Original Research Article

Growing Green: Unravelling Trait Associations in Sunnhemp (*Crotalaria juncea* L.) for Higher Biomass.

ABSTRACT

Sunnhemp (*Crotalaria juncea* L.) is a leguminous crop native to India, cultivated for its industrial value and soft fibre. Its high biomass and nutrient content make it a good choice for fodder and green manure. As a legume, it thrives on poor or reclaimed soil, serving as a soil builder and nematode deterrent. In this study, the investigation was carried out with the objective of elucidating the associations among traits and theircontribution towards high biomass in sunnhemp. The investigation was carried out with the objective of elucidating the associations among traits and its contribution towards high biomass in sunnhemp.Genotypic correlation analysis revealed significant associations between biomass and traits such asthenumber of primary branches (0.631), dry matter yield (0.543), leaf length (0.540) and leaf width (0.470). Phenotypic correlation analysis demonstrated that biomass showed positive correlation with number of primary branches (0.604), dry matter yield (0.540), leaf length (0.539) and plant height (0.456).In addition to this, path analysis revealed the direct and indirect effects of traitsonbiomass yield. The trait dry matter yield (1.421) exhibited the highest positive direct effect towards biomass yield. These findings suggest that selecting plants for plant height, leaf length, leaf width, dry matter yield and primary branch count can enhance biomass in sunnhemp breeding programs, which willfurther increase its valueas a green manure crop.

Keywords: Sunnhemp, high biomass, correlation, path analysis, selection criteria

1. INTRODUCTION

Sunnhemp (*Crotalaria juncea* L.) belonging to Fabaceae family is commercially cultivated for its industrial values and soft fibre. Because of its high biomass and nutrient content, it is also being cultivated as fodder(Mosqueda et al. 2023) and green manure crop (Mondin et al. 2007). The crop being a legume is having advantage of growingin fields with less resources or freshly reclaimed soil where its major role would be soil builder or renovator.The crop once a major commercial crop was replaced by cultivation of other high value crops. At present, the use of chemical fertilizers has become dominant among developed as well as developing countries, leading to continuous agroecosystem damage. This has become the major concern for the current day and scientists of early days of green revolution (Agarwal 1959 ; Kanwar and Singh 1959 ; Panse et al. 1965 ; Tandon et al. 1959). Sunnhemp can play a major role in solving these problems as green manure crop, which maintains the soil health and agroecosystem (Bhardwaj and Datt 1995 ; Gupta and Tripathi 1999). After huge hike in fertilizer price, farmers realized the value of green manure crop and returned back to the cultivation of sunnhemp as nutrient supplement. Sunnhemp cultivation not only increases the soil health but also helps in increasing the water holding capacity of the soil by addition of large amount of organic matter.

"A high magnitude of variability in a population provides the opportunity for selection to evolve a variety having desirable characteristics"(Desai Tarjani et al. 2020b ; Maruthi et al. 2024). "Information on association of characters, direct and indirect effects contributed by each character towards biomass will be an added advantage in aiding the selection process. Correlation and path analysis establish the extent of the association between biomass and its components and also bring out relative importance of their direct and indirect effects, thus giving an obvious understanding of their association with high biomass"(Rajagopal et al. 2021). Ultimately, this kind of analysis could help the breederdesign his selection strategies to improve biomass content. In this context, the investigation was carried out with the objective of elucidating the associations among traits and its contribution towards high biomass in sunnhemp.

