Indian Journal of Agricultural Sciences **92** (10): 1190–1195, October 2022/Article
https://doi.org/10.56093/ijas.v92i10.118837

Optimization of response and sufficiency index in Bt cotton (Gossypium spp.) through optical sensor based nitrogen management

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Received: 8 December 2021; Accepted: 2 August 2022

ABSTRACT

To break the productivity barriers in Bt cotton (*Gossypium* spp.), adoption of optical sensor based nitrogen (N) management practices is the need of the hour. In light of this, a field experiment was conducted at the main Agricultural Research Station, Dharwad, Karnataka during rainy (*kharif*) season 2019 and 2020 to optimize the response index (RI) and sufficiency index (SI) for real time nitrogen management in Bt cotton through optical sensors. Experiment was conducted in split plot design with 16 treatment combinations having 2 genotypes (main plot) and 8 N management practices (subplot). Pooled data indicated that non-significant (P=0.3480) difference in seed cotton yield was observed with genotypes (First Class and Ajeet 155 recorded 3313 and 3159 kg/ha, respectively). Seed cotton yields varied significantly (P<.0001) due to different optical sensor-based N management practices. N supplementation at 1.1–1.5 RI and 81–90% SI (4460 and 4412 kg/ha, respectively) produced higher but on par yields with RDF (4386 kg/ha) with saving of 15 kg N through sensors during both the years. Interactions were found non-significant (P>.9999). Similarly, N supplementation at 1.1–1.5 RI and 81–90% SI recorded significantly (P<.0001) higher number of good and bad opened bolls, total number of bolls, sympodials, seed cotton yield per plant, boll weight, lint index and harvest index but was found on par with RDF.

Keywords: Bt cotton, Optical sensor, Real time nitrogen management, Response index (RI), Sufficiency index (SI)

Cotton (*Gossypium* spp.) the king of fibres as well as 'white gold' is having predominant position among cash crops in India and world. It is a high nutrient demanding crop especially under irrigated conditions. To obtain its high yields, the nutrients must be available. Under current negative nutrient balance condition, it is difficult to expect depleted soils to support bumper crops or yields with high growth rate, even in a superior hybrid or a genetically modified crop. In order to get higher yields and to increase nutrient use efficiency, improved technologies should be used in crop production. Real time nutrient management is one of such method which helps to increase yield with minimum hazard to soil. Optimizing soil nitrogen availability to the crop using soil tests has proven to be quite difficult. Scarf and Oliveira (2008) opined that measuring chlorophyll meter readings and NDVI (sensitive to leaf spectral properties) were far better in predicting optimal N rates than soil mineral measurements or soil rapid tests. Hence, it is proved that measuring crop spectral properties are most promising methods for optimal N rate diagnosis. Reflectance sensors allow real time measurement of crop spectral properties with nearly immediate translation into N rate decision. In cotton, threshold level based nitrogen management research work is lacking. Hence, nitrogen applications based on response and sufficiency index is the best approach for real time management of nitrogen instead of direct readings based applications.

Crop sensors based N status diagnosis is influenced by many factors other than nitrogen. Hence, nutrient rich strip is being maintained to overcome the above variability. It helps in calibration and normalization of sensor readings. This approach of response and sufficiency index based real time nitrogen application has the benefit of being self-adjusting for spatial, temporal and varietal variations as these threshold values are established with respect to N rich plot (Peterson *et al*. 1993). Considering all above facts, the present study was planned to optimize response and sufficiency index for nitrogen management in Bt cotton through optical sensors.

