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Genetic analysis for morphological and biochemical characterization in B x N Hybrids

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Abstract
Bajra × Napier (B × N) hybrids (*Pennisetum glaucum* (L.) R. Br. × *Pennisetum purpureum* (K.) Schum.) are perennial fodder grasses that combine high biomass production with good forage quality. A study entitled "Genetic analysis for morphological and biochemical characterization in B × N hybrids" was conducted at the Grass Research Scheme, Mahatma Phule Krishi Vidyapeeth, Rahuri, District Ahilyanagar, Maharashtra (India) during *Kharif* season 2025 to assess thirty B × N hybrid genotypes, including two checks, for genetic variability, heritability, genetic advance, correlation coefficients and path analysis. The genotypes were planted in a Randomized Block Design with two replications. Data were collected for sixteen characters *viz*., plant height, number of tillers, number of leaves, number of internodes, leaf length, leaf width, leaf: stem ratio, dry matter content, dry matter yield, crude protein content, crude protein yield, crude fibre, oxalic acid content, acid detergent fibre, neutral detergent fibre and green forage yield per plant. Significant differences were found among the genotypes for all the characters. The phenotypic coefficient of variation was higher than the genotypic coefficient of variation for every character, and heritability was high (73.06 to 98.99 %) for all of them. High GCV and PCV were recorded for crude protein yield, number of tillers, leaf: stem ratio, dry matter yield and number of internodes. High heritability coupled with high genetic advance as per cent of mean was observed for thirteen characters, indicating predominance of additive gene action. Green forage yield per plant exhibited significant and positive correlation at both genotypic and phenotypic levels with dry matter yield, crude protein yield, plant height, crude protein content, number of tillers and leaf width. The path analysis indicated that dry matter yield had by far the highest direct positive effect on green forage yield (1.432), followed by plant height and leaf width, and its strong positive correlation confirmed a true and consistent relationship. This suggests that direct selection based on dry matter yield, along with plant height and leaf width, would be effective in identifying high-yielding Bajra × Napier hybrids.

Keywords: Bajra × Napier hybrid, genetic variability, heritability, genetic advance, correlation, path analysis

Introduction

India possesses the world's largest livestock population, with a total of 535.78 million animals recorded in the 20th Livestock Census (Department of Animal Husbandry and Dairying, 2019) [11], and it is also the largest producer of milk in the world, with 247.87 million tonnes produced during 2024-25 (Department of Animal Husbandry and Dairying, 2025) [12]. Despite this, the inadequate availability of quality fodder remains a major constraint to livestock productivity. India experiences an estimated deficit of 11.24 % in green fodder, about 23.4 % in dry fodder and 28-35 % in concentrate feed ingredients, while cultivated fodder crops occupy only about 4-5 % of the gross cropped area (Roy *et al*., 2019) [31], (ICAR-IGFRI, 2023) [16]. Improving fodder productivity per unit area has therefore become one of the most effective strategies for bridging the gap between fodder demand and supply.

Napier grass (*Pennisetum purpureum* Schumach.) is a perennial, highly productive forage species indigenous to tropical Africa, which produces higher dry matter than most tropical forage grasses (Skerman and Riveros, 1990) [38]. Hybrids between pearl millet (Bajra) and Napier grass have finer stems, greater succulence, more leaf production, better palatability and faster growth, while retaining the perennial habit and high biomass potential of Napier grass (Bogdan, 1977) [5], (Lokhande, 2015) [27]. Under good management, Bajra × Napier (B × N) hybrids can produce about 200-350 tonnes of green fodder per hectare annually through six to eight harvests, and contain about 8.7-10.2 % crude protein and 28-30.5 % crude fibre on dry matter basis (Faruqui *et al*., 2009) [14], (Anderson *et al*., 2008) [4], (ICAR-IGFRI, 2019) [15].

Because Napier grass is highly heterozygous and cross-pollinated, B × N hybrids exhibit considerable genetic variability, which provides scope for clonal selection of superior genotypes. Genetic variability is the basis of every crop improvement programme, since the extent of variability present in a population determines the efficiency of selection (Allard, 1960) [2], (Burton and DeVane, 1953) [7]. Green fodder yield is a complex quantitative trait

governed by several interrelated characters; hence, the estimation of genotypic and phenotypic correlation coefficients helps to quantify the relationships among component traits, while path coefficient analysis partitions these correlations into direct and indirect effects and thereby identifies the key yield-contributing attributes (Wright, 1921) [43], (Dewey and Lu, 1959) [13], (Roy *et al*., 2019) [31].
In addition to biomass production, fodder quality is a major objective in forage breeding. Crude protein, crude fibre, neutral detergent fibre (NDF), acid detergent fibre (ADF), dry matter content and oxalic acid concentration influence the digestibility, feed intake and overall performance of livestock (Thimmaiah, 1999) [40]. Considerable variation still exists among B × N hybrids for both morphological and biochemical traits. The present investigation was therefore undertaken to assess genetic variability, heritability, genetic advance, correlation and path coefficients for sixteen morphological, yield and biochemical characters in thirty B × N hybrid genotypes.

Material and Methods

Experimental site and material

The present investigation, "Genetic analysis for morphological and biochemical characterization in B × N hybrids", was carried out at the Grass Research Scheme, Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri, District Ahilyanagar, Maharashtra, India, from July 2025 to December 2025 (*Kharif* season 2025). The experimental material comprised 30 genotypes of Bajra × Napier hybrids, including the two checks Phule Gunwant and Phule Jaywant, which were supplied by the Research Officer of the Grass Research Scheme, MPKV, Rahuri (Table 1).