2. MATERIALS AND METHODS

The current investigation was carried out at the Department of Genetics and Plant Breeding, Tamil Nadu Agricultural University, Coimbatore (11^{o}N latitude and 77^{o}E longitude) during *Kharif* 2019–2020. The experiment was laid out in a Randomized Block Design (RBD) with three replications. Theexperimentalmaterialconsistedof twentygermplasmaccessionscollectedfrom differentparts of TamilNaduandalsofromCRIJAF (ICAR-Central Research Institute for Jute and Allied Fibres, Barrackpore). Each accession was raised in 4 m x 2 m sized plot with 60 cm spacing between rows. All necessary precautions were taken to maintain uniform plant population in each treatment per replication. All the recommended package of practices were followed along with necessary prophylactic plant protection measures to raise a good crop. Observations were recorded for traits such as plant height (cm), leaf length (cm), leaf width (cm), number of leaves per plant, stem grith (cm), days to first flowering, days to 50% flowering, number of primary branches, number of secondary branches, root length, dry matter yield (kg/plot), moisture content and biomass yield (kg/plot) and the data was subjected to statistical analysis. Association among biomass and its contributing traits were elucidated through correlation analysis suggested by Johnson et al. (1955), which provides us the direction of association. The cause and effect of different traits on the biomass were interrupted through path analysis given by Wright (1921) and illustrated by Dewey and Lu (1959).

3. RESULTS AND DISCUSSION

3.1 Correlation Analysis

3.1.1 Genotypic Correlation

The results of genotypic correlation analysis were presented in Table 1. Biomass yield per plant demonstrated positive and highly significant association with number of primary branches (0.631), whereas it exhibited positive and significant association with dry matter yield (0.543), leaf length (0.540), leaf width (0.470). Plant height registered positive and highly significant association with stem girth (0.697), positive and significant association with leaf length (0.559) and leaf width

(0.551). Leaf length showed positive and highly significant association with leaf width (0.758), positive and significant association with plant height (0.559), stem girth (0.509) and dry matter yield (0.480).

Table 1. Genotypic correlation among biomass contributing traits

Traits	PH	LL	LW	NLP	SG	DF	DFF	NPB	NSB	RL	DMY	MC	BMY
PH	1.000	0.559*	0.551*	0.401	0.697**	0.085	0.147	0.307	0.257	0.215	0.411	-0.135	0.455
LL		1.000	0.758**	-0.150	0.509*	-0.212	-0.076	0.450	0.311	0.251	0.480*	-0.150	0.540*
LW			1.000	-0.195	0.435	0.040	0.213	0.442	0.230	-0.106	0.446	-0.138	0.470*
NLP				1.000	0.374	0.419	0.172	0.094	0.255	0.252	0.043	0.153	0.278
SG					1.000	0.034	0.049	0.296	0.481*	0.050	0.249	-0.111	0.272
DF						1.000	0.743**	0.120	0.162	-0.092	0.111	0.008	0.167
DFF							1.000	0.221	0.301	-0.102	0.355	-0.184	0.288
NPB								1.000	0.388	-0.104	0.525*	-0.112	0.631**
NSB									1.000	0.175	0.251	-0.017	0.369
RL										1.000	-0.119	0.299	0.242
DMY											1.000	-0.741**	0.543*
MC												1.000	0.154
BMY													1.000

*, ** Significant at 5 and 1 percent probability level, respectively.

PH - Plant height
LL - Leaf length
LW - Leaf width
NLP - No. of leaves per plant
SG - Stem girth
DF - Days to first flowering
DFF - Days to 50 % flowering
NPB - No. of primary branches
NSB - No. of secondary branches
RL - Root length
DMY - Dry matter yield
MC - Moisture content
BMY - Biomass yield

Leaf width hadapositive and highly significant association with leaf length (0.758), positive and significant association with plant height (0.551). Stem girth registered positive and highly significant association with plant height (0.697), whereasthere was a positive and significant association with leaf length (0.509) and number of secondary branches (0.481). Days to first flowering demonstrated positive and highly significant association with days to 50 % flowering (0.743). Days to 50 % flowering demonstrated positive and highly significant association with days to first flowering (0.743). The number of primary branches demonstrated positive and significant association with dry matter yield (0.525).Thenumber of secondary branches demonstrated positive and significant association with stem girth (0.481). Dry matter yield demonstrated positive and significant association with number of primary branches (0.525) and leaf length (0.480). Dry matter yield exhibited negative and highly significant association with moisture content (-0.741). Moisture content registered negative and highly significant association with dry matter yield (-0.741). Similar results were reported by Desai Tarjani et al. (2020a).

