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Response of Integrated Nutrient Management Practices in Red Cabbage (*Brassica oleracea* var. *capitata* f. *rubra* L.)

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Abstract

The present research was conducted in the academic year 2022-23 at Experimental Farm, Kharora, Department of Agriculture, Mata Gujri College, Fatehgarh Sahib, Punjab. The experimented design was RBD with 8 treatments i.e. T_1 (Absolute control), T_2 (100% RDF), T_3 (100% RDF + FYM @ 40 t/ha), T_4 (100% RDF + Vermicompost @ 10 t/ha), T_5 (75% RDF + FYM @ 40 t/ha + Azotobacter @ 5.0 kg ha^{-1}), T_6 (75% RDF + Vermicompost @ 10 t/ha + PSB @ 5.0 kg ha^{-1}), T_7 (50% RDF + FYM @ 40 t/ha + Azotobacter @ 5.0 kg ha^{-1}), T_8 (50% RDF + Vermicompost @ 10 t/ha + PSB @ 5.0 kg ha^{-1}). The maximum plant height (42.78 cm), plant spread (63.05 cm), leaf length (39.22 cm) and leaf breadth at harvest (33.03 cm) was recorded in treatment T_4. In yield parameters maximum head weight (1.48 kg) and head yield (66.33 t/ha) was found in treatment T_6. In terms of economics, best benefit to cost ratio (3.48) was observed in treatment T_2. These results suggested that optimum production of red cabbage can be obtained with treatment T_6 in terms of yield and treatment T_4 in term of growth parameters.

***Key words*:** Red cabbage, FYM, Vermicompost, Azotobacter, PSB

Red cabbage (*Brassica oleracea* var. *capitata* f. *rubra* L.) is also known as purple cabbage or red kraut. It belongs to the family Brassicaceae and comes under the subgroup *rubra* of cabbage with chromosome number 2n=18 [1]. It is a cool season crop and widely grown in temperate and subtropical region of India. The optimum temperature for growth is 15-18^{o} C. It can tolerate freezing temperatures but is less tolerant to high temperatures [2]. Red cabbage synthesized and accumulated anthocyanin at all the developmental stages of vegetative growth [3]. It is distinguished by the presence of exceptional health enhancing properties like anticancer properties due to the presence of Indole-3-Carbinol and many beneficial sensory traits [4]. An important advantage of red cabbage is that it is generally consumed raw, which permits the preservation of vitamins sensitive to thermal processing and some polyphenolic compounds [5]. In terms of nutritional value red cabbage has ten times more vitamin A and twice as much iron as green cabbage [6]. The increasing use of chemical fertilizers to increase vegetable production has been widely recognized but its long run impact on soil health, ecology and other natural resources are detrimental which affect living organisms including beneficial soil microorganisms and human being. Therefore, to reduce dependency on chemical fertilizers and conserving the natural resources in align with sustainable vegetable production are vital issues in present time which is only possible through integrated plant nutrient supply system [7]. The integrated nutrient management paves the way to overcome these problems, which involves conjunctive use of chemical fertilizers and organic manures to sustain crop production as well as maintenance of soil health [8]. The cohesive use of organic and inorganic sources will improve soil health and helps in maximizing production as it involves utilization of local resources and hence, turned to be a rational, realistic and economically viable way to supply nutrients to the crop. Manures are the organic materials derived from animal, human and plant residues which contain plant nutrients in complex organic forms. Farmyard manure (FYM), compost and green-manure are the most important and widely used bulky organic manures. Farmyard manure refers to the decomposed mixture of dung and urine of farm animals along with litter and left over material from roughages or fodder fed to the cattle. Composting is the natural process of 'Rotting' or decomposition of organic matter by microorganisms under controlled conditions. Vermicomposting is the process of turning organic debris into worm castings [9]. Bio fertilizers are derived from living microorganism that are capable of fixing atmospheric nitrogen and also convert insoluble phosphorous to soluble phosphorous for uptake of plants [10]. *Azotobacter* belongs to the family of *Azotobacteriaceae*, aerobic and free-living nitrogen fixing bacteria which has the capability to fix an average 20 kg Nitrogen per hectare per year [11]. An important role is played by the addition of bio fertilizer in improvement of soil fertility yield attributed character which ultimately leads to increase in the final yield of vegetable. Phosphate solubilizing bacteria (PSB) are heterotrophic microbes, which play a significant role in the solubilization of insoluble phosphate. It helps in the release insoluble inorganic phosphate and makes it available to the plants [12]. The strategy to adopt integrated nutrient management using combination of chemical

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fertilizers, organic manures and bio-fertilizers became essential to minimize the cost of production and to maintain biological productivity of soils.

MATERIALS AND METHODS

The present investigation was carried out at Experimental Farm, Kharora, Department of Agriculture, Mata Gujri College, Fatehgarh Sahib, Punjab during winter season of 2022-23. The experimental material was a red cabbage variety called Ruby Ball developed by Takii seed. The nursery was sown at the experimental farm in a 3m × 1m × 0.15 m seed bed on 14th October, 2022 and seedlings were ready for transplanting within 28 days of sowing. Before planting the seedlings, Farm Yard Manure @ 40 t/ha and Vermicompost @ 10 t/ha were applied in plots according to the treatments. The sources of the nutrient N, P, and K were urea, single superphosphate, and murate of potash, respectively. The doses of fertilizers viz. N, P_2O_5, and K_2O @ 125:62.5:62.5 kg ha for cabbage was applied as recommended by Punjab Agricultural University, Ludhiana [13]. Following the transplanting of seedlings after 15 days, bio-fertilizers, namely *Azotobacter* and PSB, were applied to plots according to the treatments.

