EVALUATION OF BLACKGRAM GENOTYPES UNDER PUDDLED TILLAGE: IMPACTS ON YIELD, SOIL FERTILITY, AGROMETEOROLOGICAL INDICES, AND ECONOMIC VIABILITY

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Abstract

An experiment was performed to evaluate the response of blackgram genotypes under puddled tillage, focusing on yield, post-harvest soil available nutrients, agrometeorological indices, and the economics of blackgram. The experiment was implemented in RBD includes seven genotypes, replicated three times. Among the yield attributes, genotype VBN 11 recorded the highest test weight, while ADT 7 exhibited the highest number of pods plant^{-1}, seeds pod^{-1}, seed yield, and haulm yield. Regarding nutrient uptake, ADT 7 also showed the highest assimilation of NPK. In terms of post-harvest soil status, the N and K levels were non-significant among genotypes but increased compared to the initial soil status. In contrast, phosphorus (P) showed significant differences, with the highest value recorded in genotype VBN 8, though it decreased compared to the initial soil status. For agro-meteorological indices, genotypes ADT 7 and VBN 11 displayed higher values for growing degree days (GDD), photothermal units (PTU), helio-thermal units (HTU), and heat use efficiency (HUE) compared to other genotypes. In terms of economics, the genotype ADT 7 (T3) recorded the highest gross income, net income, and a benefit-cost ratio (BCR) of 2.83. Based on the results of this study, genotypes ADT 7 and VBN 11 demonstrated superior performance in yield attributes, yield, agrometeorological indices, and economics of blackgram under puddled tillage during the relay pulse season in Tamil Nadu.

Keywords: Genotypes, Yield, Nutrient uptake, Agrometeorological, Economics

Introduction

India's population relies on pulses as their primary protein source. They form a crucial part of the balanced diet (Jukanti et al., 2012) and contain 20-25% protein on a dry seed basis roughly 2.5-3 times the protein content of cereals. This makes pulses an important part of the diet, especially in underdeveloped nations where they are known as "poor man's meat" due to their low cost compared to meat. Additionally, pulses play a key role in various cropping systems because of their short duration and ability to improve soil health through nitrogen fixation, which reduces the need for chemical fertilizers.

Black gram (Vigna mungo (L.) Hepper) ranks as the third most produced pulse in India, contributing 10% of the total production from 13% of the cultivated area. Across India, pulses are cultivated on 7.91 lakh hectares, resulting in a total yield of 5.03 lakh tons, with an average productivity of 636 kg per hectare. In Tamil Nadu, black gram is cultivated over 3.97 lakh hectares, producing 2.68 lakh tons and achieving a productivity rate of 675 kg ha^{-1} (DES, 2023).

However, the black gram productivity is low due to several factors. It is often grown on marginal and sub-marginal lands, suffers from poor farming practices, and lacks appropriate varieties for different seasons and agro-climatic conditions (Reddy et al., 2020). The absence of suitable genotypes that can adapt to environmental conditions, such as unsuitable soil and water deficit, also hampers production. Therefore, increasing the productivity and production of black gram is of urgent importance. Black gram's adaptability to diverse environments suggests that efforts should be made to expand its cultivation into new niches (Patidar and Singh, 2018).

Enhancing pulse production is a national priority. Expanding pulse cultivation into non-traditional areas, non-traditional seasons, and under non-traditional growing conditions are major avenues for increasing the area under cultivation (Kumar et al., 2015). Traditional approaches to increasing pulse production involve utilizing enhanced genotypes, adopting advanced production techniques, and implementing effective pest control methods. These strategies aim to close the gap between current production levels and market demand.

Phenotypically stable genotypes are especially important because environmental conditions can vary significantly from year to year and season to season. Consistent seed yield performance across different environments is essential for effective cultivar production (Yousaf and Sarwar, 2008). Improved varieties of pulses have the potential to increase productivity by 20-25% (Ali and Gupta, 2012).