3.1.2 PhenotypicCorrelation

The results of the phenotypic correlation analysis are presented in Table 2. Biomass yield per plant demonstrated positive and highly significant association with number of primary branches (0.604), It had positive and significant association with dry matter yield (0.540), leaf length (0.539) and plant height (0.456). Plant height registered positive and highly significant association with stem girth (0.686), it exhibited positive and significant association with leaf length (0.556) and leaf width (0.516). Leaf length exhibited positive and highly significant association with leaf width (0.748), positive and significant association with plant height (0.556), stem girth (0.523) and dry matter yield (0.493). Leaf width exhibited positive and highly significant association with leaf length (0.748), positive and significant association with plant height (0.516), stem girth (0.473), dry matter yield (0.469) and the number of primary branches (0.465). Stem girth registered positive and highly significant association with plant height (0.686). Positive and significant association with leaf length (0.523), number of secondary branches (0.479) and leaf width (0.473). Days to first flowering demonstrated positive and highly significant association with days to 50 % flowering (0.743). Days to 50 % flowering demonstrated positive and highly significant association with days to first flowering (0.743). The number of primary branches demonstrated positive and significant association with dry matter yield (0.524) and leaf width (0.465). Number of secondary branches registered positive and significant association with stem girth (0.479). Dry matter yield demonstrated positive and significant association with number of primary branches (0.524), leaf length (0.493) and leaf width (0.469). Dry matter yield exhibited negative and highly significant association with moisture content (-0.748). Moisture content registered negative and highly significant association with dry matter yield (-0.748). Similar results were reported by Desai Tarjani et al. (2020a).

Table 2. Phenotypic correlation among biomass contributing traits

Traits	PH	LL	LW	NLP	SG	DF	DFF	NPB	NSB	RL	DMY	MC	BMY
PH	1.000	0.556*	0.516*	0.402	0.686**	0.085	0.146	0.295	0.257	0.201	0.409	-0.137	0.456*
LL		1.000	0.748**	-0.145	0.523*	-0.210	-0.075	0.451	0.314	0.287	0.493*	-0.171	0.539*
LW			1.000	-0.172	0.473*	0.037	0.197	0.465*	0.231	0.086	0.469*	-0.192	0.445
NLP				1.000	0.371	0.418	0.172	0.093	0.255	0.234	0.045	0.147	0.278
SG					1.000	0.034	0.048	0.317	0.479*	0.138	0.274	-0.143	0.272
DF						1.000	0.743**	0.114	0.162	-0.082	0.109	0.008	0.167
DFF							1.000	0.210	0.300	-0.091	0.350	-0.181	0.288
NPB								1.000	0.391	0.003	0.524*	-0.141	0.604**
NSB									1.000	0.178	0.255	-0.026	0.369
RL										1.000	-0.031	0.186	0.229
DMY											1.000	-0.748**	0.540*
MC												1.000	0.147
BMY													1.000

*, ** Significant at 5 and 1 percent probability level, respectively.

PH - Plant height
LL - Leaf length
LW - Leaf width
NLP - No. of leaves per plant
SG - Stem girth
DF - Days to first flowering
DFF - Days to 50 % flowering
NPB - No. of primary branches
NSB - No. of secondary branches
RL - Root length
DMY - Dry matter yield
MC - Moisture content
BMY - Biomass yield

Genotypic and phenotypic correlation coefficients revealed that the characters such as plant height, leaf length, leaf width, number of primary branches and dry matter yield registered significant positive correlation with biomass yield of the plant. As our trait of interest is biomass, genotypes with high vegetative growth in short term with high nutrient content is preferable. High plant height, high leaf length, leaf width, stem girth and dry matter yield could contribute unquestionably to high biomass, which could result in crop with high biomass. Therefore, plant height, leaf length, leaf width, stem girth, number of primary branches and dry matter yield would be important selection criteria for improvement in biomass of the crop.