The experiment consists of 8 treatments and three replications were carried out by Randomized Block Design (RBD). The experiment included 8 treatment combinations of recommended dose of fertilizers with two organic manures i.e. FYM and vermicompost and two biofertilizers i.e. *Azotobacter* and PSB. The treatment combination are T_1 (Absolute control), T_2 (100% RDF), T_3 (100% RDF + FYM @ 40 t/ha), T_4 (100% RDF + Vermicompost @ 10 t/ha), T_5 (75% RDF + FYM @ 40 t/ha + Azotobacter @ 5.0 kg ha^{-1}), T_6 (75% RDF + Vermicompost @ 10 t/ha + PSB @ 5.0 kg ha^{-1}), T_7 (50% RDF + FYM @ 40 t/ha + Azotobacter @ 5.0 kg ha^{-1}), T_8 (50% RDF + Vermicompost @ 10 t/ha + PSB @ 5.0 kg ha^{-1}). Observations were recorded at randomly selected five plants and tagged them in each plot for data collection. The observations on growth parameter were plant height (cm), plant spread (cm), leaf length (cm), leaf breadth (cm) at 30, 60, 90 (DAT) and at harvest and other growth parameters include days taken to head initiation, days taken to head maturity, number of jacket leaves plant^{-1} and leaf area (cm^2). The yield parameters include equatorial diameter of head (cm), polar diameter of head (cm), average head weight (kg), biological yield (kg plant^{-1}), head yield (kg/plot), head yield (t/ha) and harvest index (%). Economic parameters include cost of cultivation (Rs/ha), gross income (Rs/ha), net income (Rs/ha) and benefit cost ration (B:C). The data obtained on various parameters was investigated in accordance with the experiment design recommended by Panse and Sukhatme [14]. The significance of the difference in treatment means was determined at a 5% level of probability.

RESULTS AND DISCUSSION

Effect on growth parameters

Plant height is the important factor for estimating the yield and harvesting stage of red cabbage. In present studies, it was significantly increased due to integrated application of nutrients. The observations on plant height at 30 days, 45 days, 60 and at harvest was presented on (Table 1, Fig 1) respectively. The highest plant height at 30 days, 45 days, 60 and at harvest was 23.47 cm, 31.87 cm, 38.97 cm, 42.78 cm respectively in treatment T_4 (100% RDF + Vermicompost @ 10 t/ha). This might be due to the favourable effect of chemical fertilizers along with vermicompost attributed to enhance soil fertility and to improve moisture retention capacity of soil [15]. Another possible reason is by providing vermicompost, the physical properties of soil increases, which in-turn increases the availability of nutrients to the plant which further enhances the plant growth [16]. This finding was in agreement with those reported by Maurya *et al.* [17] in broccoli, Padamwar and Dakore [18] in cauliflower and Singh *et al.* [19] 2009 in cauliflower The minimum plant height at 30 days, 45 days, 60 days and at harvest was observed 18.00 cm, 20.19 cm, 29.46 cm and 32.92 cm respectively in control (T_1) treatment.

Table 1 Response of integrated nutrient management practices on plant height (cm) of red cabbage

Treatments	Plant height (cm)			
	30 DAT	45 DAT	60 DAT	At harvest
T_1 (Absolute control)	18.00	20.19	29.46	32.92
T_2 (100% RDF)	21.55	26.68	35.73	39.50
T_3 (100% RDF + FYM @ 40 t/ha)	22.39	29.20	36.47	41.42
T_4 (100% RDF + Vermicompost @ 10 t/ha)	23.47	31.87	38.97	42.78
T_5 (75% RDF + FYM @ 40 t/ha + *Azotobacter* @ 5.0 kg ha^{-1})	19.93	26.35	33.87	37.87
T_6 (75% RDF + Vermicompost @ 10 t/ha + PSB @ 5.0 kg ha^{-1})	20.85	26.80	35.20	38.80
T_7 (50% RDF + FYM @ 40 t/ha + *Azotobacter* @ 5.0 kg ha^{-1})	17.74	24.80	31.47	35.07
T_8 (50% RDF + Vermicompost @ 10 t/ha + PSB @ 5.0 kg ha^{-1})	18.87	25.73	32.40	36.13
Sem (±)	NS	1.30	1.22	1.36
$CD_{0.05}$		3.94	3.71	4.12

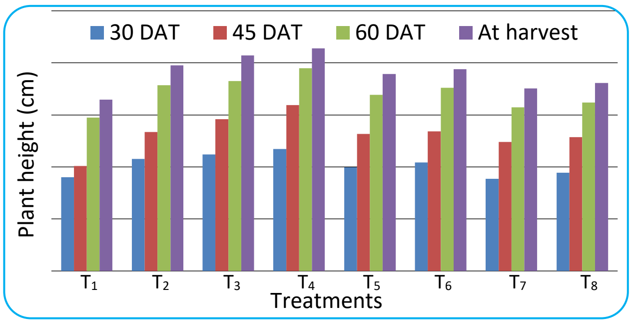

Fig 1 Response of integrated nutrient management practices on plant height (cm) of red cabbage

The observations on plant spread at 30 days, 45 days, 60 and at harvest was presented on (Table 2, Fig 2) respectively. The highest plant spread at 30 days, 45 days, 60 and at harvest was observed 30.80 cm, 45.82 cm, 59.12 cm and 63.05 cm respectively in treatment T_4 (100% RDF + Vermicompost @ 10 t/ha). According to Islam [20] plant spread increases due to progress of time and vermicompost creates healthy and optimum condition in the soil. As a result, plant spread increased vigorously in the open air [19]. The minimum plant spread at 30 days, 45 days, and 60 days and at harvest was observed 20.13 cm, 22.79 cm, 43.33 cm and 49.24 cm respectively in control (T_1) treatment where no organic or inorganic fertilizer was applied.