The Cauvery Delta region in Tamil Nadu, covering 1.45 million hectares (11% of the state's total land area; Subrahmaniyan et al., 2023), is where relay-sown black gram is practiced as a winter (Jan–Feb) pulse following the immediate harvest of the rice crop. However, delays in water availability in the Cauvery canals lead to late planting of rabi rice, which is typically a medium- or long-duration variety. These delays create unfavorable conditions for the relay black gram crop. To address these challenges, this study evaluates the performance of black gram genotypes under puddled tillage, which facilitates immediate sowing after rice harvest. The study focuses on the crop's yield, post-harvest soil nutrient levels, agrometeorological indices, and economics.

Materials and methods:

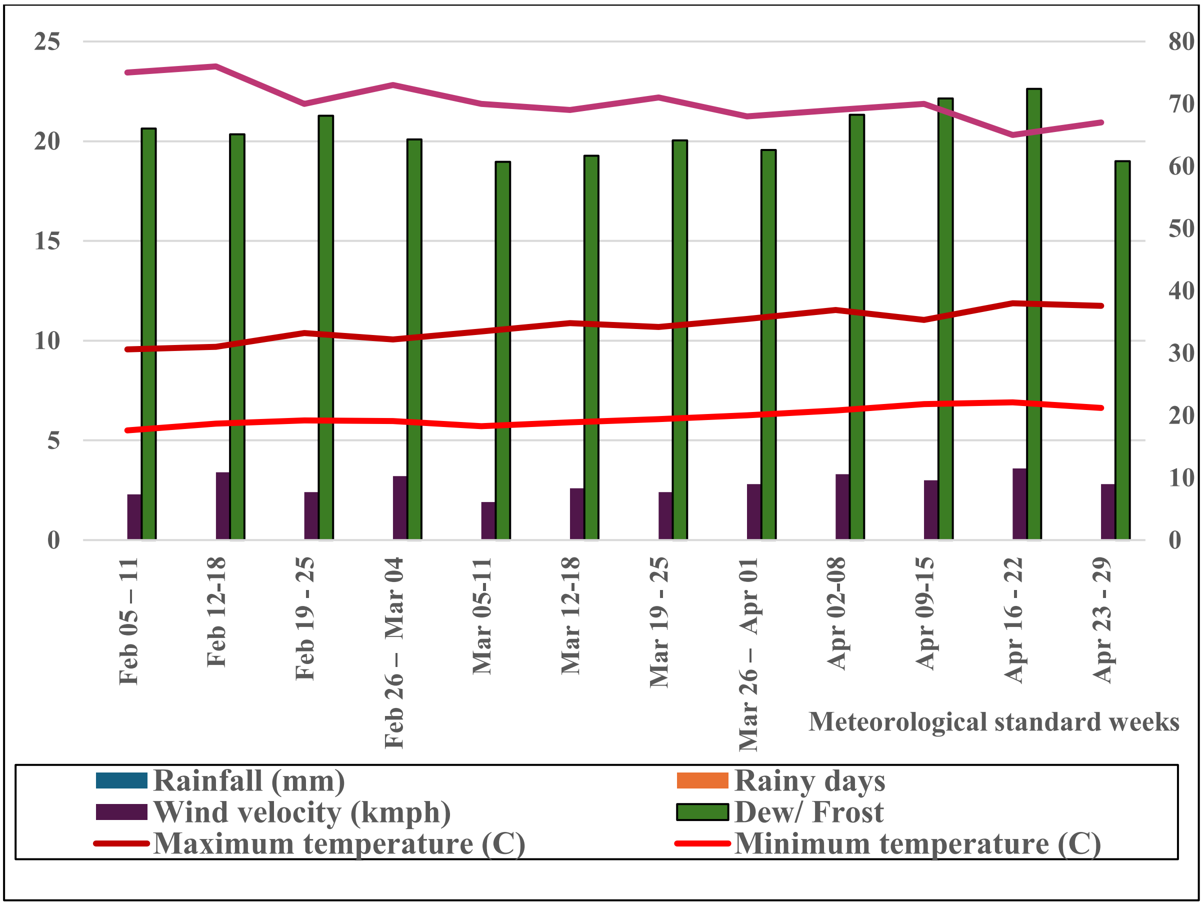

Fig 1. Weather prevailed during the crop growth period

At Annamalai University Experimental Farm, Department of Agronomy, a field experiment was carried out using seven genotypes: T1 - ADT 3, T2 - ADT 5, T3 - ADT 7, T4 - VBN 3, T5 - VBN 8, T6 - VBN 11, and T7 - LBG 932, with three replications. Annamalainagar's climate is categorized as tropical wet and dry (Köppen climate classification: Aw), situated 6 kilometers from the Bay of Bengal coastline. At the experimental farm, the average maximum and minimum temperatures were 33.04°C and 21.06°C, respectively, with an annual average rainfall of 1500 mm. Throughout the crop-growing season, there was a total of 46 mm of rainfall over 8 rainy days. The maximum temperature fluctuated between 30.06°C and 39.05°C, while the minimum temperature varied from 17.06°C to 23.09°C. Wind speeds ranged from 1.9 km/h to 4.06 km/h, averaging 3.04 km/h, and relative humidity levels were between 61% and 78%. Weekly weather data during the cropping season are illustrated in Fig. 1.

Composite soil samples taken at a depth of 15 cm prior to sowing were used to analyze the experimental field's soil. The texture of the soil was determined to be clayey loam. The available potassium was high, the available phosphorus was medium, and the available nitrogen was low in the fertility condition. Table 1 lists the chemical characteristics (original soil status) of the experimental field.