Table 1: List of 30 genotypes of Bajra × Napier hybrids

Sr. No.	Genotype	Sr. No.	Genotype
1	RBN-2024-1	16	RBN-2024-16
2	RBN-2024-2	17	RBN-2024-17
3	RBN-2024-3	18	RBN-2024-18
4	RBN-2024-4	19	RBN-2024-19
5	RBN-2024-5	20	RBN-2024-20
6	RBN-2024-6	21	RBN-2024-21
7	RBN-2024-7	22	RBN-2024-22
8	RBN-2024-8	23	RBN-2024-23
9	RBN-2024-9	24	RBN-2024-24
10	RBN-2024-10	25	RBN-2024-25
11	RBN-2024-11	26	RBN-2024-26
12	RBN-2024-12	27	RBN-2024-27
13	RBN-2024-13	28	RBN-2024-28
14	RBN-2024-14	29	Phule Gunwant (Check)
15	RBN-2024-15	30	Phule Jaywant (Check)

Experimental design and cultural practices

The experiment was carried out in a Randomized Block Design (RBD) with two replications and a spacing of 90 cm × 60 cm. After planting, an initial irrigation was given, followed by subsequent irrigations at intervals of 10-12 days. A basal dose of fertilizers was applied at the rate of 150 kg N, 60 kg P and 60 kg K per hectare, and manual weeding was carried out regularly. Observations were recorded on five randomly selected plants from each plot at the time of each cut, and the averages were worked out. Data on green forage yield and dry matter yield were collected throughout the experimental period and expressed in g per plant.

Statistical Analysis

Analysis of variance, GCV and PCV

The analysis of variance was done as per the suggestions of Panse and Sukhatme (1995) [28]. The genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) were calculated using the formulae recommended by Burton (1952) [6], where $\sigma^2 g$ and $\sigma^2 p$ are the genotypic and phenotypic variances, respectively.

$$GCV\ (\%) = \frac{\sqrt{(\sigma^2 g)}}{\text{General mean}} \times 100$$

$$PCV\ (\%) = \frac{\sqrt{(\sigma^2 p)}}{\text{General mean}} \times 100$$

Heritability and genetic advance

Heritability in the broad sense was estimated as given by Burton (1952) [6] and categorised as low (below 30 %), moderate (30-60 %) and high (above 60 %) according to Robinson *et al*. (1949) [30].

$$h^2\ (b.s.)\ \% = \frac{\sigma^2 g}{\sigma^2 p} \times 100$$

Genetic advance was calculated by the formula given by Johnson *et al*. (1955) [18] and expressed as per cent of mean (GAM), where K is the selection differential, which is 2.06 at 5 per cent selection intensity. GAM was categorised as low (below 10 %), moderate (10-20 %) and high (above 20 %).

$$GAM\ (\%) = \frac{K \times h^2 \times \sqrt{(\sigma^2 p)}}{\text{General mean}} \times 100$$

Correlation analysis

To examine the relationships among the traits, genotypic and phenotypic correlation coefficients were calculated using the method outlined by Singh and Choudhary (1977) [37] and tested for significance by the 't' test (Panse and Sukhatme, 1995) [28].

Path coefficient analysis

Path coefficient analysis was performed following the procedure recommended by Dewey and Lu (1959) [13].

Results and Discussion

The current study on "Genetic analysis for morphological and biochemical characterization in B × N hybrids" was conducted with the aim of understanding genetic variability, correlation and path analysis among 30 genotypes at the Grass Research Scheme, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahilyanagar, Maharashtra, during *Kharif* season 2025. The analysis of variance revealed that the mean sum of squares due to genotypes was significant (P = 0.01) for all the sixteen characters studied, which indicated the presence of appreciable variability among the B × N hybrid genotypes.

Genetic variability

The present study indicated a wide range of variation for most of the traits. Highly notable differences were noted

among the thirty genotypes for plant height (122.69 to 353.76 cm), dry matter yield (214.37 to 906.01 g/plant), crude protein yield (16.32 to 89.90 g/plant) and green forage yield (1184.98 to 3622.21 g/plant), whereas crude fibre, acid detergent fibre and neutral detergent fibre exhibited a comparatively narrow range. Among the characters studied, crude protein yield recorded the highest coefficient of variation (GCV 37.51 %, PCV 39.23 %), followed by number of tillers (26.98 and 28.89 %), leaf: stem ratio (24.79 and 25.39 %), dry matter yield (24.57 and 26.99 %) and number of internodes (20.07 and 22.95 %). Shalini *et al*. (2020) [33] similarly observed wide variation for green forage yield, dry matter yield, crude protein yield, number of tillers per plant and leaf: stem ratio in B × N hybrids.

For all the traits, the PCV was higher than the GCV, although the differences were narrow, indicating that environmental factors had a limited influence on trait expression and that phenotypic performance can be relied upon for selection. This is in conformity with Kapoor (2020) [21], who also reported PCV higher than GCV for all the traits in B × N hybrids. Moderate GCV and PCV were recorded for oxalic acid content, number of leaves, green forage yield, crude protein content, plant height, leaf width, leaf length and dry matter content, while crude fibre, acid detergent fibre and neutral detergent fibre recorded low GCV and PCV. The GCV indicates the extent of genetic variability present in the germplasm, whereas the proportion that can be transmitted from parents to offspring is reflected by heritability. As per Robinson *et al*. (1949) [30], broad sense heritability was high (above 70 %) for all sixteen characters, ranging from 73.06 % for green forage yield to 98.99 % for oxalic acid content. Traits with high heritability coupled with high genetic advance are governed mainly by additive gene action, whereas high heritability with low or moderate genetic advance suggests non-additive gene action. The estimates of mean, range, GCV, PCV, ECV, heritability and genetic advance are presented in Table 2.