MATERIALS AND METHODS

The field experiment was conducted during rainy (*kharif*) seasons of 2019 and 2020 at the Main Agricultural Research Station, UAS, Dharwad, Karnataka. The soil of the experimental site was medium deep black soil, neutral to slightly alkaline in reaction (*p*H 7.65) with normal electrical conductivity (0.31 dS/m), low in organic carbon

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(0.45%) and medium in available nitrogen and P_2O_5 (278 and 34 kg/ha, respectively) and high in available K_2O (358 kg/ha). The experiment was laid out in a split-plot design with three replications. The main plot consisted of two Bt cotton genotypes (BG-II), viz. G_1: Ajeet 155 and G_2: First Class and the subplot consisted of eight different optical sensor-based nitrogen treatments i.e. N_1 to N_3: N supplementation at 60–70, 71–80 and 81–90% SI, N_4 to N_6: N supplementation at 1.1–1.5, 1.6–2.0 and 2.1–2.5 RI , N_7: RDF (150: 75: 75; N: P_2O_5: K_2O kg/ha) and N_8: N omission (0: 75: 75; N: P_2O_5: K_2O kg/ha). Two nitrogen-rich strip (200% RDF) and absolute control reference plots were maintained for respective genotypes. The SPAD (Soil plant analysis development) and GreenSeeker values were recorded at 7 days intervals from early squaring up to the mid-bloom stage preferably during 9.30–11.30 a.m.

The sufficiency index was calculated from SPAD value (Lu *et al*. 2017). If SI is more than 90%, further application of nitrogen has no yield advantage. Hence, Sufficiency Index (SI) of less than 90% up to 60% till mid-flowering was considered. Similarly, Response Index (RI) was calculated using GreenSeeker NDVI (normalized difference vegetation index) (Lu *et al*. 2017). With the assumption of a simple linear relationship between the RI and crop yield, it is possible to identify the RI classification (1.10) above which additional nitrogen application may be economically worthwhile. Hence, RI of more than 1.10 up to 2.0 till mid-flowering was considered.

$$\text{N Sufficiency Index (SI)} = \frac{\text{SPAD value of test plot}}{\text{SPAD value of N rich plot}} \times 100$$

$$\text{N Response Index (RI)} = \frac{\text{NDVI value of N rich plot}}{\text{NDVI value of test plot}} \times 100$$

Nitrogen was top-dressed at the rate of 30 kg N/ha whenever Sufficiency and Response Index values fall in the set range. 50% of nitrogen fertilizer and a full dose of phosphorous and potassium was applied at the time of sowing as basal dose in all the treatments (N_1 to N_7) except N omission (N_8). The remaining 50% N in the form of nitrogen was applied in two splits at 30 and 60 days after sowing (DAS) in the conventional practice (RDF) treatment (N_7). In the rest of the treatments (N_1 to N_6) nitrogen was applied when the decision aids indicated the readings within threshold level (Table 1).

Yield and yield parameters were calculated as per the standard procedures. The pooled data (two years) of the experiment was statistically analyzed by adopting Fischer's method of analysis of variance technique as outlined by Gomez and Gomez (1984). At 5% level of significance F-test was carried out and the critical difference (CD) values were calculated wherever F-test is significant. The mean value of main plot, sub plot and interactions were separately subjected to Duncan Multiple Range Test (DMRT) using the corresponding error mean sum of squares and degrees of freedom. Statistical analysis, Karl Pearson's correlation heat maps and graphs were plotted using R-Software.

RESULTS AND DISCUSSION

Yield parameters: Pooled data (Table 2) indicated that genotypes did not show significant difference for yield parameters i.e. number of good opened bolls, bad opened bolls, total number of bolls, number of sympodials, seed cotton yield per plant and boll weight. This might be due to genotypes having similar yield potential and duration. Numerically higher number of good opened bolls (GOB), bad opened bolls (BOB), total number of bolls, number of sympodials, seed cotton yield per plant and boll weight was recorded with First Class as compared to Ajeet 155. These results are in conformity with findings of Kalaichelvi (2009) and Gowramma (2017).