Table 1. Mechanical and chemical characteristics of soil of the experimental field

S. No.	Chemical analysis (Initial soil status)			
	Characters	**Value**	**Method**	**Reference**
1.	Soil pH (1:2 of soil : water)	7.23	Glass electrode method	Jackson (1973)
2.	Electrical conductivity (dS m^{-1}) (1:2.5 of soil : water)	0.4	Conductivity bridge	Jackson (1973)
3.	Organic carbon (%)	0.47	Chromic acid wet digestion method	Walkley and Black (1934)
4.	Available N (kg ha^{-1})	179.28	Alkaline permanganate method	Subbiah and Asija (1956)

5.	Available P (kg ha^{-1})	18.04	Colorimetric method	Olsen *et al.* (1954)
6.	Available K (kg ha^{-1})	264.31	Flame photometric method	Stanford and English (1949)

In the relay-sown season, the field was puddled, black gram seeds were broad casted and one supplemental irrigation was provided at 30 DAS. Yield characteristics, including the number of pods per plant, the number of seeds per pod, and test weight, were recorded from five sample plants, with mean values calculated for each experimental plot. Seed yield was assessed at 14% moisture content and reported in kg ha^{-1}. The sun-dried haulm yield from each plot was also measured and expressed in kg ha^{-1}. The ratio of seed yield to total dry matter production per plant was calculated. The formula used to compute the harvest index for different treatments is provided in Equation (1):

$$\text{Harvest index (HI)} = \frac{Economic\ yield}{Biological\ yield} \times 100 \qquad (1)$$

Soil samples were taken from each plot after harvest, air-dried in a shaded area, passed through a 2 mm sieve, and analyzed for nitrogen (N), phosphorus (P), and potassium (K). Plant samples from the different treatments were collected at 30 and 60 days after sowing (DAS) and at harvest to assess dry matter and nutrient uptake. These samples were dried in an oven, finely ground using a Wiley mill, and analyzed for their N, P, and K content. The nutrient concentrations were multiplied by the corresponding dry matter yields, and the absorption values for N, P, and K were calculated using the formula specified in Equation (2).

$$\text{Nutrient uptake (kg ha}^{-1}) = \frac{\text{\% of nutrient content} \times \text{Total dry matter production kg ha}^{-1}}{100} \qquad \textbf{(2)}$$