Table 2: Genetic variability parameters in 30 B × N hybrid genotypes

Sr. No.	Character	Mean	Range	GCV (%)	PCV (%)	ECV (%)	h^2 (b.s.) %	Genetic advance	Gen. adv. as % of mean
1	Plant height (cm)	216.56	122.69-353.76	16.17	17.73	7.27	83.16	65.78	30.38
2	Number of tillers	14.40	8.34-26.34	26.98	28.89	10.33	87.24	7.48	51.91
3	Number of leaves	12.98	8.95-24.11	17.64	19.38	8.03	82.82	4.29	33.07
4	Number of internodes	6.04	2.11-9.27	20.07	22.95	11.13	76.42	2.18	36.13
5	Leaf length (cm)	100.36	60.88-133.00	13.55	14.46	5.05	87.86	26.27	26.17
6	Leaf width (cm)	3.85	2.53-5.26	13.67	14.46	4.71	89.32	1.02	26.61
7	Leaf: Stem Ratio	0.65	0.41-0.98	24.79	25.39	5.49	95.27	0.33	49.84
8	Dry matter content (%)	22.67	15.80-26.32	10.99	11.34	2.80	93.88	4.97	21.94
9	Dry matter yield (g/plant)	569.67	214.37-906.01	24.57	26.99	11.17	82.84	262.39	46.06
10	Crude protein content (%)	8.05	5.91-10.96	16.27	16.40	2.06	98.41	2.68	33.25
11	Crude protein yield (g/plant)	46.76	16.32-89.90	37.51	39.23	11.49	91.41	34.54	73.87
12	Crude fibre (%)	32.01	29.20-35.00	4.52	4.56	0.60	98.44	2.96	9.24
13	Oxalic acid content (%)	2.39	1.67-3.21	17.04	17.12	1.65	98.99	0.83	34.92
14	Acid detergent fibre (%)	46.10	40.08-49.72	5.60	5.64	0.67	98.31	5.27	11.43
15	Neutral detergent fibre (%)	65.18	58.78-68.95	3.84	4.01	1.16	91.62	4.93	7.57
16	Green forage yield (g/plant)	2485.09	1184.98-3622.21	17.00	19.89	10.33	73.06	744.02	29.94

GCV = genotypic coefficient of variation; PCV = phenotypic coefficient of variation; ECV = environmental coefficient of variation; h^2 (b.s.) = broad sense heritability.

Plant height (cm)

Moderate GCV (16.17 %) and PCV (17.73 %) indicated moderate scope for selection. High heritability (83.16 %) coupled with high genetic advance as per cent of mean (30.38 %) indicated predominance of additive gene action, and selection for this character would be effective. Similar results were reported by Kapoor (2020) [21] in B × N hybrids.

Number of tillers

High GCV (26.98 %) and PCV (28.89 %) indicated ample scope for selection. High heritability (87.24 %) with high genetic advance as per cent of mean (51.91 %) indicated additive gene action. These findings are in close agreement with Kumari *et al*. (2018) [26].

Number of leaves

Moderate GCV (17.64 %) and PCV (19.38 %) were recorded, with high heritability (82.82 %) and high genetic advance as per cent of mean (33.07 %), indicating predominance of additive gene action. Kumar *et al*. (2017) [25] also recorded high heritability coupled with high genetic advance for number of leaves per tiller in Napier grass.

Number of internodes
High GCV (20.07 %) and PCV (22.95 %) with high heritability (76.42 %) and high genetic advance as per cent of mean (36.13 %) indicated additive gene action. Chavan (2012) [8] reported similar results in B × N hybrid derivatives.

Leaf length (cm)
Moderate GCV (13.55 %) and PCV (14.46 %) were recorded, along with high heritability (87.86 %) and high genetic advance as per cent of mean (26.17 %), indicating that selection for leaf length would be effective. High heritability coupled with high genetic advance was also reported by Kapoor (2020) [21].

Leaf width (cm)
Moderate GCV (13.67 %) and PCV (14.46 %) with high heritability (89.32 %) and high genetic advance as per cent of mean (26.61 %) indicated predominance of additive gene action. Similar results were reported by Kumari *et al*. (2018) [26].

Leaf: stem ratio
High GCV (24.79 %) and PCV (25.39 %) with high heritability (95.27 %) and high genetic advance as per cent of mean (49.84 %) indicated that the trait is expected to respond well to direct phenotypic selection. This is in close conformity with Kapoor (2020) [21].

Dry matter content (%)
Moderate GCV (10.99 %) and PCV (11.34 %) with high heritability (93.88 %) and high genetic advance as per cent of mean (21.94 %) indicated additive gene action. These results contrast with Pattanashetti *et al*. (2015) [29], who reported low heritability for dry matter content in *Pennisetum purpureum*.

Dry matter yield (g/plant)
High GCV (24.57 %) and PCV (26.99 %) with high heritability (82.84 %) and high genetic advance as per cent of mean (46.06 %) indicated ample scope for selection. Satapute (2012) [32] reported a high GCV (33.50 %) for dry matter yield per plant in B × N hybrid derivatives.

Crude protein content (%)
Moderate GCV (16.27 %) and PCV (16.40 %) were recorded with very high heritability (98.41 %) and high genetic advance as per cent of mean (33.25 %), suggesting predominance of additive gene action. Kumar *et al*. (2017) [25] also reported high GCV, heritability and genetic advance for crude protein content.

