EVALUATION OF STCR BASED TARGETED YIELD EQUATIONS OF AMARANTHUS (*Amaranthus tricolor* L.) IN SOUTHERN LATERITE SOILS (AEU-8) OF KERALA.

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by

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DECLARATION

I, hereby declare that this thesis entitled **"EVALUATION OF STCR BASED TARGETED YIELD EQUATIONS OF AMARANTHUS (*Amaranthus tricolor* L.) IN SOUTHERN LATERITE SOILS (AEU-8) OF KERALA"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Vellayani

Date: 06-05-2023

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CERTIFICATE

Certified that this thesis entitled **"EVALUATION OF STCR BASED TARGETED YIELD EQUATIONS OF AMARANTHUS (*Amaranthus tricolor* L.) IN SOUTHERN LATERITE SOILS (AEU-8) OF KERALA"** is a record of research work done independently by Dara Hadassah Eunice (2020-11-036) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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LIST OF ABBREVIATIONS

%	-	per cent
^{o} C	-	degree Celsius
µg	-	microgram
AEU	-	Agro-ecological Unit
AICRP	-	All India Co-ordinated Research Project
AICRPSTCR	-	All India Coordinated Research Project for Soil Test Crop Response Correlation Studies
Al	-	Aluminium
B	-	Boron
BCR	-	Benefit-Cost Ratio
BD	-	Bulk density
Ca	-	Calcium
CDS	-	Cow dung slurry
cm	-	Centimetre
DAS	-	Days After Sowing
dS m^{-1}	-	deci Siemen per meter
EC	-	Electrical Conductivity
et al.	-	and others
etc.	-	Et cetera
Fe	-	Iron
Fig.	-	Figure
G	-	Gram
H	-	Hour
ha	-	Hectare
IPNS	-	Integrated Plant Nutrition System
K	-	Potassium
KAU	-	Kerala Agricultural University
kg ha^{-1}	-	kilogram per hectare
M	-	metre
Mg	-	Magnesium
mg kg^{-1}	-	milligram per kilogram
Mg m^{-3}	-	Mega gram per cubic metre

Ml	-	Milliliter
Mm	-	Millimeter
Mn	-	Manganese
N	-	Nitrogen
No.	-	Number
NR	-	Nutritional Requirement
OC	-	Organic carbon
P	-	Phosphorus
PD	-	Particle density
RBD	-	Randomized block design
RR	-	Response Ratio
S	-	Sulphur
SD	-	Standard deviation
STCR	-	Soil Test Based Crop Response
viz.	-	Namely
Zn	-	Zinc

INTRODUCTION

Vegetables form an indispensable part of the daily diet, particularly in India. Among the common leafy vegetables grown, Amaranthus is the most popular vegetable consumed by people all over India. It is a high-yielding nutritious tropical leafy vegetable and is a commercially grown leafy vegetable in Kerala. In Kerala, it is cultivated in an area of 1956 ha (GOK, 2022). Because of its short cropping period, high productivity, drought tolerance, and relatively low incidence of pests and diseases, this crop had been attractive to farmers. It is referred to as poor man's spinach as it is a rich source of proteins, vitamins, and minerals.

The variety Arun developed by Kerala Agricultural University is popularly known for its high-yielding nature. It is a fast-growing plant and is easily cultivated throughout the year which produces a yield of 20 t ha^{-1} on an average (KAU, 2016). Considering the growing pattern of the crop, the present experiment was conducted to determine the effect of the STCR-based targeted yield approach on yield, nutrient content and uptake by Amaranthus (*Amaranthus tricolor* L.).

Long-term studies indicated that soil fertility is decreased mostly due to excessive removal of nutrients and inadequate replacement through manures and fertilizers. Balanced application of fertilizers based on soil test, nutrient availability and crop response to fertilizers applied for specific target yield seemed to be a good option to achieve targeted yield as well as reduce soil degradation and helps to protect environment.