GDD also known as accumulated degree days (ADD), are the arithmetic accumulation of daily mean temperatures above a predetermined threshold. In this study, GDD was calculated using Iwata's (1984) formula found in Equation (3), with a base temperature of 10°C. PTU were calculated for different growth stages using the formula as given in Equation (4):

$$\text{Growing degree days} = \frac{\text{Maximum + Minimum temp (°C)}}{2} - \text{base temp (10°C)} \quad (3)$$

$$\text{PTU} = \text{Growing Degree Days} \times \text{Mean day Length (N)} \quad (4)$$

HTU at various crop stages were calculated using the formula provided in Equation (5):

$$\text{HTU} = \text{Growing Degree Days} \times \text{Number of Bright Sunshine Hours} \quad (5)$$

Heat unit effectiveness (HUE) reflects the total heat needed for a crop to attain a certain growth stage and is important for assessing both grain yield and dry matter. HUE was determined using the formula outlined in Equation (6):

$$\text{HUE} = \frac{\text{Grain Yield (kg ha}^{-1}\text{)}}{\text{Accumulated heat Units (°C)}} \quad (6)$$

The economics of the experiment were evaluated based on gross and net returns for all treatments. The cost of inputs, labor charges, and the prevailing market price of the products were considered. Benefit-cost ratio (BCR) analysis was performed for all treatments using the following formula as given in Equations (7)-(9):

Gross return (Rs. ha^{-1}) = Yield (kg ha^{-1}) × market value of the product (Rs. kg^{-1}) (7)

Net return (Rs. ha^{-1}) =Gross return (Rs. ha^{-1}) – Cost of cultivation (Rs. ha^{-1}) (8)

Benefit Cost ratio (BCR) = $\frac{Gross\ return\ (Rs.\ ha^{-1})}{Cost\ of\ cultivation\ (Rs.\ ha^{-1})}$ (9)

The biometric observations, analytical data from soil and plant samples, and calculated data were statistically analyzed in accordance with the Gomez and Gomez (1984) approach. Where treatment differences were shown to be significant using the F-test, crucial differences at the 5% probability level were calculated, and the results are presented in the tables.

Results and Discussion

The number of pods plant^{-1}, seeds pod^{-1}, and test weight differed significantly among the genotypes (Table 2). Genotype ADT 7 recorded the highest number of pods plant^{-1} (15.79) and seeds pod^{-1} (7.00), followed by VBN 11. The lowest values were observed in ADT 5 (T2). In terms of test weight, VBN 11 (4.03 g) had the highest value, closely followed by LBG 932 (4.01 g), while ADT 5 recorded the lowest test weight at 3.32 g. All yield parameters number of pods plant^{-1}, seeds pod^{-1}, and test weight were influenced by environmental factors, which affected the genotypes' expression. Similarity have been reported by Ahmed et al. (2020), Babbar and Tiwari (2018), and Dhillon *et al.* (2024). These traits are considered reliable indicators of higher yield potential (Singh *et al.,* 2012).

Table 2. Performance of blackgram genotypes on seeds pod^{-1}, Number of pods plant^{-1} and test weight (g)

Genotypes	Number of pods Plant^{-1}	Seeds pod^{-1}	Test weight (g)
T_1 - ADT 3	11.32	5.76	3.38
T_2 - ADT 5	10.04	5.32	3.32
T_3 - ADT 7	15.79	7.00	3.93
T_4 - VBN 3	13.14	6.12	3.35
T5 - VBN 8	11.87	5.89	3.69
T6 - VBN 11	14.32	6.93	4.03
T7 - LBG 932	13.39	5.78	4.01
S.Ed	**0.13**	**0.07**	**0.04**
CD (0.05)	**0.28**	**0.15**	**0.09**

Significant differences were observed in seed and stover yields among the blackgram genotypes. The genotype ADT 7 achieved the highest yields, recorded 977 kg ha^{-1} for seeds and 2309 kg ha^{-1} for stover. This was closely followed by VBN 11, with a seed yield of 952 kg ha^{-1} and stover yield of 2287 kg ha^{-1}. The lowest yields were observed in ADT 5, with a seed yield of 704 kg ha^{-1} and stover yield of 1992 kg ha^{-1}. In terms of harvest index, genotype VBN 8 exhibited the highest value (42.32), closely followed by ADT 7 (42.30) and VBN 11 (41.64), indicating that these genotypes are the