Table 2 Response of integrated nutrient management practices on plant spread (cm) of red cabbage

Treatments	Plant spread (cm)			
	30 DAT	45 DAT	60 DAT	At harvest
T_1 (Absolute control)	20.13	22.79	43.33	49.24
T_2 (100% RDF)	27.49	36.12	53.53	61.65
T_3 (100% RDF + FYM @ 40 t/ha)	28.93	41.59	57.23	62.60
T_4 (100% RDF + Vermicompost @ 10 t/ha)	30.80	45.82	59.12	63.05
T_5 (75% RDF + FYM @ 40 t/ha + *Azotobacter* @ 5.0 kg ha^{-1})	23.43	31.67	49.28	55.60
T_6 (75% RDF + Vermicompost @ 10 t/ha + PSB @ 5.0 kg ha^{-1})	25.63	32.80	52.02	58.33
T_7 (50% RDF + FYM @ 40 t/ha + *Azotobacter* @ 5.0 kg ha^{-1})	19.11	25.80	46.80	52.40
T_8 (50% RDF + Vermicompost @ 10 t/ha + PSB @ 5.0 kg ha^{-1})	22.27	27.93	48.47	54.20
Sem (±)	NS	1.40	1.81	1.99
$CD_{0.05}$		4.25	5.48	6.02

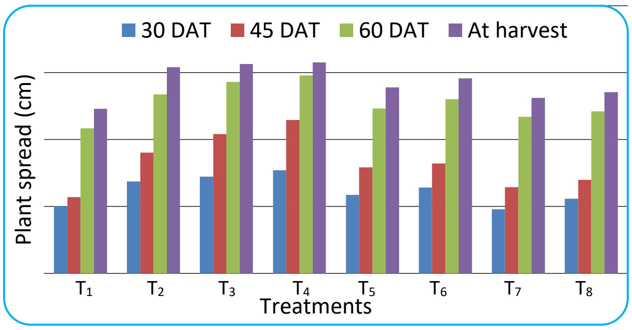

Fig 2 Response of integrated nutrient management practices on plant spread (cm) of red cabbage

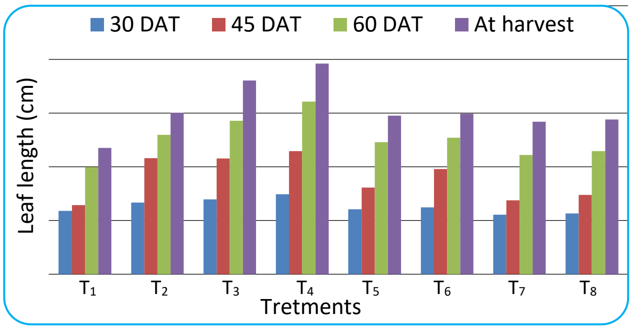

Fig 3 Response of integrated nutrient management practices on leaf length (cm) of red cabbage

Table 3 Response of integrated nutrient management practices on leaf length (cm) of red cabbage

Treatments	Leaf length (cm)			
	30 DAT	45 DAT	60 DAT	At harvest
T_1 (Absolute control)	11.82	12.87	19.93	23.53
T_2 (100% RDF)	13.33	21.60	25.93	30.07
T_3 (100% RDF + FYM @ 40 t/ha)	13.93	21.68	28.55	36.07
T_4 (100% RDF + Vermicompost @ 10 t/ha)	14.87	22.93	32.13	39.22
T_5 (75% RDF + FYM @ 40 t/ha + *Azotobacter* @ 5.0 kg ha^{-1})	12.08	16.13	24.60	29.53
T_6 (75% RDF + Vermicompost @ 10 t/ha + PSB @ 5.0 kg ha^{-1})	12.45	19.60	25.40	29.87
T_7 (50% RDF + FYM @ 40 t/ha + *Azotobacter* @ 5.0 kg ha^{-1})	11.09	13.73	22.20	28.40
T_8 (50% RDF + Vermicompost @ 10 t/ha + PSB @ 5.0 kg ha^{-1})	11.32	14.80	22.93	28.80
Sem (±)	NS	0.85	1.19	1.33
$CD_{0.05}$		2.58	3.62	4.04

The observations on leaf length at 30 days, 45 days, 60 and at harvest was presented on (Table 3, Fig 3) respectively. The maximum leaf length at 30 days, 45 days, 60 and at harvest was observed 14.87 cm, 22.93 cm, 32.13 cm and 39.22 cm respectively in treatment T_4 (100% RDF + Vermicompost @ 10 t/ha). The increase in individual leaf lengths due to the optimal supply of plant nutrients and growth hormones in the right amount throughout the harvest period caused more vegetative growth, ultimately more photosynthesis, and thus the elongation of cauliflower leaves [21]. These findings are in close agreement with the results of Salim *et al.* [22] in cauliflower and Easmin *et al.* [23] in Chinese cabbage. The minimum leaf length at 30 days, 45 days, 60 days and at harvest was observed 11.82 cm, 12.87 cm, 19.93 cm and 23.53 cm respectively control (T_1) treatment.