Crude protein yield (g/plant)
The highest GCV (37.51 %) and PCV (39.23 %) among all the characters were recorded, together with high heritability (91.41 %) and the highest genetic advance as per cent of mean (73.87 %), indicating strong additive gene action. Shinde (2005) [35] and Kumari *et al*. (2018) [26] reported similar findings in B × N hybrids.

Crude fibre (%)
Low GCV (4.52 %) and PCV (4.56 %) indicated limited scope for selection. High heritability (98.44 %) with low genetic advance as per cent of mean (9.24 %) suggested that non-additive gene action contributes to the inheritance of this trait. Khan and Sukumar (2001) [23] reported generally high heritability for the characters studied in *Pennisetum purpureum*, including crude fibre.

Oxalic acid content (%)
Moderate GCV (17.04 %) and PCV (17.12 %) with the highest heritability (98.99 %) and high genetic advance as per cent of mean (34.92 %) indicated predominance of additive gene action. These findings agree with Kumari *et al*. (2018) [26], who reported high heritability coupled with high genetic advance for oxalate content.

Acid detergent fibre (%)
Low GCV (5.60 %) and PCV (5.64 %) indicated limited scope for selection. High heritability (98.31 %) with moderate genetic advance as per cent of mean (11.43 %) suggested that non-additive gene action may also contribute to the inheritance of this trait. Kumari *et al*. (2018) [26] reported high genetic advance for this trait, which is only partly in agreement with the present findings.

Neutral detergent fibre (%)
The lowest GCV (3.84 %) and PCV (4.01 %) were recorded, indicating very limited scope for selection. High heritability (91.62 %) coupled with low genetic advance as per cent of mean (7.57 %) indicated predominance of non-additive gene action. The narrow variability is consistent with that reported for related fibre traits such as crude fibre (Khan and Sukumar, 2001) [23].

Green forage yield (g/plant)
Moderate GCV (17.00 %) and PCV (19.89 %) were recorded. High heritability (73.06 %) with high genetic advance as per cent of mean (29.94 %) indicated predominance of additive gene action, and selection for green forage yield would be effective. These results are in close conformity with Kapoor (2020) [21].
For all the traits studied, the minimal differences between GCV and PCV suggest that environmental effects on their expression are limited and that phenotypic values can be reliably used for selection. Traits such as plant height, number of tillers, number of leaves, number of internodes, leaf length, leaf width, leaf: stem ratio, dry matter content, dry matter yield, crude protein content, crude protein yield, oxalic acid content and green forage yield showed high heritability along with high genetic advance as per cent of mean, suggesting that they are primarily controlled by additive gene action.

Correlation coefficient analysis
Yield is a complex character resulting from the interaction of several component traits, and knowledge of the association between yield and its components, and among the components themselves, is essential for planning an effective selection programme. The genotypic correlation reflects the true heritable association between two characters, whereas the phenotypic correlation is useful for formulating selection indices. The genotypic and phenotypic correlation coefficients among the sixteen characters are presented in Table 3. In general, the genotypic correlation coefficients were higher in magnitude than the corresponding phenotypic coefficients, indicating that the environment masked the expression of the association in several cases. This is in conformity with Krishna and John (2007) [24] in B × N hybrids.

Table 3: Estimates of genotypic (above diagonal) and phenotypic (below diagonal) correlation coefficients among green forage yield and yield contributing characters in 30 B × N hybrid genotypes

Sr. No.	Character	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Plant height (cm)	1.000	0.471**	0.337	0.251	0.471**	0.522**	-0.092	0.285	0.716**	0.674**	0.728**	0.606**	-0.095	0.415*	0.587**	0.884**
2	Number of tillers	0.390**	1.000	0.164	0.356	0.258	0.330	-0.103	0.398*	0.603**	0.426*	0.550**	0.011	-0.176	0.139	0.198	0.585**
3	Number of leaves	0.335**	0.198	1.000	0.595**	-0.248	0.153	0.152	0.091	0.303	0.252	0.285	0.096	-0.151	-0.009	0.119	0.402*
4	Number of internodes	0.197	0.310*	0.517**	1.000	-0.342	0.319	0.054	0.303	0.311	-0.126	0.118	0.043	0.043	0.212	0.128	0.295
5	Leaf length (cm)	0.431**	0.238	-0.200	-0.324	1.000	0.290	-0.217	0.156	0.409*	0.454*	0.481**	0.323	-0.082	0.072	0.208	0.451*
6	Leaf width (cm)	0.475**	0.292*	0.129	0.266*	0.278*	1.000	0.061	0.342	0.512**	0.256	0.389*	0.356	-0.099	0.383*	0.182	0.570**
7	Leaf: Stem Ratio	-0.061	-0.087	0.174	0.014	-0.185	0.073	1.000	-0.100	-0.038	0.212	0.116	-0.041	-0.389*	-0.036	-0.129	0.002
8	Dry matter content (%)	0.258*	0.376**	0.097	0.269*	0.140	0.313*	-0.100	1.000	0.811**	0.167	0.571**	0.157	-0.193	0.499**	-0.005	0.492**
9	Dry matter yield (g/plant)	0.717**	0.506**	0.303*	0.269*	0.357**	0.468**	-0.025	0.765**	1.000	0.667**	0.921**	0.411*	-0.232	0.462*	0.311	0.903**
10	Crude protein content (%)	0.618**	0.397**	0.239	-0.108	0.418**	0.234	0.203	0.171	0.626**	1.000	0.884**	0.309	-0.208	0.069	0.331	0.839**
11	Crude protein yield (g/plant)	0.706**	0.491**	0.286*	0.103	0.435**	0.354**	0.116	0.563**	0.912**	0.866**	1.000	0.362*	-0.273	0.260	0.315	0.936**
12	Crude fibre (%)	0.550**	0.017	0.100	0.043	0.293*	0.324*	-0.043	0.169	0.391**	0.310*	0.361**	1.000	0.135	0.613**	0.446*	0.54**
13	Oxalic acid content (%)	-0.075	-0.159	-0.125	0.030	-0.060	-0.087	-0.376**	-0.192	-0.209	-0.208	-0.259*	0.131	1.000	0.222	0.384*	-0.167
14	Acid detergent fibre (%)	0.374**	0.135	0.005	0.192	0.061	0.349**	-0.038	0.507**	0.439**	0.074	0.263*	0.619**	0.217	1.000	0.472**	0.369*
15	Neutral detergent fibre (%)	0.523**	0.191	0.124	0.119	0.185	0.155	-0.131	0.015	0.297*	0.332**	0.317*	0.457**	0.374**	0.482**	1.000	0.479**
16	Green forage yield (g/plant)	0.846**	0.427**	0.359**	0.218	0.364**	0.492**	0.017	0.422**	0.898**	0.714**	0.876**	0.459**	-0.130	0.315*	0.402**	1.000