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most efficient in producing seeds relative to their total biomass. The lowest harvest index was recorded in ADT 5 (Table 3). These variable yields indicate genetic diversity among the genotypes, showing different responses to environmental conditions. Similar results have been observed by Bhowaland and Bhowmik (2014), Abbas *et al.* (2019), Majid *et al.* (2017), Sozen and Karadavut (2017), and Pavithra *et al.* (2024). Genotypes with longer growing durations typically show higher yields (Patra *et al.,* 2001; Rathore *et al.,* 2010). The improvement in yield can be attributed to better utilization of resources and the genetic makeup of the genotypes (Singh *et al.,* 2013a).

Table 3. Performance of blackgram genotypes on seed yield, haulm yield and harvest index

Genotypes	Grain yield (Kg ha^{-1})	Haulm yield (Kg ha^{-1})	Harvest Index
T_1 - ADT 3	824	2103	39.16
T_2 - ADT 5	704	1992	35.33
T_3 - ADT 7	977	2309	42.30
T_4 - VBN 3	814	2101	38.73
T5 - VBN 8	904	2135	42.32
T6 - VBN 11	952	2287	41.64
T7 - LBG 932	848	2138	39.67
S.Ed	**9.66**	**24.36**	**0.46**
CD (0.05)	**21.05**	**53.08**	**1.00**

Nutrient uptake across the seven blackgram genotypes revealed variations in nitrogen (N), phosphorus (P), and potassium (K) absorption. ADT 7 exhibited the highest nitrogen uptake at 49.16 kg ha^{-1}, while ADT 5 had the lowest at 33.56 kg ha^{-1}. For phosphorus uptake, ADT 7 also led with 6.07 kg ha^{-1}, compared to the lowest value recorded for ADT 5 at 3.13 kg ha^{-1}. Regarding potassium uptake, ADT 7 again showed the highest level at 19.38 kg ha^{-1}, with ADT 5 having the lowest at 14.54 kg ha^{-1} (Table 4). High-yielding genotypes generally exhibit higher nutrient uptake, consistent with findings by Kaleeswari et al. (2022). Inherent genetic variations among genotypes affect their ability to absorb and utilize nutrients (Pani et al., 2024). Adverse environmental conditions can reduce nutrient uptake, as observed by Vennila et al. (2023). Genotypes that are more tolerant to biotic and abiotic stresses tend to maintain better nutrient uptake under unfavorable conditions (Yadav et al., 2024; Lone et al., 2024; Bela, 2023).

Table 4. Performance of blackgram genotypes on N, P and K uptake

Genotypes	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})
T_1 - ADT 3	40.27	4.28	16.36
T_2 - ADT 5	33.56	3.13	14.54
T_3 - ADT 7	49.16	6.07	19.38
T_4 - VBN 3	40.11	4.26	16.80
T5 - VBN 8	42.30	5.02	17.19
T6 - VBN 11	48.47	5.99	19.10
T7 - LBG 932	41.57	4.94	16.89
S.Ed	**0.46**	**0.05**	**0.19**
CD (0.05)	**1.01**	**0.11**	**0.42**

Post-harvest soil nutrient analysis revealed non-significant differences in nitrogen (N) and potassium (K) but notable variations in phosphorus (P) content (Table 5). Similar studies were conducted by Marimuthu et al. (2024), Meena and Ram (2016), Kumari et al. (2020), Srinivasulu et al. (2020), and Patel (2018). Genotype ADT 7 demonstrated the highest nitrogen content at 182.76 kg ha^{-1} but had the lowest phosphorus level of 16.42 kg ha^{-1}. In contrast, VBN 8 had the highest phosphorus content at 17.87 kg ha^{-1}, with a relatively high nitrogen level of 181.98 kg ha^{-1}. VBN 11 also exhibited a high nitrogen level (182.34 kg ha^{-1}) but the lowest phosphorus content (16.18 kg ha^{-1}). Potassium levels were fairly consistent across the genotypes, ranging from 264.85 kg ha^{-1} to 266.74 kg ha^{-1}. Post-harvest soil nutrient analysis showed no significant variations in nitrogen and potassium, but differences in phosphorus were observed. Compared to the initial soil status, there was an improvement in nitrogen and potassium levels. However, phosphorus levels decreased, likely due to the activity of phosphorus-solubilizing bacteria (PSB) in the nodules of blackgram, which convert inorganic phosphorus to organic forms, leading to higher uptake by the crop (Dinic et al., 2014; Marra et al., 2011).