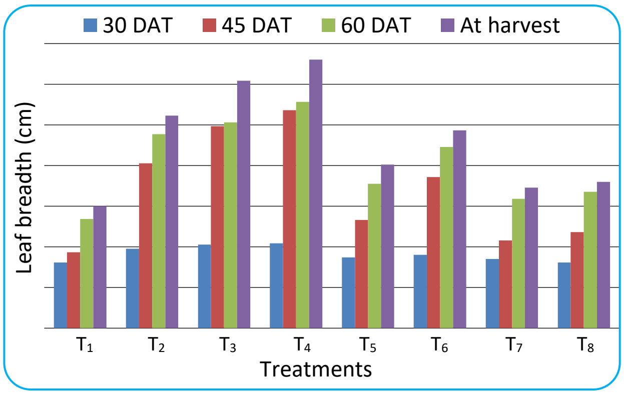

Fig 4 Response of integrated nutrient management practices on leaf breadth (cm) of red cabbage

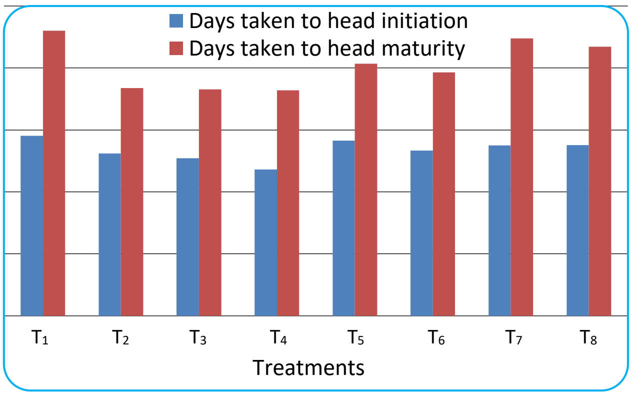

Fig 5 Response of integrated nutrient management practices on days taken to head initiation and days taken to head maturity of red cabbage

Table 4 Response of integrated nutrient management practices on leaf breadth (cm) of red cabbage

Treatments	Leaf breadth (cm)			
	30 DAT	45 DAT	60 DAT	At harvest
T_1 (Absolute control)	8.07	9.33	13.43	15.00
T_2 (100% RDF)	9.76	20.27	23.87	26.13
T_3 (100% RDF + FYM @ 40 t/ha)	10.29	24.86	25.30	30.43
T_4 (100% RDF + Vermicompost @ 10 t/ha)	10.44	26.83	27.85	33.03
T_5 (75% RDF + FYM @ 40 t/ha + *Azotobacter* @ 5.0 kg ha^{-1})	8.72	13.33	17.77	20.13
T_6 (75% RDF + Vermicompost @ 10 t/ha + PSB @ 5.0 kg ha^{-1})	9.01	18.60	22.27	24.33
T_7 (50% RDF + FYM @ 40 t/ha + *Azotobacter* @ 5.0 kg ha^{-1})	8.50	10.80	15.90	17.27
T_8 (50% RDF + Vermicompost @ 10 t/ha + PSB @ 5.0 kg ha^{-1})	8.60	11.80	16.77	18.00
Sem (±)	NS	0.67	1.06	0.87
$CD_{0.05}$		2.03	3.21	2.65

The observations on leaf breadth at 30 days, 45 days, 60 and at harvest was presented on (Table 4, Fig 4) respectively. The maximum leaf breadth at 30 days, 45 days, 60 and at harvest was observed (10.44 cm, 26.83 cm, 27.85 cm and 33.03 cm) in treatment T_4 (100% RDF + Vermicompost @ 10 t/ha). Organic manure mainly vermicompost creates good soil environment and inorganic fertilizer influence plant growth. As a result, combination of organic and inorganic probably supplied adequate plant nutrients and showed the highest performance [24]. These findings are in close agreement with the results of Salim *et al.* [22] in cauliflower, Easmin *et al.* [23] in Chinese cabbage and Pawar and Barkule [25] in cauliflower. The minimum leaf breadth at 30 days, 45 days, 60 and at harvest was observed (8.07 cm, 9.33 cm, 13.43 cm and 15.00 cm) control (T_1) treatment.

The observations on head initiation were presented on (Table 5, Fig 5) respectively. The minimum days to taken to head initiation was observed (47.20 days) in treatment T_4 (100% RDF + Vermicompost @ 10 t/ha). It might be due to the release of nitrogen and phosphorus in the soil enabling plants to use them which leads to increase plant hormonal activities resulting to produce earlier head initiation of broccoli [26]. Similar result was also obtained by Mohanta *et al.* [27]. The maximum days to taken to head initiation was observed (58.09 days) in control (T_1) treatment.

The observations on head maturation were presented on (Table 5, Fig 5) respectively. The minimum days to taken to head maturation (72.78 days) was observed in T_4 (100% RDF + Vermicompost @ 10 t/ha). This may be attributed to the fact that nutrients like nitrogen, phosphate and potassium are more readily available and biofertilizers work by contributing significantly to the production of protein and chlorophyll, which promotes early head development [28]. Negi *et al.* [29] and Sharma and Arya [30] observed quite similar results from their study. The maximum days to taken to head maturation (92.06 days) was observed in control (T_1) treatment.