3.2 Path Analysis

The estimates of path coefficient analysis are furnished for biomass and biomass component characters in Table 3. The results of path co-efficient analysis disclosed that dry matter yield (1.421) exhibited the highest positive direct effect followed by moisture content (1.207), leaf length (0.051), root length (0.038) and days to 50% flowering (0.035).Similar results were reported by Desai Tarjani et al. (2020a).

Plant height registered highest positive indirect effect with biomass through dry matter yield (0.584) followed by stem girth (0.046). Whereas, plant height registered negative indirect effect with biomass through moisture content (-0.163) followed by leaf width (-0.030). Leaf length exhibited highest positive indirect effect through dry matter yield (0.683) followed by stem girth (0.033). Leaf length exhibited negative indirect effect through moisture content (-0.180) followed by leaf width (-0.041). Leaf width displayed positive indirect contribution towards biomass through dry matter yield (0.634) followed by leaf length (0.039). In addition to that, leaf width displayed negative indirect effect through moisture content (-0.167) followed by plant height (-0.014). The number of leaves exhibited positive indirect effect towards biomass through moisture content (0.185) followed by dry matter yield (0.060). The number of leaves displayed negative indirect effect towards biomass through plant height (-0.010) followed by leaf length (-0.008). Stem girth exhibited positive indirect effect towards biomass through dry matter yield (0.354) followed by leaf length (0.026). In addition to that, stem girth registered negative indirect effect through moisture content (-0.134) followed by leaf width (-0.024). Days to first flowering displayed positive indirect contribution with regard to biomass through dry matter yield (0.158) followed by days to 50 % flowering (0.026). Along with these, days to first flowering exhibited negative indirect effect through leaf length (-0.011) followed by root length (-0.004). Days to 50 % flowering exhibited positive indirect effect with regard to biomass through dry matter yield (0.504) followed by number of primary branches (0.003). Days to 50 % flowering registered negative indirect effect towards biomass via moisture content (-0.222) followed by leaf width (-0.012). Number of primary branches showed positive indirect contribution towards biomass by means of dry matter yield (0.746) followed by leaf length (0.023). In addition, it exhibited negative indirect contribution towards biomass via moisture content (-0.136) followed by leaf width (-0.024). Number of secondary branches registered positive indirect effect towards biomass through dry matter yield (0.356) followed by stem girth (0.031). Whereas, number of secondary branches registered negative indirect effect towards biomass by means of moisture content (-0.021) followed by leaf width (-0.013).

Table 3. Genotypic path analysis showing direct (diagonal) and indirect effects of traits on biomass yield

Traits	PH	LL	LW	NLP	SG	DF	DFF	NPB	NSB	RL	DMY	MC	BMY
PH	**-0.024**	0.029	-0.030	0.003	0.046	-0.001	0.005	0.004	-0.005	0.008	0.584	-0.163	0.455
LL	-0.014	**0.051**	-0.041	-0.001	0.033	0.002	-0.003	0.006	-0.006	0.010	0.683	-0.180	0.540*
LW	-0.014	0.039	**-0.055**	-0.001	0.028	0.000	0.007	0.006	-0.004	-0.004	0.634	-0.167	0.470*
NLP	-0.010	-0.008	0.011	**0.007**	0.024	-0.005	0.006	0.001	-0.005	0.010	0.060	0.185	0.278
SG	-0.017	0.026	-0.024	0.003	**0.065**	0.000	0.002	0.004	-0.008	0.002	0.354	-0.134	0.272
DF	-0.002	-0.011	-0.002	0.003	0.002	**-0.011**	0.026	0.002	-0.003	-0.004	0.158	0.009	0.167
DFF	-0.004	-0.004	-0.012	0.001	0.003	-0.008	**0.035**	0.003	-0.005	-0.004	0.504	-0.222	0.288
NPB	-0.008	0.023	-0.024	0.001	0.019	-0.001	0.008	**0.014**	-0.007	-0.004	0.746	-0.136	0.631**
NSB	-0.006	0.016	-0.013	0.002	0.031	-0.002	0.011	0.005	**-0.018**	0.007	0.356	-0.021	0.369
RL	-0.005	0.013	0.006	0.002	0.003	0.001	-0.004	-0.001	-0.003	**0.038**	-0.169	0.361	0.242
DMY	-0.010	0.025	-0.024	0.000	0.016	-0.001	0.012	0.007	-0.004	-0.005	**1.421**	-0.895	0.543*
MC	0.003	-0.008	0.008	0.001	-0.007	0.000	-0.006	-0.002	0.000	0.012	-1.054	**1.207**	0.154