Table 5. Performance of blackgram genotypes on post harvest soil nutrient status

Genotypes	N (Kg ha^{-1})	P_2O_5 (Kg ha^{-1})	K_2O (Kg ha^{-1})
T_1 - ADT 3	181.17	17.21	265.32
T_2 - ADT 5	179.93	17.03	264.85
T_3 - ADT 7	182.76	16.42	266.74
T_4 - VBN 3	180.85	17.11	265.01
T5 - VBN 8	181.98	17.87	265.93
T6 - VBN 11	182.34	16.18	266.17
T7 - LBG 932	181.62	17.65	265.78
S.Ed	**2.10**	**0.20**	**3.08**
CD (0.05)	**NS**	**0.44**	**NS**

Growing degree days (GDD) for different blackgram genotypes showed variability in the accumulation of heat units required for growth, reflecting differences in their developmental rates (Table 6). Genotypes ADT 7 and VBN 11 had the highest GDD values of 1290.7°C, indicating that these genotypes require more accumulated heat to reach developmental stages, suggesting potentially longer growth periods. Genotypes ADT 3, VBN 3, VBN 8, and LBG 932 had identical GDD values of 1191.55°C, while ADT 5 had the lowest GDD value of 1092.45°C, indicating a shorter growth period.

Photothermal units (PTU) of the different genotypes showed significant differences in the cumulative exposure to light and temperature required for growth. ADT 7 and VBN 11 had the highest PTU values (15368.45°C day^{-1}), indicating that these genotypes require more combined light and heat exposure to reach maturity. Genotypes ADT 3, VBN 3, VBN 8, and LBG 932 all shared the same PTU value of 14156.81°C day^{-1}, while ADT 5 had the lowest PTU value of 12949.06°C day^{-1} (Table 6).

Heliothermal units (HTU) for the genotypes also exhibited variation in the combined heat and sunlight exposure required for growth (Table 6). ADT 7 and VBN 11 had the highest HTU values of 10222.7°C day^{-1}, while ADT 3, VBN 3, VBN 8, and LBG 932 had identical HTU values of 9378.39°C day^{-1}. ADT 5 had the lowest HTU value of 8553.23°C day^{-1}.

Heat use efficiency (HUE) across the genotypes reflected variability in how effectively each genotype converts absorbed heat into biomass (Table 6). VBN 8 exhibited the highest HUE at 0.76, followed by ADT 7 at 0.76 and VBN 11 at 0.74 kg ha^{-1}°C^{-1} day^{-1}, indicating these genotypes are the most efficient in utilizing heat for growth. Genotypes ADT 3 and VBN 3 had moderate HUE values (0.69 and 0.68 kg ha^{-1}°C^{-1} day^{-1}, respectively), while ADT 5 had the lowest HUE at 0.64 kg ha^{-1}°C^{-1} day^{-1}.

The maximum and minimum temperatures over the cropping period increased gradually. Genotypes ADT 5 (65 days) and VBN 8, LBG 932, ADT 3, VBN 3 (70 days), and ADT 7, VBN 11 (75 days) showed a positive correlation between crop duration and GDD, PTU, HTU, and HUE. This supports previous studies indicating that longer-duration genotypes accumulate higher heat units and achieve higher grain yields (Laxmi, 2022; Hoque et al., 2021; Mane et al., 2017; Subbulakshmi, 2021; Jhondhale et al., 2018; Aruna and Kumar, 2023).