Table 5 Response of integrated nutrient management practices on days taken to head initiation and days taken to head maturity of red cabbage

Treatments	Days taken to head initiation	Days taken to head maturity
T_1 (Absolute control)	58.09	92.06
T_2 (100% RDF)	52.39	73.47
T_3 (100% RDF + FYM @ 40 t/ha)	50.82	73.07
T_4 (100% RDF + Vermicompost @ 10 t/ha)	47.20	72.78
T_5 (75% RDF + FYM @ 40 t/ha + *Azotobacter* @ 5.0 kg ha^{-1})	56.53	81.42
T_6 (75% RDF + Vermicompost @ 10 t/ha + PSB @ 5.0 kg ha^{-1})	53.39	78.57
T_7 (50% RDF + FYM @ 40 t/ha + *Azotobacter* @ 5.0 kg ha^{-1})	55.02	89.51
T_8 (50% RDF + Vermicompost @ 10 t/ha + PSB @ 5.0 kg ha^{-1})	55.13	86.81
Sem (±)	2.02	2.81
$CD_{0.05}$	6.14	8.52

Table 6 Response of integrated nutrient management practices on number of jacket leaves $plant^{-1}$ and leaf area (cm^2) of red cabbage

Treatments	Number of jacket leaves $plant^{-1}$	Leaf area (cm^2)
T_1 (Absolute control)	4.20	281.37
T_2 (100% RDF)	6.82	301.58
T_3 (100% RDF + FYM @ 40 t/ha)	7.07	304.60
T_4 (100% RDF + Vermicompost @ 10 t/ha)	7.27	308.86
T_5 (75% RDF + FYM @ 40 t/ha + *Azotobacter* @ 5.0 kg ha^{-1})	5.93	296.08
T_6 (75% RDF + Vermicompost @ 10 t/ha + PSB @ 5.0 kg ha^{-1})	6.43	298.77
T_7 (50% RDF + FYM @ 40 t/ha + *Azotobacter* @ 5.0 kg ha^{-1})	4.80	286.13
T_8 (50% RDF + Vermicompost @ 10 t/ha + PSB @ 5.0 kg ha^{-1})	5.13	288.28
Sem (±)	0.26	5.62
$CD_{0.05}$	0.78	17.06

The observations on jacket leaves $plant^{-1}$and leaf area (cm^2) were presented on (Table 6, Fig 6) respectively. The maximum number of jacket leaves $plant^{-1}$ (7.27) at harvest was observed in treatment T_4 (100% RDF + Vermicompost @ 10 t/ha). The minimum number of jacket $plant^{-1}$ (4.20) leaves was observed in control (T_1) treatment. The maximum leaf area (308.86 cm^2) was observed in treatment T_4 (100% RDF + Vermicompost @ 10 t/ha). Vermicompost shows increased effect on vegetative growth of leaf of plant when applied alone or in combination. These findings are in line with those of Mollah *et al.* [31] in broccoli and Zango *et al.* [32]. The minimum leaf area (281.37 cm^2) was observed in control (T_1).

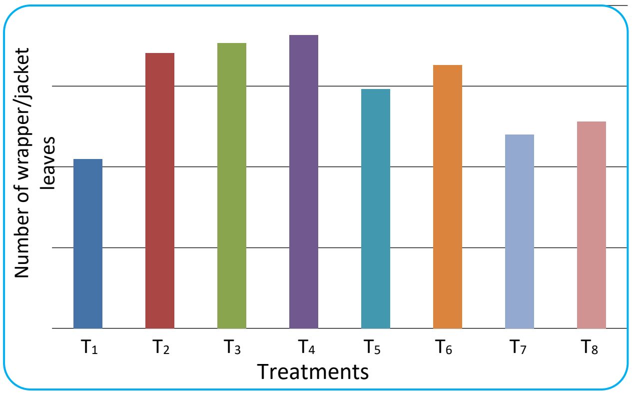

Fig 6 Response of integrated nutrient management practices on number of wrapper/jacket leaves of red cabbage

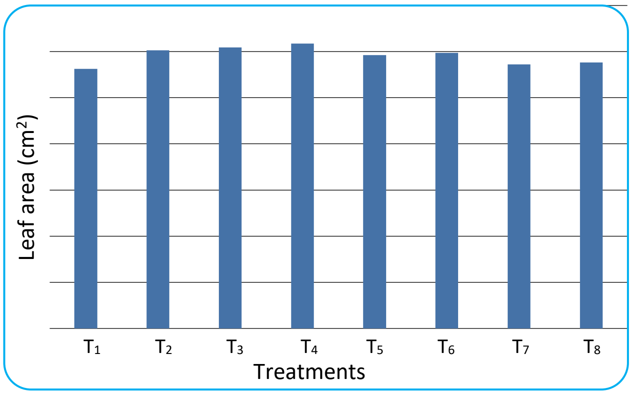

Fig 7 Response of integrated nutrient management practices on Leaf area (cm^2) of red cabbage

Table 7 Response of integrated nutrient management practices on equatorial diameter of head (cm) and polar diameter of head (cm)