Different optical sensor based N management practices significantly (P<.0001) influenced yield parameters. N supplementation at 1.1–1.5 RI, 81–90% SI and RDF were

Table 1 Scheduling of nitrogen application through RI, SI and conventional approaches

Treatment	Basal dose		Real time/conventional nitrogen application				Total N (kg/ha)	
	2019	2020	2019		2020		2019	2020
			1st	2nd	1st	2nd		
N_1	75	75	-	-	-	-	75	75
N_2	75	75	-	30 (70 DAS)	-	30(61 DAS)	105	105
N_3	75	75	30 (55 DAS)	30 (70 DAS)	30 (41 DAS)	30 (61 DAS)	135	135
N_4	75	75	30 (55 DAS)	30 (70 DAS)	30 (41 DAS)	30 (53 DAS)	135	135
N_5	75	75	-	-	-	-	75	75
N_6	75	75	-	-	-	-	75	75
N_7	75	75	37.5 (30 DAS)	37.5 (60DAS)	37.5 (30 DAS)	37.5 (60 DAS)	150	150
N_8	0	0	-	-	-	-	0	0
Reference plots								
N rich	150	150	75	75	75	75	300	300
Absolute control	0	0	-	-	-	-	0	0

Treatment details are given in Materials and Methods.

comparable and recorded significantly higher number of GOB, BOB, total number of bolls, number of sympodials, seed cotton yield per plant and boll weight over all other treatments during both the years. Increase in the number of GOB and total number of bolls could be attributed to the fact that nitrogen is an important nutrient for new growth and preventing abscission of squares and bolls (Borowski 2001). Results obtained are at parity with Saranga *et al*. (1998) who reported higher and at par number of bolls/m^2 in reflectance based (60 kg N/ha) and blanket N recommendations (150 kg N/ha). Increased sympodial numbers per plant with increased N application was in line with the results obtained by Hallikeri (2008) and Sunitha *et al*. (2010). Increased seed cotton yield per plant might be due to increased total number of bolls per plant, mean boll weight, higher number of GOB and lower BOB per plant. Similar response of increased yield per plant was reported by Buttar *et al*. (2010) and Hallikeri *et al*. (2010). Boll weight increased to 6.86 g in RDF and 6.90 g in 81–90% SI and further increased to 6.93 g in N supplementation at 1.1–1.5% RI. Increased boll weight may be associated with more mineral uptake and photosynthetic rate resulting in more dry matter accumulation in the real time N supplementation and RDF treatments.

Among interactions, First Class and Ajeet 155 with N supplementation at 1.1–1.5 RI, 81–90% SI and RDF followed same trend with respect to yield parameters. The variation in yield parameters might be due to the diverse genetic potential of these genotypes and its response to sensor based nitrogen management practices. Increased nitrogen nutrition up to mid flowering stage as and when the crop was in need with higher genetic potential of the genotypes led to higher uptake of nitrogen and its efficient utilization by crop resulting in better vegetative growth and dry matter accumulation in source, which in turn translocated to sink. Similarly in RDF, 15 kg more nitrogen was added as compared to sensor based N management practices resulting in higher yield parameters. Results obtained are in line with the findings of Ramanjit *et al*. (2015).

Seed cotton yield, lint index and harvest index: Seed cotton yield (Table 3) (Fig 1) did not vary significantly with genotypes (First Class and Ajeet 155 recorded 3313 and 3159 kg/ha, respectively). This is mainly due to genotypes having similar yield potential and duration.

Seed cotton yields varied significantly due to optical sensor-based N management practices. N supplementation at 1.1–1.5 RI and 81–90% SI (4460 and 4412 kg/ha, respectively) produced higher but similar yields with RDF (4386 kg/ha) with saving of 15 kg N through sensors during both the years. Chaua *et al*. (2003) obtained similar yields with soil test based N application (134 kg/ha N) and in-season N management (101 kg N/ha). Significantly lower seed cotton yield was achieved with N omission (1527 kg/ha). Higher yields obtained through optical sensor-based practices were mainly due to synchronized N demand with supply of nitrogen to cotton crop on real time basis. In cotton, peak nutrient demand and uptake is during pinhead square stage (45 DAS) and early flowering (60 DAS) to mid bloom stage (90 DAS) and the sensor-based treatments received nitrogen during these stages. Improved N uptake, photosynthetic rate and enhanced biomass aggregation were observed under these treatments. In RDF, top dressing was done at fixed growth stages i.e. early squaring (30 DAS) and early flowering stage (60 DAS). When moisture was not a constraint, nitrogen supply coincided with the crop demand increasing the absorption of nitrogen throughout the growing period. This accelerated photosynthetic rate led to higher production of carbohydrate reserves. Hence, the crop might have put forth its full potential in terms of economic yield. These results are in conformity with Ramanjit *et al*. (2015) who reported saving of 20–25 kg N/ha as compared to RDN in Bt cotton using SPAD meter ≤ 35 and GreenSeeker (NDVI value 0.67) for real time nitrogen management.