Soil test crop response approach of fertilizer application involved both soil and plant analysis on a scientific basis that proved to be a refined and unique technique for the most efficient use of fertilizers. Several studies have documented the effects of STCR based fertilizer recommendation with integrated plant nutrient systems on soil nutrient status, soil organic carbon pools and potassium dynamics in soils. STCR-based targeted yield approach is aiming at obtaining a basis for precise quantitative adjustment of fertilizer doses under varying soil test values and crop response conditions of the farmers for a targeted yield of the crop. According to the STCR-based research experiment, results show a very close correlation between targeted yield and the yield obtained by the crop.

In recent years, agricultural yields of many crops have been slowly increasing due to a considerable loss in soil fertility and organic matter across the nation. Higher amounts of NPK failed to increase crop yield because of increasing secondary and micronutrient deficiency, as well as incorrect and imbalanced fertiliser application. It is suggested that using organic manure along with balanced fertilisers is a good agricultural practice for sustaining and increasing fertiliser usage efficiency, as well as restoring soil fertility (Verma, 2013). Fertilizers are now an essential component of Indian agriculture and have been crucial in raising agricultural production and consequently supplying the country's expanding population with food.

The best approach of using fertiliser input properly is to apply fertilisers based on soil tests since improper fertiliser application can lead to problems with salt and alkalinity in agricultural land as well as an increase in groundwater contaminants, posing major environmental hazards. Santhi *et al*. (2010) discovered that a complete dependency on mineral fertilisers is neither environmentally friendly nor cost-effective. As a result, developing a comprehensive strategy for fertilizer recommendation based on soil testing becomes extremely important. There are numerous ways for recommending fertilisers, including the General Recommended Dose, the Soil Test and Crop Response Based Recommendation, the Critical Value Approach, and others. While STCR (soil test crop response) provides a correlation between a soil test value and crop yield, fertiliser dose recommendations typically do not account for differences in field fertility levels. One of the most recognisable techniques for determining the soil test-based fertiliser dose and the amount of yield that may be obtained through well-planned agronomic practises is the Soil Test Crop Response (STCR), which is also one of the most well-known strategies for increasing crop yield.

The soil test crop response (STCR) experiment, which was conducted in the field, provided data on a range of soil test values, nutrient uptake, and various targeted yield levels. The four basic parameters of STCR : nutrient requirement per unit grain production, per cent contribution from soil-available nutrients, per cent contribution from applied fertiliser nutrients, and per cent contribution from organic manure nutrients have been generated for major crops from soil test crop response experiment. From this fertilizer prescription equations could be derived for a particular crop and yield. In order to make the agriculture viable and profitable, a rational use of fertilizers based on demand of crops and native nutrient supplying capacity of soil need to be worked out. A higher crop response ratio to fertilisers and a higher B: C (benefit: cost) ratio will result from applying fertiliser doses based on soil test crop response targeted yield equations. Each nutrient is applied according to the crop's nutritional requirements depending on the extent of a specific nutrient deficiency in the crop.

The nutrient use efficiency can be improved by adopting nutrient management programmes which are based on soil properties especially the inherent properties of soil to support plant growth. The soil test data provides the required information about the inherent fertility status of the soil, the amount of available nutrients in the soil and their imbalances. Balanced nutrition does not imply the application of nitrogen, phosphorus and potassium in specific proportions. But it rather implies that the available nutrients are in the sufficiency range in the soil to meet the crop needs to achieve the desired targeted yield levels. It is necessary to supplement crops with both organic and inorganic fertilizer sources to maintain the nutrient supply, correct the deficiency and ensure sustained crop production. Fertilizer recommendations aim to correct the imbalance in nutrients according to crop requirements.

A targeted yield may be obtained by applying integrated plant nutrients based on soil test values and which cannot be attained through the use of fertilizer recommendations based on qualitative or semi-quantitative agronomic methods or other approaches. Therefore, a refined method of fertilizer recommendation for varying soil test values has been developed by Kerala centre of All India Co-ordinated Research Project on Soil Test Crop Response (AICRP-STCR) for some of the crops.