* and ** significant at P = 0.05 and P = 0.01 level of significance, respectively. Character numbers 1 to 16 in the column headings correspond to the serial numbers of the characters in the second column.

Correlation of green forage yield with its component characters

Green forage yield per plant showed significant and positive correlation, at both genotypic and phenotypic levels, with crude protein yield (r_g = 0.936 and r_p = 0.876), dry matter yield (r_g = 0.903 and r_p = 0.898), plant height (r_g = 0.884 and r_p = 0.846), crude protein content (r_g = 0.839 and r_p = 0.714), number of tillers (r_g = 0.585 and r_p = 0.427), leaf width (r_g = 0.570 and r_p = 0.492), crude fibre (r_g = 0.540 and r_p = 0.459), dry matter content (r_g = 0.492 and r_p = 0.422), neutral detergent fibre (r_g = 0.479 and r_p = 0.402), leaf length (r_g = 0.451 and r_p = 0.364), number of leaves (r_g = 0.402 and r_p = 0.359) and acid detergent fibre (r_g = 0.369 and r_p = 0.315). It showed positive but non-significant association with number of internodes (r_g = 0.295 and r_p = 0.218) and leaf: stem ratio (r_g = 0.002 and r_p = 0.017), and negative non-significant correlation with oxalic acid content (r_g = -0.167 and r_p = -0.130).

The strong positive association of green forage yield with dry matter yield, crude protein yield, plant height and number of tillers is in close agreement with Shinde (2005) [35], Kamble (2011) [19], Satapute (2012) [32], Chavan (2012) [8], Lokhande (2015) [27], Shinde (2015) [34] and Kumari *et al*. (2018) [26] in B × N hybrids. Amirthaselvarathinam and Dorairaj (1994) [3] reported significant positive correlation of green fodder yield with plant height, dry matter yield and crude protein yield in Napier grass, and Kapoor (2017) [20] reported positive and significant correlation of plant height, leaf width, dry matter yield and NDF with green fodder yield. The non-significant association with leaf : stem ratio contrasts with Zhang *et al*. (2009) [44], who reported a significant negative correlation between yield and leaf : stem ratio, which may be due to differences in genetic material.

Correlation between yield contributing components

Plant height (cm)

Plant height showed significant positive correlation, at both levels, with number of tillers (r_g = 0.471 and r_p = 0.390), leaf length (0.471 and 0.431), leaf width (0.522 and 0.475),

dry matter yield (0.716 and 0.717), crude protein content (0.674 and 0.618), crude protein yield (0.728 and 0.706), crude fibre (0.606 and 0.550), acid detergent fibre (0.415 and 0.374) and neutral detergent fibre (0.587 and 0.523). Number of leaves (r_g = 0.337, r_p = 0.335) and dry matter content (r_g = 0.285, r_p = 0.258) were significant at the phenotypic level only. Leaf : stem ratio (-0.092 and -0.061) and oxalic acid content (-0.095 and -0.075) showed negative non-significant correlation. Cheng *et al*. (1995) [9] reported positive correlation of plant height with leaf width and negative correlation with leaf : stem ratio in Napier grass, and Das and Ratnam Nadar (1991) [10] observed positive correlation of plant height with green fodder yield.

Number of tillers

Number of tillers was significantly and positively correlated at both levels with dry matter content (r_g = 0.398 and r_p = 0.376), dry matter yield (0.603 and 0.506), crude protein content (0.426 and 0.397) and crude protein yield (0.550 and 0.491). Number of internodes (r_p = 0.310) and leaf width (r_p = 0.292) were significant at the phenotypic level only. Its correlation with number of leaves, leaf : stem ratio, crude fibre, oxalic acid content, ADF and NDF was non-significant. Katoch and Gupta (1976) [22] reported number of tillers per plant to be the most important component of green fodder yield in Napier × Bajra hybrids.

Number of leaves

Number of leaves showed significant positive correlation with number of internodes (r_g = 0.595 and r_p = 0.517) at both levels, and with dry matter yield (r_p = 0.303) and crude protein yield (r_p = 0.286) at the phenotypic level only. Its association with the remaining characters was non-significant. Katoch and Gupta (1976) [22] reported number of leaves, along with number of tillers and plant height, as an important component of green fodder yield.