The interaction of genotypes and different optical sensor-based N management practices had a significant influence on seed cotton yield. N supplementation at 1.1–1.5 RI, 81–90% SI and RDF with First Class (4536, 4483 and 4457 kg/ha, respectively) and Ajeet 155 (4383, 4341 and 4315 kg/ha, respectively) produced comparable yields which were significantly superior over rest of the treatment combinations. Whereas, N omission of both the genotypes recorded significantly lowest yields (3312 and 3159 kg/ha with First class and Ajeet 155, respectively). These results are in conformity with Pyati (2016) and Goudra *et al*. (2019). The higher seed cotton yield of these treatment combinations were due to higher yield attributing characters. Similar trend was followed for lint index.

Significantly higher lint index and numerically higher harvest index was recorded with N supplementation at 1.1–1.5 RI (5.95% and 0.40) and 81–90% SI (5.72% and 0.40) and RDF (5.65% and 0.40) over N omission (4.71% and 0.35). Increased lint and harvest index was due to higher proportion of seed cotton yield to biological yield which was in turn due to enhanced photosynthetic activity since N is the essential component of chlorophyll (Bondada and Oosterhuis 2000).

Conversely, seed cotton yields were significantly lower in N omission of both the genotypes and comparatively lower with rest of the treatment combinations. This might be due to non-supply of nitrogen in N omission treatment combinations which severely affected the cell division, cell elongation and protein synthesis hindering the growth and yield parameters. This was evidenced in terms of reduced efficiency of converting dry matter into economic yield i.e. harvest index and yield parameters like number of GOB (30.38), total number of bolls (31.65), seed cotton yield per plant (80.49 g/plant), boll weight (4.09), lint index (4.71) and harvest index (0.35).

Yield reduction was also associated with early flowering and maturity. In rest of the treatments, the yield reduction was mainly due to supply of nitrogen beyond the critical stage of nutrient requirement. Higher levels of Response Index (>1.5) and lower level of Sufficiency Index (<80%) caused economic yield loss since, those readings were

Table 2 Effect of optical sensor-based nitrogen management practices on yield parameters of Bt cotton