The efficient application of fertilizers can result in optimal crop response, high profit and environmental sustainability. It is beneficial to protect soil health by adopting balanced fertilization through soil testing and adopting an INM approach. Among the various methods and approaches for predicting the fertilizer requirements of crops, the STCR-based targeted yield recommendation is more scientific and economic. In the STCR approach, fertilizer recommendations are made based on the yield target by increasing or decreasing the fertilizer dose based on farmer's resources. This approach is site-specific and situation-specific, which helps the farmer to get targeted yield and thereby profit.

The All India Co-ordinated Research Project on STCR at the College of Horticulture, Kerala Agricultural University, Vellanikkara has been conducting experiments since 1996 in diversified crops. So far targeted yield equations for more than 25 vegetable crops were developed (Sreelatha *et al*., 2014). A targeted yield equation for the vegetable Amaranthus variety Arun grown in the laterite soil of Thrissur and Palakkad has been developed (Annual report on STCR, KAU 2004). Therefore, an experiment was conducted in the southern laterites of (AEU-8) to validate the above-mentioned targeted yield equation. The main objectives of the study were to

Test verify the targeted yield equation developed under AICRP on STCR for (*Amaranthus tricolor*. L) in southern laterites of (AEU-8).

- Study the post-harvest soil quality by analysing the physicochemical and biological characteristics of the soil
- Analyse the nutrient content of plant parts
- Study the nutrient uptake by different plant parts
- Study the correlation between various parameters and yield

2. REVIEW OF LITERATURE

With a rising population, the need for food production is increasing day by day. Soil overexploitation is increasingly growing to fulfill food production demand and this, along with an imbalanced application of nutrients, has resulted in a long-term decline and unsustainability of soil fertility. The maintenance and sustainability of soil health, as well as the delivery of nutrients based on soil tests, provide a solution for growing food demand without harming soil fertility. The integrated application of nutrients, such as the use of inorganic fertilizers in conjunction with organic manure bio-fertilizers, will improve soil fertility. The soil test-based fertilizer recommendation takes into account specific soil types, crops, variety and fertilizer management and when combined with IPNS, will improve crop production as well as the maintenance and sustainability of soil health. The proposed experiment on soil test crop response (STCR) investigations provided the correct stimulation for understanding the variances in soil type, crop and addressing the current challenge encountered by the agricultural system in improving the nutrient usage efficiencies and crop production of each field.

Indian soils are found to be deficient in the available nitrogen and phosphorus. So, to increase the nutrient status of the soil, there is a higher demand for fertilizer application, but due to the high cost of fertilizers and their low usage efficiency, fertilizers should be used judiciously and efficiently (Kadam and Sonar, 2006). The foremost step in knowing the soil fertility status of soil is soil testing. The much-discussed techniques to fertilize the soil and fertilize the crop are balanced by soil test-based fertilizer recommendations, ensuring the true balance between the applied fertilizer nutrients among themselves and with the available nutrients of the soil.

The judicious application of chemical fertilizers in an agricultural system improves the nutritional status of the soil and provides the crop with adequate nutrients to attain optimum yield. Nitrate leaching and its repercussions, such as eutrophication and possible health concerns such as blue baby syndrome are side effects of fertilizer contamination (Savci, 2012). Fertilizers high in salt and potassium have a negative impact on soil pH and the degradation of soil structure. Fertilizers should be applied on a timely basis based on a soil analysis to achieve sustainable agricultural yield.

Scientists have made several successful attempts to calibrate soil testing such that they may be used as a tool for predicting fertilizer recommendations. Many scientists have reported on the cost-effective and judicious application of fertilizers based on soil testing studies. The literature for soil test based fertilizer recommendations for crops is reviewed in this chapter, with a focus on STCR based targeted yield equations.