Treatments	Equatorial diameter of head (cm)	Polar diameter of head (cm)
T_1 (Absolute control)	10.84	10.89
T_2 (100% RDF)	13.06	15.07
T_3 (100% RDF + FYM @ 40 t/ha)	12.27	14.34
T_4 (100% RDF + Vermicompost @ 10 t/ha)	12.89	15.81
T_5 (75% RDF + FYM @ 40 t/ha + *Azotobacter* @ 5.0 kg ha^{-1})	15.25	16.36
T_6 (75% RDF + Vermicompost @ 10 t/ha + PSB @ 5.0 kg ha^{-1})	16.33	17.45
T_7 (50% RDF + FYM @ 40 t/ha + *Azotobacter* @ 5.0 kg ha^{-1})	12.19	12.97
T_8 (50% RDF + Vermicompost @ 10 t/ha + PSB @ 5.0 kg ha^{-1})	12.52	13.54
Sem (±)	0.49	0.73
$CD_{0.05}$	1.49	2.21

Effect on yield parameters

Head diameter is the important parameter which has great influences on the yield of red cabbage. The observations on equatorial diameter and polar diameter were presented on (Table 7, Fig 8) respectively. The maximum equatorial diameter (16.33 cm) and polar diameter (17.45 cm) was observed in treatment T_6 (75% RDF + Vermicompost @ 10 t/ha + PSB @ 5.0 kg ha^{-1}). Positive response of organic source of nutrient and inorganic fertilizers on head diameter may be due to the better availability of micro and macro nutrient in the soil that produced healthy plants with large vegetative growth, which reflected head diameter [26]. Also, improvement in plant growth attributes with the application of vermicompost might due to better photosynthesis, energy storage, cell division and cell enlargement, moisture holding capacity, supply of micronutrients and availability of major nutrients due to favorable soil condition Reddy *et al.* [33] and Uddain *et al.* [34]. Similar result has been reported of Mohanta *et al.* [27] and Singh *et al.* [35]. The minimum equatorial diameter (10.84 cm) and polar diameter (10.89 cm) was observed in control (T_1).

Table 8 Response of integrated nutrient management practices on average head weight (kg) and biological yield (kg $plant^{-1}$) of red cabbage

Treatments	Average head weight (kg)	Biological yield (kg $plant^{-1}$)
T_1 (Absolute control)	0.43	1.21
T_2 (100% RDF)	1.25	2.02
T_3 (100% RDF + FYM @ 40 t/ha)	1.07	1.76
T_4 (100% RDF + Vermicompost @ 10 t/ha)	1.19	1.94
T_5 (75% RDF + FYM @ 40 t/ha + *Azotobacter* @ 5.0 kg ha^{-1})	1.37	2.17
T_6 (75% RDF + Vermicompost @ 10 t/ha + PSB @ 5.0 kg ha^{-1})	1.48	1.95
T_7 (50% RDF + FYM @ 40 t/ha + *Azotobacter* @ 5.0 kg ha^{-1})	0.70	1.48
T_8 (50% RDF + Vermicompost @ 10 t/ha + PSB @ 5.0 kg ha^{-1})	0.87	1.52
Sem (±)	0.06	0.14
$CD_{0.05}$	0.18	0.41

The observations on average head weight and biological yield (kg $plant^{-1}$) were presented on (Table 8, Fig 8) respectively. The maximum average head weight (1.48 kg) and biological yield (2.17 kg $plant^{-1}$) was observed in treatment T_6 (75% RDF + Vermicompost @ 10 t/ha + PSB @ 5.0 kg ha^{-1}). The weight of the cabbage head has increased due to prolonged availability of nutrients from the plot which is treated with vermicompost, increased in nutrient availability and water intake, as well as increased leaf area development, resulting in a higher rate of photosynthetic activity [16]. Similar, results were found in Chaudhary *et al.* [15], Khatkar *et al.* [36] and Zargar *et al.* [37]. With the application of PSB there is increase in the uptake of phosphorus but also mediated solubilization of insoluble phosphates through release of organic acid, metabolites which control soil born phytopathogens and release of pathogen suppressing metabolites mainly siderphores, phytohormones and lytic enzyme [38]. Similar result was observed by Kachari and Korla [39]. Organic manure mainly vermicompost and inorganic fertilizer combined create good soil environment that supplied adequate plant nutrients for proper vegetative growth of cabbage plants, which ultimately influenced the unfolded healthy larger type leaves and increase the biological yield [24]. Similar results were observed by Parbhakaran and Pitchai [40] and Ghuge *et al.* [41]. The minimum average head weight (0.43 kg) and biological yield (1.21 kg plant^{-1}) was recorded in control (T_1) treatment.

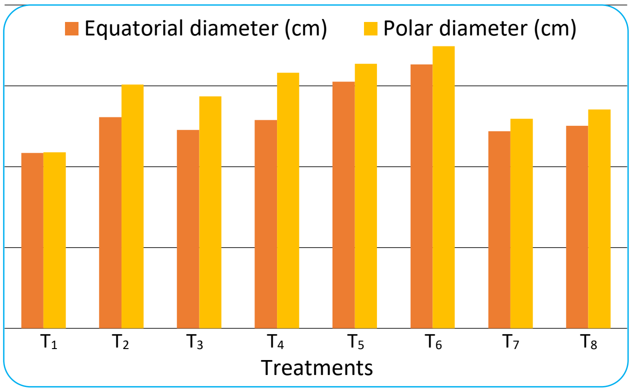

Fig 8 Response of integrated nutrient management practices on equatorial diameter and polar diameter of head (cm) of red cabbage