Number of internodes

Number of internodes showed significant positive correlation at the phenotypic level only with leaf width (r_p = 0.266), dry matter content (r_p = 0.269) and dry matter yield (r_p = 0.269), while its correlation with leaf length was negative (r_g = -0.342 and r_p = -0.324) and non-significant. Its correlation with the other characters was non-significant at both levels.

Leaf length (cm)

Leaf length was significantly and positively correlated at both levels with dry matter yield (r_g = 0.409 and r_p = 0.357), crude protein content (0.454 and 0.418) and crude protein yield (0.481 and 0.435), and at the phenotypic level only with leaf width (r_p = 0.278) and crude fibre (r_p = 0.293). These results are in agreement with Kumar *et al*. (2017) [25] and Sukanya (1998) [39], who reported positive association of leaf length with yield-related traits in Napier grass.

Leaf width (cm)

Leaf width showed significant positive correlation at both levels with dry matter yield (r_g = 0.512 and r_p = 0.468), crude protein yield (0.389 and 0.354) and acid detergent fibre (0.383 and 0.349), and at the phenotypic level only with dry matter content (r_p = 0.313) and crude fibre (r_p = 0.324). Zhang *et al*. (2009) [44] also emphasised leaf width, along with plant height and leaf : stem ratio, as an important morphological trait influencing yield in Napier grass.

Leaf: stem ratio

Leaf: stem ratio showed significant negative correlation only with oxalic acid content (r_g = -0.389 and r_p = -0.376); its correlation with all other characters was non-significant at both levels. Cheng *et al*. (1995) [9] reported a negative correlation between leaf: stem ratio and plant height and a positive correlation with crude protein, indicating a mixed pattern of association for this trait.

Dry matter content (%)

Dry matter content showed significant positive correlation at both levels with dry matter yield (r_g = 0.811 and r_p = 0.765), crude protein yield (0.571 and 0.563) and acid detergent fibre (0.499 and 0.507); its correlation with crude protein content, crude fibre, oxalic acid content and NDF was non-significant. Kumar *et al*. (2017) [25] reported positive correlation of dry matter content with green forage yield in Napier grass.

Dry matter yield (g/plant)

Dry matter yield showed significant positive correlation at both levels with crude protein content (r_g = 0.667 and r_p = 0.626), crude protein yield (0.921 and 0.912), acid detergent fibre (0.462 and 0.439) and crude fibre (0.411 and 0.391), and with NDF at the phenotypic level only (r_p = 0.297). Oxalic acid content showed negative non-significant correlation (r_g = -0.232 and r_p = -0.209). Shinde (2005) [35], Shinde *et al*. (2010) [36] and Shinde (2015) [34] consistently reported significant positive association of dry matter yield with green forage yield.

Crude protein content (%)

Crude protein content showed significant positive correlation with crude protein yield (r_g = 0.884 and r_p = 0.866) at both levels, and with crude fibre (r_p = 0.310) and NDF (r_p = 0.332) at the phenotypic level only. Its association with oxalic acid content and ADF was non-significant. Krishna and John (2007) [24] reported significant positive association of dry matter yield with crude protein content in B × N hybrids.

Crude protein yield (g/plant)

Crude protein yield was significantly and positively correlated with crude fibre (r_g = 0.362 and r_p = 0.361) at both levels, and with acid detergent fibre (r_p = 0.263) and neutral detergent fibre (r_p = 0.317) at the phenotypic level only. It showed a negative correlation with oxalic acid content (r_g = -0.273 and r_p = -0.259), significant only at the phenotypic level. Together with dry matter yield, crude protein yield showed the strongest positive correlation with green forage yield, in line with Amirthaselvarathinam and Dorairaj (1994) [3].

Crude fibre (%)

Crude fibre showed significant positive correlation at both levels with acid detergent fibre (r_g = 0.613 and r_p = 0.619) and neutral detergent fibre (0.446 and 0.457), and a non-significant positive correlation with oxalic acid content (0.135 and 0.131). Krishna and John (2007) [24] reported positive association of crude fibre with green fodder yield in B × N hybrids.

Oxalic acid content (%)

Oxalic acid content showed significant positive correlation with neutral detergent fibre (r_g = 0.384 and r_p = 0.374) and non-significant positive correlation with acid detergent fibre (0.222 and 0.217). Its association with green forage yield and with the yield-related traits was negative or non-significant, a desirable feature since oxalates are anti-nutritional in ruminant nutrition. This agrees with Krishna and John (2007) [24], who reported a non-significant negative association of oxalate content with dry matter yield.

Acid detergent fibre (%) and neutral detergent fibre (%)

Acid detergent fibre showed highly significant positive correlation with neutral detergent fibre (r_g = 0.472 and r_p = 0.482). Neutral detergent fibre was also significantly and positively correlated with green forage yield (r_g = 0.479 and r_p = 0.402). Kapoor (2017) [20] reported that NDF had a positive effect on green fodder yield in Napier grass, which supports the present findings.

Path analysis

Path coefficient analysis partitions the genotypic correlation of each component character with the dependent character into direct and indirect effects, thereby separating true cause-and-effect relationships from spurious ones (Wright, 1921) [43], (Dewey and Lu, 1959) [13]. In the present study, green forage yield per plant was treated as the dependent character, and the direct and indirect contributions of the fifteen component characters are presented in Table 4.