*, ** Significant at 5 and 1 percent probability level, respectively. Residue = 0.1111

PH - Plant height
LL - Leaf length
LW - Leaf width
NLP - No. of leaves per plant
SG - Stem girth
DF - Days to first flowering
DFF - Days to 50 % flowering
NPB - No. of primary branches
NSB - No. of secondary branches
RL - Root length
DMY - Dry matter yield
MC - Moisture content
BMY - Biomass yield

Root length registered positive indirect contribution towards biomass through moisture content (0.361) followed by leaf length (0.013). In addition to that root length exhibited negative indirect contribution towards biomass by means of dry matter yield (-0.169) followed by plant height (-0.005). Dry matter yield displayed positive indirect contribution with regard to biomass through leaf length (0.025) followed by stem girth (0.016). Along with these, dry matter yield exhibited negative indirect effect through moisture content (-0.895) followed by leaf width (-0.024).Moisture content exhibited positive indirect effect with regard to biomass through root length (0.012) followed by leaf width (0.008). Moisture content registered negative indirect effect towards biomass via dry matter yield (-1.054) followed by leaf length (-0.008).

The outcomes of path co-efficient analysis disclosed that dry matter yield exhibited the highest positive direct effect followed by moisture content, stem girth, leaf length, root length, days to 50 % flowering, number of primary branches and number of leaves per plant towards the biomass. On the other hand, characters such as leaf width, plant height, number of secondary branches and days to first flowering exhibited negative direct effect towards the biomass yield of the crop. While indirect contribution is significantly higher, the characters bequeathing indirect contribution could also be included in selection strategy for the effective crop improvement programme. In the light of results obtained in present study, the highest indirect effect on biomass was exhibited by number of primary branches followed by leaf length through dry matter yield.

Selection of the genotypes should be done very prudently keeping in view higher dry matter yield plant per plant along with a greater number of primary branches plant per plant, plants with higher plant height, higher leaf length, higher leaf width, greater number of leaves per plant and higher stem girth to improve biomass yield per plant in sunnhemp. The lines may be used in further hybridization program and these crosses may yield more transgressive segregants for these traits for biomass improvement.

4. CONCLUSION

The association between biomass and its contributing characters revealed that traits such as, plant height, leaf length, leaf width, stem girth, number of primary branches and dry matter yield contributedto the high biomass yield per plant. Use of these traits associated with high biomass in selection will help to improve the biomass of the crop. The results of path co-efficient analysis showed that selection of characters such as dry matter yield, moisture content, number of leaves per plant, days to 50 % flowering, number of secondary branches, leaf length, stem girth and root length had high direct effect on biomass yield per plant. These results inferred that plant height, leaf length, leaf width, stem grith, number of primary branches and dry matter yield could be used in selection for biomass improvement of sunnhemp crop.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

Disclaimer (Artificial intelligence) Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.,) and text-to-image generators have been used during writing or editing of manuscripts.

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