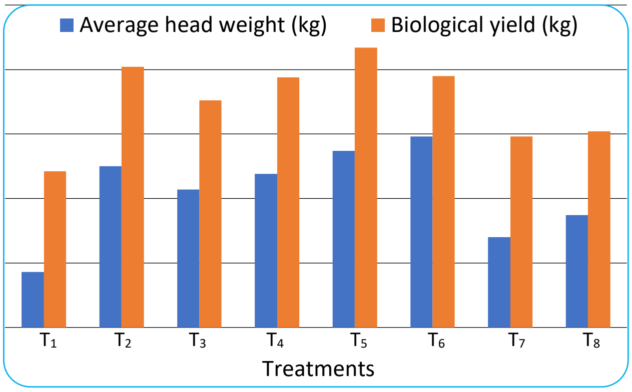

Fig 9 Response of integrated nutrient management practices on average head weight (kg) and biological yield (kg) of red cabbage

Table 9 Response of integrated nutrient management practices on head yield (kg/plot) head yield (t/ha) and harvest index (%) of red cabbage

Treatments	Head yield (kg/plot)	Head yield (t/ha)	Harvest index (%)
T_1 (Absolute control)	6.88	21.23	35.66
T_2 (100% RDF)	20.07	56.19	61.96
T_3 (100% RDF + FYM @ 40 t/ha)	17.18	48.09	61.07
T_4 (100% RDF + Vermicompost @ 10 t/ha)	19.09	53.46	61.52
T_5 (75% RDF + FYM @ 40 t/ha + *Azotobacter* @ 5.0 kg ha^{-1})	21.88	61.26	63.01
T_6 (75% RDF + Vermicompost @ 10 t/ha + PSB @ 5.0 kg ha^{-1})	23.68	66.30	75.85
T_7 (50% RDF + FYM @ 40 t/ha + *Azotobacter* @ 5.0 kg ha^{-1})	11.15	34.40	47.21
T_8 (50% RDF + Vermicompost @ 10 t/ha + PSB @ 5.0 kg ha^{-1})	13.85	40.09	56.98
Sem (±)	0.96	2.77	4.65
$CD_{0.05}$	2.90	8.39	14.10

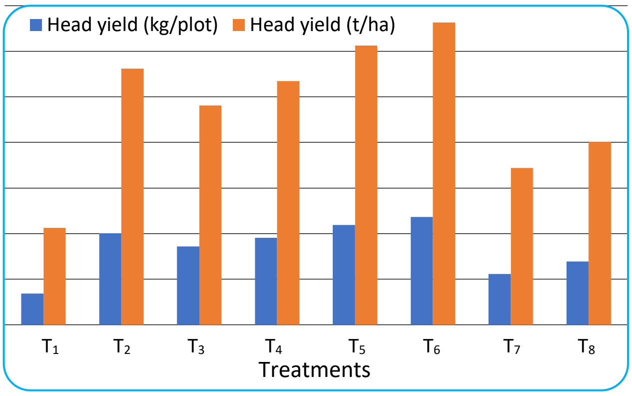

Fig 10 Response of integrated nutrient management practices on head yield (kg/plot) and head yield (t/ha) of red cabbage

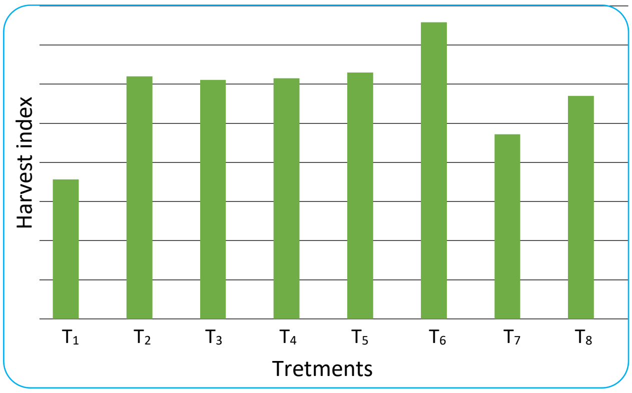

Fig 11 Response of integrated nutrient management practices on harvest index (%) of red cabbage

The observations related to head yield (kg/plot) and head yield (t/ha) was depicted in (Table 9, Fig 10). The maximum head yield (23.68 kg/plot) and head yield (66.33 t/ha) was observed in treatment T_6 (75% RDF + Vermicompost @ 10 t/ha + PSB @ 5.0 kg ha^{-1}). The enhanced yield might be due to the fact that organic manures kept the soil loose and friable that conserved more soil moisture and maintained proper aeration for better root growth and on the other hand, inorganic fertilizers supplied sufficient plant nutrients readily for vigorous vegetative growth [24]. Similar result was also obtained by Ola *et al.* [42], Mohanta *et al.* [27] and Singh *et al.* [35]. The minimum yield (6.88 kg/plot) and yield (21.23 t/ha) was recorded in control (T_1) treatment.

The observations related to harvest index was depicted in (Table 9, Fig 11). Treatment containing 75% RDF + Vermicompost @ 10 t/ha + PSB @ 5.0 kg ha^{-1} resulted in maximum harvest index (75.85%). The maximum harvest index observed with the application of vermicompost is due to higher level of various plant growth regulating materials and humic acid produced by the increased activity of microbes [43]. The minimum harvest index (35.66 %) was observed in control (T_1) treatment [44].