Table 6. Performance of blackgram genotypes on growing degree days, photo thermal unit, helio thermal unit, heat use efficiency

Genotypes	**Growing Degree Days (°C day^{-1})**	**Photo Thermal Unit (°C day^{-1})**	**Helio Thermal Unit (°C day^{-1})**	**Heat Use Efficiency (kg ha^{-1} °C^{-1} day^{-1})**
T_1 - ADT 3	1191.55	14156.81	9378.39	0.69
T_2 - ADT 5	1092.45	12949.06	8553.23	0.64
T_3 - ADT 7	1290.70	15368.45	10222.70	0.76
T_4 - VBN 3	1191.55	14156.81	9378.39	0.68
T5 - VBN 8	1191.55	14156.81	9378.39	0.76
T6 - VBN 11	1290.70	15368.45	10222.70	0.74
T7 - LBG 932	1191.55	14156.81	9378.39	0.71
S.Ed	**13.63**	**161.87**	**107.19**	**0.01**
CD (0.05)	**29.69**	**352.68**	**233.56**	**0.02**

The genotypes exhibited notable differences in economic performance, as shown in Table 7. Genotype ADT 7 achieved the highest gross income of Rs. 69,531, paired with the highest net income of Rs. 44,929 and a strong Benefit-Cost Ratio (BCR) of 2.83, making it the most profitable and efficient genotype in the group. In contrast, ADT 5 recorded the lowest gross income (Rs. 50,258), the lowest net income (Rs. 25,656), and a BCR of 2.04, indicating that it was less economically advantageous despite generating a moderate gross income (Table 7). The observed differences in economic performance were primarily driven by variations in yield. No significant variation in the cost of cultivation was noted across the genotypes, as the package of practices remained consistent for all treatments. Thus, the variations in gross income, net income, and BCR can be attributed to differences in grain and stover yields. These findings align with those of Singh and Singh (2022) and Potkile (2018).

Although the yield varied among the genotypes, the BCR range (2.04–2.83) demonstrates that the genotype has a significant impact on both grain yield and economic returns. The higher seed and stover yields observed in ADT 7 led to increased gross and net income, with values of Rs. 69,531 and Rs. 44,929, respectively. The BCR of 2.83 for ADT 7 was notably higher than that of other genotypes, indicating that it is particularly well-suited for cultivation under puddled tillage practices. These results are in line with findings by Kumar and Rajput (2020). Conversely, genotype ADT 5 may not have experienced the most favorable environmental conditions, contributing to its lower economic performance.

Table 7. Performance of blackgram genotypes on economics of blackgram

* Data not analysed statistically

Authors contribution

Suriya S G: Conceptualization, Methodology, Investigation, Resources, Validation, Formal Analysis, Writing - Original Draft

Anandan P: Conceptualization, Methodology, Investigation, Validation, Supervision, Project Administration, Writing – Review & Editing.

Natarajan S: Methodology, Validation, Supervision, Project Administration, Writing – Review & Editing.

Raja J: Validation, Supervision, Project Administration, Writing – Review & Editing.

Conflict of Interest

All authors declare no conflict of interest.

Ethical statement

The seeds are procured from the Tamil Nadu Rice Research Institute - Aduthurai, Regional Research Station - Vridhachalam, and agro product dealers of Cuddalore district, Tamil Nadu. The seed collection program and field experiment were approved and laid out in the Experimental Farm, Department of Agronomy, Annamalai University. The guidelines for data collection and statistical analysis were approved by the university research committee, which is carried out by corresponding authors.

Treatment	General cost of cultivation	Gross Income	Net Income	BCR
T_1 - ADT 3	24602	58705	34103	2.39
T_2 - ADT 5	24602	50258	25656	2.04
T_3 - ADT 7	24602	69531	44929	2.83
T_4 - VBN 3	24602	58005	33403	2.36
T5 - VBN 8	24602	64315	39714	2.61
T6 - VBN 11	24602	67810	43209	2.76
T7 - LBG 932	24602	60432	35830	2.46

Declaration

All data generated or analysed during this study are included in this published article

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Other weather parameters were observed in the Annamalainagar meteorology station, Annamalai University.

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