	GOB/plant			BOB/plant			Total number of bolls/plant			Sympodials			Seed cotton yield/plant			Boll weight (g)		
	G_1	G_2	Mean	G_1	G_2	Mean	G_1	G_2	Mean	G_1	G_2	Mean	G_1	G_2	Mean	G_1	G_2	Mean
N_1	37.76^{d}	39.25^{bcd}	38.51^{c}	1.43^{b}	1.63^{b}	1.53^{b}	39.20^{d}	40.88^{cd}	40.04^{c}	17.17^{d}	18.78^{cd}	17.97^{b}	136.03^{b}	143.85^{b}	139.94^{b}	5.07^{c}	5.13^{c}	5.10^{b}
N_2	41.77^{bc}	42.87^{b}	42.32^{b}	1.5^{b}	1.67^{b}	1.59^{b}	43.27^{bc}	44.54^{b}	43.90^{b}	19.77^{cd}	21.93^{bc}	20.85^{b}	160.58^{b}	168.34^{b}	164.46^{b}	5.25^{c}	5.32^{bc}	5.28^{b}
N_3	58.97^{a}	60.01^{a}	59.49^{a}	3.13^{a}	3.37^{a}	3.25^{a}	62.10^{a}	63.37^{a}	62.74^{a}	24.13^{ab}	25.87^{a}	25.00^{a}	233.01^{a}	243.25^{a}	238.13^{a}	5.86^{ab}	5.93^{ab}	5.89^{a}
N_4	59.12^{a}	60.58^{a}	59.85^{a}	3.07^{a}	3.33^{a}	3.20^{a}	62.18^{a}	63.91^{a}	63.05^{a}	25.23^{ab}	26.40^{a}	25.82^{a}	236.39^{a}	248.25^{a}	242.32^{a}	5.90^{ab}	5.97^{a}	5.93^{a}
N_5	37.85^{cd}	39.12^{bcd}	38.48^{c}	1.47^{b}	1.60^{b}	1.53^{b}	39.32^{d}	40.72^{cd}	40.02^{c}	17.14^{d}	19.23^{cd}	18.19^{b}	136.39^{b}	145.42^{b}	140.90^{b}	5.06^{c}	5.15^{c}	5.10^{b}
N_6	37.90^{cd}	39.09^{bcd}	38.49^{c}	1.55^{b}	1.65^{b}	1.60^{b}	39.45^{d}	40.74^{cd}	40.09^{c}	17.12^{d}	19.17^{cd}	18.14^{b}	135.74^{b}	144.25^{b}	139.99^{b}	5.04^{c}	5.15^{c}	5.09^{b}
N_7	58.97^{a}	59.86^{a}	59.41^{a}	3.20^{a}	3.43^{a}	3.32^{a}	62.17^{a}	63.29^{a}	62.73^{a}	24.07^{ab}	25.77^{a}	24.92^{a}	229.73^{a}	240.79^{a}	235.26^{a}	5.83^{ab}	5.89^{ab}	5.86^{a}
N_8	29.77^{e}	31.00^{e}	30.38^{d}	1.17^{b}	1.37^{b}	1.27^{b}	30.94^{e}	32.36^{e}	31.65^{d}	10.73^{e}	11.67^{e}	11.20^{c}	77.33^{c}	83.64^{c}	80.49^{c}	4.05^{d}	4.13^{d}	4.09^{c}
Mean	45.26^{a}	46.47^{a}		2.07^{a}	2.26^{a}		47.33^{a}	48.73^{a}		19.42^{a}	21.10^{a}		168.15c	177.23		5.25^{a}	5.33^{a}	
*N Rich	46.08	47.06	46.57	6.16	7.20	6.68	42.24	44.26	43.25	29.65	31.70	30.68	245.50	254.68	250.09	5.98	6.04	6.01
*Control	13.84	14.25	14.04	1.11	1.13	1.12	14.95	15.38	15.16	9.94	10.70	10.32	66.76	69.92	68.34	4.00	4.04	4.02
SV	S.Em.±		P value	S.Em.±		P value	S.Em.±		P value	S.Em.±		P value	S.Em.±		P value	S.Em.±		P value
G	0.415		0.1759	0.125		0.3685	0.303		0.0824	0.604		0.1882	4.855		0.2956	0.073		0.5338
N	0.854		0.0000	0.204		0.0001	0.828		0.0000	0.765		0.0000	11.236		0.0000	0.134		0.0000
G×N	1.174		1.0000	0.333		0.9999	0.857		1.0000	1.710		0.9988	13.733		1.0000	0.206		1.0000

*Reference plots-not included in statistical analysis; Means followed by the same letter (s) within a column and row are not different significantly by DMRT (P=0.05); SV, Source of Variation; G, Genotype; N, Nitrogen. Treatment details are given in Materials and Methods.