Table 4: Estimates of genotypic direct (diagonal, bold) and indirect effects (above and below diagonal) of component characters on green forage yield in 30 B × N hybrid genotypes

Sr. No.	Character	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	r with GFY
1	Plant height (cm)	0.088	-0.017	-0.009	0.006	-0.036	0.034	0.001	-0.188	1.026	0.016	-0.031	0.021	-0.003	-0.011	-0.011	0.884**
2	Number of tillers	0.042	-0.037	-0.004	0.008	-0.020	0.021	0.001	-0.263	0.863	0.010	-0.024	0.0004	-0.006	-0.004	-0.004	0.585**
3	Number of leaves	0.030	-0.006	-0.026	0.014	0.019	0.010	-0.002	-0.060	0.434	0.006	-0.012	0.003	-0.005	0.0002	-0.002	0.402*
4	Number of internodes	0.022	-0.013	-0.015	0.023	0.026	0.021	-0.001	-0.200	0.446	-0.003	-0.005	0.001	0.001	-0.006	-0.002	0.295
5	Leaf length (cm)	0.042	-0.009	0.006	-0.008	-0.077	0.019	0.003	-0.103	0.586	0.011	-0.021	0.011	-0.003	-0.002	-0.004	0.450*
6	Leaf width (cm)	0.046	-0.012	-0.004	0.007	-0.022	0.064	-0.001	-0.226	0.733	0.006	-0.017	0.012	-0.003	-0.010	-0.003	0.570**
7	Leaf: Stem Ratio	-0.008	0.004	-0.004	0.001	0.017	0.004	-0.014	0.066	-0.054	0.005	-0.005	-0.001	-0.012	0.001	0.002	0.002
8	Dry matter content (%)	0.025	-0.015	-0.002	0.007	-0.012	0.022	0.001	-0.661	1.162	0.004	-0.024	0.005	-0.006	-0.014	0.009	0.492**
9	Dry matter yield (g/plant)	0.063	-0.022	-0.008	0.007	-0.031	0.033	0.001	-0.536	1.432	0.016	-0.040	0.014	-0.007	-0.013	-0.006	0.902**
10	Crude protein content (%)	0.059	-0.016	-0.006	-0.003	-0.035	0.016	-0.003	-0.111	0.955	0.023	-0.038	0.011	-0.007	-0.002	-0.006	0.839**
11	Crude protein yield (g/plant)	0.064	-0.020	-0.007	0.003	-0.037	0.025	-0.002	-0.377	1.319	0.021	-0.043	0.012	-0.009	-0.007	-0.006	0.935**
12	Crude fibre (%)	0.053	-0.0004	-0.002	0.001	-0.025	0.023	0.001	-0.104	0.589	0.007	-0.016	0.034	0.004	-0.017	-0.009	0.540**
13	Oxalic acid content (%)	-0.008	0.006	0.004	0.001	0.006	-0.006	0.005	0.127	-0.333	-0.005	0.012	0.005	0.032	-0.006	-0.007	-0.167
14	Acid detergent fibre (%)	0.037	-0.005	0.000	0.005	-0.006	0.025	0.000	-0.330	0.661	0.002	-0.011	0.021	0.007	-0.027	-0.009	0.369*
15	Neutral detergent fibre (%)	0.052	-0.007	-0.003	0.003	-0.016	0.012	0.002	0.003	0.445	0.008	-0.014	0.015	0.012	-0.013	-0.019	0.479**

Residual effect (R) = 0.41. Last column: genotypic correlation (r) with green forage yield (GFY). Character numbers 1 to 15 in the column headings correspond to the serial numbers of the characters in the second column; GFY = green forage yield (g/plant).

Direct effects of component characters on green forage yield

Dry matter yield per plant exhibited by far the highest direct positive effect on green forage yield (1.432, very high), followed by plant height (0.088), leaf width (0.064), crude fibre (0.034), oxalic acid content (0.032), crude protein content (0.023) and number of internodes (0.023), which had low to negligible positive direct effects. Direct selection for dry matter yield would therefore be rewarding for improving green forage yield. On the other hand, dry matter content (-0.661) exerted the highest negative direct effect, followed by leaf length (-0.077), crude protein yield (-0.043), number of tillers (-0.037), acid detergent fibre (-0.027), number of leaves (-0.026), neutral detergent fibre (-0.019) and leaf: stem ratio (-0.014). The dominant positive direct effect of dry matter yield agrees with Shinde *et al*. (2010) [36] and Kamble (2011) [19], who also reported dry matter yield as the character with the highest positive direct effect on green forage yield in B × N hybrids.

Indirect effects of component characters on green forage yield

Plant height (cm)

Plant height exerted its highest positive indirect effect via dry matter yield (1.026), followed by leaf width (0.034) and crude fibre (0.021); its maximum negative indirect effect was via dry matter content (-0.188), followed by leaf length (-0.036). This agrees with Kumari *et al*. (2018) [26], who reported plant height and dry matter yield as important traits for selection in B × N hybrids.

Number of tillers

Number of tillers registered its highest positive indirect effect via dry matter yield (0.863), followed by plant height (0.042), and its highest negative indirect effect via dry matter content (-0.263). Katoch and Gupta (1976) [22] observed that number of tillers acts largely through its association with correlated yield traits.

Number of leaves

The highest positive indirect effect of number of leaves was through dry matter yield (0.434), followed by plant height (0.030), and the main negative indirect effect was via dry matter content (-0.060). Kamble (2011) [19] likewise reported positive association of green forage yield with dry matter yield, plant height and number of leaves.

Number of internodes

Number of internodes exerted its highest positive indirect effect via dry matter yield (0.446), and its highest negative

indirect effect through dry matter content (-0.200). Satapute (2012) [32] reported that green forage yield was significantly and positively associated with number of internodes per tiller in Napier hybrids.

Leaf length (cm)
Leaf length showed its highest positive indirect effect via dry matter yield (0.586), followed by plant height (0.042), and its maximum negative indirect effect through dry matter content (-0.103). Zhang *et al*. (2010) [45] reported that leaf length was negatively correlated with dry matter yield in elephant grass, which is consistent with the negative direct effect of leaf length observed here.

