4137	20683	125017	91706	33311	1.36
W_{14}	2063	103167	4077	20383	123550	91266	32284	1.35
W_{15}	1513	75667	2497	12483	88150	92146	-3996	0.96
W_{16}	1553	77667	2983	14917	92583	92661	-78	1.00
W_{17}	3607	180333	7033	35167	215500	130746	84754	1.25
W_{18}	1463	73167	2453	12267	85433	88346	-2913	0.97

Here, W_1 - Fenoxapro-p-ethyl @ 650 ml ha^{-1}; W_2 - Quizalofop-p-ethyl @ 650 ml ha^{-1}; W_3 - Fluazifop-p-butyl @ 1 L ha^{-1}; W_4 - Ethoxysulfuron @ 200 g ha^{-1}; W_5 - Quizalofop-p-tefuryl @ 650 ml ha^{-1}; W_6 - Pendimethalin @ 1 L ha^{-1}; W_7 - Fluazifop-p-ethyl 10% + Ethoxysulfuron 10% @ 400 g ha^{-1} ; W_8 - Fluazifop-p-ethyl 10% + Ethoxysulfuron 10% @ 500 g ha^{-1} ; W_9- Quizalofop-p-ethyl 5% + Ethoxysulfuron15% @ 500 g ha^{-1} ; W_{10} - Quizalofop-p-ethyl 5% + Ethoxysulfuron15% @ 400 g ha^{-1} ; W_{11} - Fenoxaprop-p-ethyl 10% + Ethoxysulfuron 10% @ 300 ml ha^{-1}; W_{12} - Fenoxaprop-p-ethyl 10% + Ethoxysulfuron 10% @ 400 ml ha^{-1} ; W_{13} - Quizalofop-p-ethyl 9% + Ethoxysulfuron 12% @ 400 ml ha^{-1} ; W_{14} - Quizalofop-p-ethyl 9% + Ethoxysulfuron 12% @ 300 ml ha^{-1} ; W_{15} - Fenoxaprop-p-ethyl 7% + Bensulfuran Methyl 15% @ 2 kg ha^{-1} ; W_{16} - Metamifop @ 750 ml ha^{-1}; W_{17} - Weeding at 15 DAS +Weeding at 30 DAS +Weeding at 45 DAS (weed free); W_{18} - Control (Season long weedy).

All weedicides were sprayed at 8 days after sowing (DAS) except Pendimethalin (Panida 33 EC). Pendimethalin (Panida 33 EC) was sprayed at 1 DAS. FY= Fibre yield, FP= Fibre price, SY= Stick yield, SP= Stick price, GI= Gross income, TC= Total cost, NR= Net return, Calculation was done as par labor wedges @ 400 Tk person^{-1} day^{-1}.

Conclusion

Weed management is still an uphill battle regarding the sustainable cultivation of *C. olitorius,* since weeds significantly reduce grain yield. The present study revealed that the spray of Fenoxaprop-p-ethyl 10% + Ethoxysulfuron 10% @ 300 ml ha^{-1} at 8 DAS appeared as the best herbicide for *C. olitorius* cultivation in terms of effective weed control with the greatest net return and BCR followed by Quizalofop-p-ethyl 5% + Ethoxysulfuron15% @ 500 g ha^{-1}. So, Fenoxaprop-p-ethyl 10% + Ethoxysulfuron 10% @ 300 ml ha^{-1} can be used for their higher weed suppressing ability and cost-effectiveness in *C. olitorius* production. However, this research was limited to a single site and should be tested at multi-location sites prior to advising the farmers to use the package. Furthermore, care should be given to environmental problems associated with the usage of herbicides because farmers normally ignore instructions and apply incorrect doses, volumes, and spray nozzles, results in poor weed suppression.

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