Table 3 Effect of optical sensor-based nitrogen management practices on seed cotton yield, lint index and harvest index of Bt cotton

Treatment	Seed cotton yield (kg/ha)			Lint index (%)			Harvest index		
	G_1	G_2	Mean	G_1	G_2	Mean	G_1	G_2	Mean
N_1	2574^b	2747^b	2660^b	5.23^c	5.20^c	5.22^c	0.38^a	0.39^a	0.38^a
N_2	3050^b	3198^b	3124^b	5.44^{bc}	5.47^{bc}	5.46^{bc}	0.39^a	0.40^a	0.39^a
N_3	4341^a	4483^a	4412^a	5.70^{ab}	5.74^{ab}	5.72^{ab}	0.40^a	0.41^a	0.40^a
N_4	4383^a	4536^a	4460^a	5.97^a	5.93^a	5.95^a	0.40^a	0.40^a	0.40^a
N_5	2577^b	2745^b	2661^b	5.20^c	5.19^c	5.19^c	0.38^a	0.39^a	0.38^a
N_6	2574^b	2743^b	2658^b	5.25^c	5.25^c	5.25^c	0.38^a	0.39^a	0.38^a
N_7	4315^a	4457^a	4386^a	5.59^{abc}	5.71^{ab}	5.65^{ab}	0.40^a	0.40^a	0.40^a
N_8	1466^c	1587^c	1527^c	4.71^d	4.71^d	4.71^d	0.35^a	0.36^a	0.35^a
Mean	3159^a	3312^a		5.39^a	5.40^a		0.38^a	0.39^a	
*N Rich	4546	4716	4631	5.94	6.00	5.97	0.41	0.42	0.41
*Control	1246	1295	1270	4.65	4.70	4.67	0.35	0.35	0.35
SV	S.Em.±		P value	S.Em.±		P value	S.Em.±		P value
G	94.53		0.3480	0.015		0.5805	0.007		0.5742
N	143.18		0.0000	0.087		0.0001	0.010		0.0359
G×N	267.38		1.0000	0.043		0.9989	0.019		0.9999

*Reference plots - not included in statistical analysis; Means followed by the same letter (s) within a column and row are not different significantly by DMRT (P=0.05); SV, Source of Variation; G, Genotype; N, Nitrogen. Treatment details are given in Materials and Methods.