Table 10 Response of integrated nutrient management practices on cost of cultivation (Rs /ha), gross Income (Rs /ha), net Income (Rs /ha) and benefit cost ration (B: C) of red cabbage

Treatments	Cost of cultivation (Rs/ha)	Gross income (Rs /ha)	Net income (Rs/ha)	B:C ratio
T_1 (Absolute control)	118891.85	212300.00	93408.15	0.79
T_2 (100% RDF)	125306.19	561941.33	436635.14	3.48
T_3 (100% RDF + FYM @ 40 t/ha)	145306.19	480942.93	335636.74	2.31
T_4 (100% RDF + Vermicompost @ 10 t/ha)	185306.19	534643.20	349337.01	1.89
T_5 (75% RDF + FYM @ 40 t/ha + *Azotobacter* @ 5.0 kg ha^{-1})	144017.86	612565.33	468547.48	3.25
T_6 (75% RDF + Vermicompost @ 10 t/ha + PSB @ 5.0 kg ha^{-1})	184023.01	663040.00	479016.99	2.60
T_7 (50% RDF + FYM @ 40 t/ha + *Azotobacter* @ 5.0 kg ha^{-1})	142414.27	344000.00	201585.73	1.42
T_8 (50% RDF + Vermicompost @ 10 t/ha + PSB @ 5.0 kg ha^{-1})	182419.42	400916.53	218497.11	1.20

*Selling Price 10 Rs/kg

Effect on crop economics

The observations related to cost of cultivation, gross return, net return and benefit cost ratio were depicted in (Table 10, Fig 12-13). The lowest cost of cultivation (Rs. 118891.85 ha^{-1}) was observed in control (T_1) treatment. The maximum cost of cultivation (Rs. 184023.01 ha^{-1}) was observed in treatment T_6 (75% RDF + Vermicompost @ 10 t/ha + PSB @ 5.0 kg ha^{-1}). The highest gross return (Rs. 663040.00 ha^{-1}) and net return (Rs. 479016.99 ha^{-1}) was observed in T_6 (75% RDF + Vermicompost @ 10 t/ha + PSB @ 5.0 kg ha^{-1}). This is due to that the availability of nutrients is in increased and total production was also increased so that the gross return was increased [45]. Whereas, the lowest gross return (Rs. 212300.00 ha^{-1}) and net return (Rs. 93408.15 ha^{-1}) was observed in treatment control (T_1) treatment. The maximum benefit cost ratio (3.48) was observed in T_2 (100% RDF). Whereas, the minimum value of benefit cost ratio (0.79) was observed in treatment control (T_1) treatment [46].

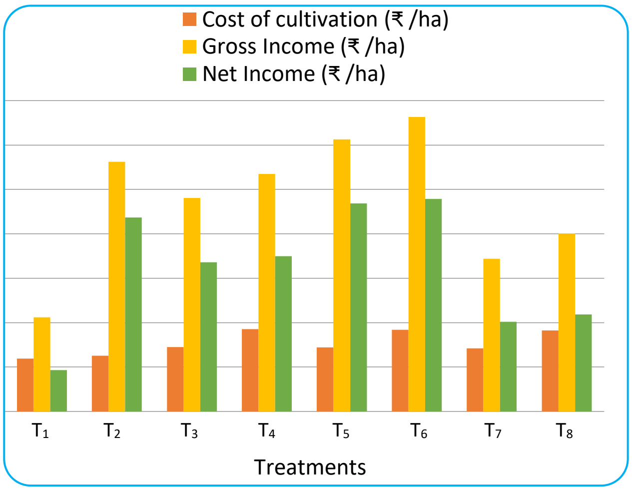

Fig 12 Response of integrated nutrient management practices on cost of cultivation (Rs/ha), gross income (Rs/ha) and net income (Rs/ha) of red cabbage

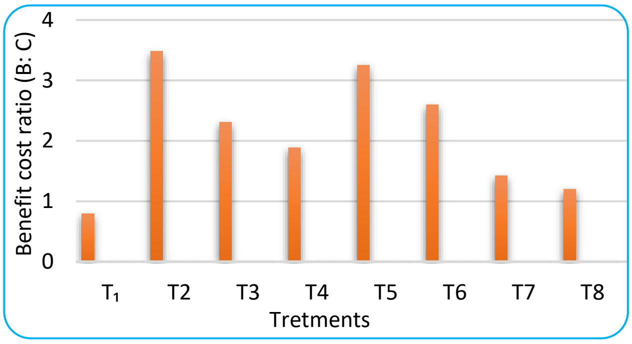

Fig 13 Response of integrated nutrient management practices on Benefit cost ratio (B: C) of red cabbage

CONCLUSION

From the finding of present investigation, it is concluded that the treatment T_4 (100% RDF + Vermicompost @ 10 t/ha) gave the best results in all presented parameters of plant growth. While, treatment T_6 (75% RDF + Vermicompost @ 10 t/ha + PSB @ 5.0 kg ha^{-1}) gave best results in yield. The highest B: C ratio was also obtained in T_2 (100% RDF). These results suggested that optimum production of red cabbage can be obtained with T_6 (75% RDF + Vermicompost @ 10 t/ha + PSB @ 5.0 kg ha^{-1}) in terms of yield and usage of T_4 (100% RDF + Vermicompost @ 10 t/ha) gave best results in term of growth parameters. Overall, these results suggest that for optimum red cabbage production, treatment T6 is recommended to maximize yield, while treatment T4 is ideal for promoting growth parameters.

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Competing interest

Authors have declared that no competing interests exist.

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