Leaf width (cm)
The highest positive indirect effect of leaf width was via dry matter yield (0.733), followed by plant height (0.046), and the highest negative indirect effect was through dry matter content (-0.226). John (2008) [17] reported that leaf width recorded the highest direct effect on green fodder yield, followed by plant height, in Napier grass.

Leaf: stem ratio
Leaf: stem ratio exerted its highest positive indirect effect via dry matter content (0.066) and its maximum negative indirect effect through dry matter yield (-0.054). Zhang *et al*. (2009) [44] reported a negative relationship between yield and leaf: stem ratio, consistent with its small negative direct effect here.

Dry matter content (%)
Dry matter content showed a very high positive indirect effect via dry matter yield (1.162) and its highest negative indirect effect through crude protein yield (-0.024). Its positive association with green forage yield, despite a large negative direct effect (-0.661), was thus mainly due to the indirect effect through dry matter yield, as Kapoor (2017) [20] also noted for dry matter yield.

Dry matter yield (g/plant)
Apart from its own direct effect, dry matter yield showed its highest positive indirect effect via plant height (0.063) and leaf width (0.033), and its highest negative indirect effect through dry matter content (-0.536). Shinde (2005) [35] and Kamble (2011) [19] concluded that dry matter yield exhibited the highest positive direct effect on green forage yield, in agreement with the present findings.

Crude protein content (%)
Crude protein content showed its highest positive indirect effect via dry matter yield (0.955), followed by plant height (0.059). Shinde *et al*. (2010) [36] reported that dry matter yield exhibited the highest positive direct effect followed by crude protein content on green forage yield.

Crude protein yield (g/plant)
Crude protein yield exerted its highest positive indirect effect via dry matter yield (1.319), followed by plant height (0.064), and its highest negative indirect effect through dry matter content (-0.377). Its positive association with green forage yield, despite a small negative direct effect (-0.043), is therefore due to its indirect effect through dry matter yield (Amirthaselvarathinam and Dorairaj, 1994) [3].

Crude fibre (%), oxalic acid content (%), acid detergent fibre (%) and neutral detergent fibre (%)
These four quality traits operated mainly through dry matter yield (indirect effects of 0.589, -0.333, 0.661 and 0.445, respectively), with dry matter content being the main negative route for crude fibre (-0.104) and acid detergent fibre (-0.330). The negative indirect effect of oxalic acid content via dry matter yield is reflected in its non-significant negative correlation with green forage yield (-0.167), a desirable feature (Krishna and John, 2007) [24]. Kapoor (2017) [20] reported a positive direct effect of NDF on green fodder yield in Napier grass, whereas in the present study NDF acted mainly through a positive indirect route via dry matter yield, its direct effect being small and negative. None of the reviewed studies reported the path of acid detergent fibre on green forage yield in B × N hybrids.

The direct effect of a character indicates how reliably selection can be practised for that character. When the correlation coefficient and the direct effect are similar in magnitude, the relationship is predominantly causal and direct selection will be effective; however, when the correlation is positive but the direct effect is negative or negligible, the indirect causal factors must be considered simultaneously. In the present study, dry matter yield showed the highest direct positive effect together with a very high and significant positive correlation with green forage yield, indicating a true relationship. Crude protein yield, dry matter content, number of tillers, number of leaves and leaf length showed significant positive correlation with green forage yield despite negative direct effects, and plant height had only a negligible direct effect (0.088) in spite of its high correlation (0.884); their association was therefore mainly due to indirect effects through dry matter yield. Hence, dry matter yield, crude protein yield, dry matter content, plant height, number of tillers, leaf width and leaf length may be considered for selection, with dry matter yield as the primary criterion. The residual effect was 0.41, indicating that the characters studied explained a major part of the variation in green forage yield, while the remaining part was due to other factors not included in the study.

Conclusion
A study of thirty Bajra × Napier hybrid genotypes for sixteen morphological, yield and biochemical characters revealed significant differences among the genotypes for all the characters. High GCV and PCV were observed for crude protein yield, number of tillers, leaf: stem ratio, dry matter yield and number of internodes, whereas crude fibre, acid detergent fibre and neutral detergent fibre recorded low GCV and PCV, indicating limited scope for selection. High heritability was recorded for all the characters, ranging from 73.06 per cent for green forage yield to 98.99 per cent for oxalic acid content. High heritability coupled with high genetic advance as per cent of mean was observed for plant height, number of tillers, number of leaves, number of internodes, leaf length, leaf width, leaf : stem ratio, dry matter content, dry matter yield, crude protein content, crude protein yield, oxalic acid content and green forage yield, suggesting predominance of additive gene action, while crude fibre, acid detergent fibre and neutral detergent fibre showed high heritability with low to moderate genetic advance, indicating the contribution of non-additive gene action. Green forage yield showed significant positive

correlation at both genotypic and phenotypic levels with dry matter yield, crude protein yield, plant height, crude protein content, number of tillers and leaf width, among others, and the genotypic correlation coefficients were in general higher than the phenotypic coefficients. Path analysis revealed that dry matter yield exhibited by far the highest direct positive effect on green forage yield, followed by plant height, leaf width, crude fibre, oxalic acid content, crude protein content and number of internodes, while dry matter content exerted the highest negative direct effect. Since dry matter yield combined a high direct effect with a strong positive correlation, direct selection for dry matter yield, along with plant height and leaf width, would be effective in identifying high-yielding Bajra × Napier hybrids.

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