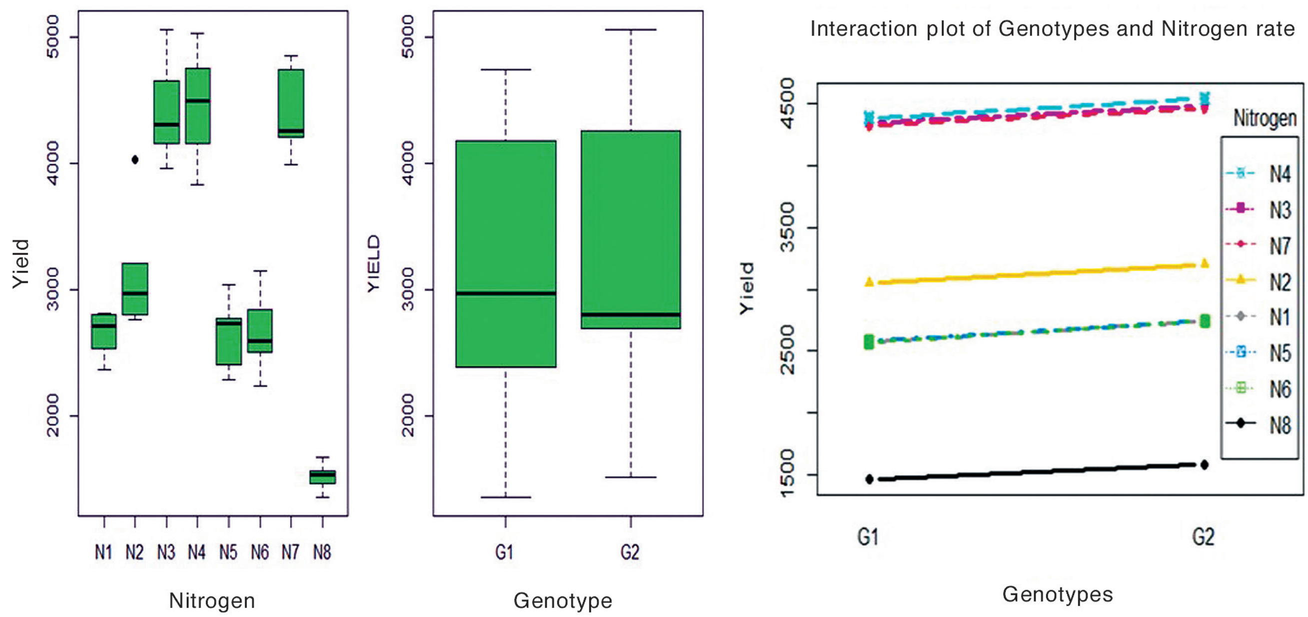

Fig 1 Effect of optical sensor based nitrogen management practices on seed cotton yield (kg/ha) of Bt cotton.

not attained and plants were showing severe symptoms of nitrogen stress. However, these treatments have taken only one split dose (55 and 53 DAS during first and second year, respectively) which was 30 kg less N than RDF and 15 kg less nitrogen than superior treatments of optical sensor based N treatments.

Correlation among yield and selected yield parameters: The correlation heat map indicates that the association between yield and yield parameters was linear and positive (Fig 2). Very strong positive correlation was observed between yield v/s GOB (0.99), total number of bolls (0.99), number of sympodials (0.98), seed cotton yield per plant (0.98), boll weight (0.98), lint index (0.96) and harvest index (0.90).

It could be concluded that, Response index of 1.1–1.5 and Sufficiency index of 81–90% proved to be useful tools for real time nitrogen management in cotton and achieved significantly higher seed cotton yields, with the saving of 15 kg N/ha (10% of recommended dose of nitrogen) than conventional practices.

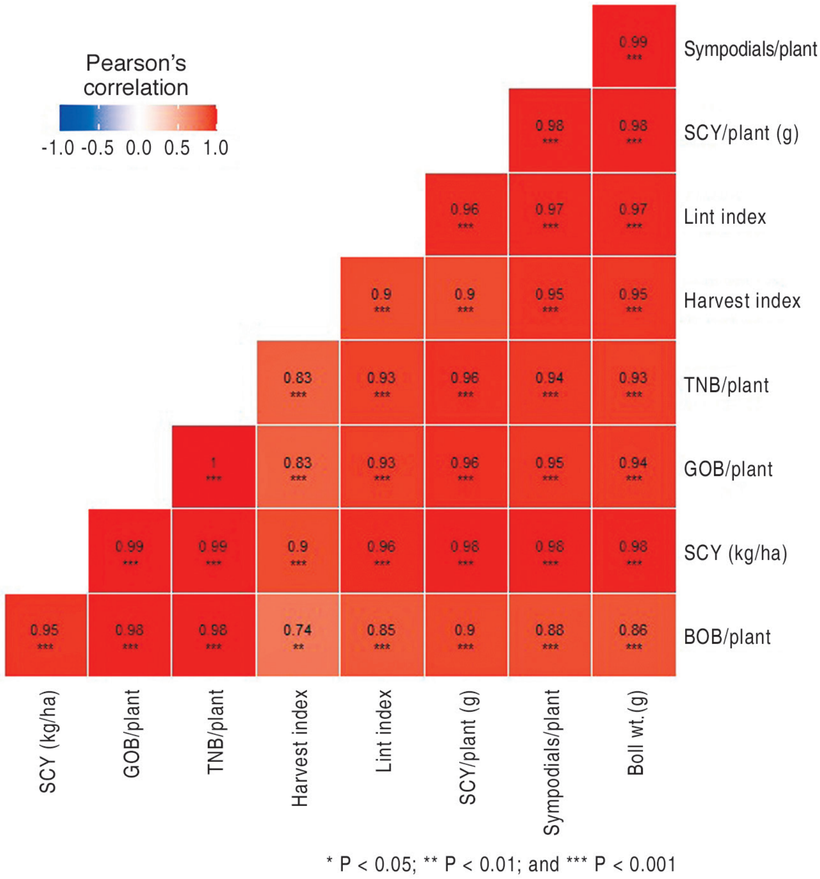

Fig 2 Heat map showing correlation of yield and yield parameters.

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