2.1. Soil testing-based nutrient management in crops

2.1.1 Fertilizer recommendation based on soil fertility class

Bangar and Zende (1978) and Sonar (1984) outlined six categories of soil test fertility classes - very low, low, moderate, moderately too high, high and very high. By decreasing or increasing the general recommendations by 25 or 50 per cent, depending on the condition, the fertilizer doses are adjusted. In this approach, medium soil fertility is equated with the general recommended dose. Most of the fertilizer recommendations issued from soil testing laboratories in India are based on this approach. The soil fertility class rating was developed in 1965 for a variety of crops. Unfortunately, since then these ratings are the same irrespective of types of soils and varieties of crops.

Nambiar *et al*. (1977) proposed a ten-class system, which enables more precision in fertilizer doses based on soil test data. Kerala soil testing institutions employed this approach to make fertilizer recommendations for crops based on soil testing.

2.1.2. Fertilizer recommendations for critical levels

Cate and Nelson (1965) developed the critical soil test level concept and suggested that level of nutrient below which reasonably satisfactory economic response could be expected from the application of a particular soil nutrient and above which the probability of such response is less. developed a critical soil test level concept of available nutrients as a primary limiting factor. The simplified method for studying the relation between STVs and percentage yield of the maximum. The critical limits of available nutrients are established by adopting graphical procedures.

2.1.3. Fertilizer prescription based on the Mitscherlich-Bray concept for a certain per centage of maximum yield

Bray (1954) gave the concept of nutrient mobility which provided the probability behind efficiency factors the soil and fertiliser forms of comparatively immobile nutrients. Accordingly, the mistcherlich equation was modified by Bray by the introduction of efficiency co-efficient to soil test values and applied nutrients. Mitscherlich-Bray equation:

$$\log (A-y) = \log A - C_1 b - Cx$$

where A is the theoretically calculated maximum yield of crops, y is the maximum yield of crops (%), x is the dose of fertilizer applied, C_1 and C are the efficiency factors for soil and fertilizer nutrients, respectively.

2.1.4. Fertilizer recommendation for maximum yield

2.1.4.1 Deductive Approach

The deductive approach developed by Colwell (1968) involves the conduct of multilocation trials scattered over a large area and the pooled data are utilised to establish soil test crop response (STCR) correlation. Many workers have adopted Colwell's approach for soil test calibrations and optimisation of fertilizer nutrients for different crops (Velayutham *et al*., 1978 and Mosi *et al*., 1987). Based on Colwell's approach, multi-location STCR experiments were conducted in farmer's fields under the All India Co-ordinated Research Project (AICRP) for investigations on STCR Correlation. Velayutham *et al.* (1985) reported that the data from these experiments have not met with much success in deriving soil test based fertilizer calibration in India. The data from multi-location trials showed insignificant correlation in most cases, which might be due to heterogeneity in the soil population studied, climatic conditions and management practices vitiating the real relationship (Reddy *et al*., 1985). Velayutham *et al*. (1978) used this model to derive location specific fertilizer recommendations for wheat grown in black soils. Multilocational soil test crop response experiments in farmer's fields were conducted in All India Co-ordinated Research Project on Soil Test Crop Response Correlation studies based on Colwell's approach and optimization of fertilizer nutrients was done for crops as rice, millets, groundnut and cotton (Anon, 1982). However, the data from these experiments have not met with much success in deriving soil test based fertilizer calibrations in India (Velayutham *et al*., 1985).

2.1.4.2. Inductive Approach

The inductive approach was developed by Ramamoorthy (1968). This involves creation of large variations in soil test values in one and the same field in a particular locality and then superimposing the complex soil fertility evaluation trial in the same field to deduce response information. This helps to minimise the variations caused due to uncontrollable factors like climate and management. This approach was further modified by Ramamoorthy and Velayutham (1971) and is being followed in All India Co-ordinated Soil Test Crop Response Correlation Project of the Indian Council of Agricultural Research.

Ramamoorthy *et al*. (1967) suggested a realistic and more practical approach for prescribing fertilizer doses based on soil test values for attaining either maximum yield or maximum profit, based on the creation of artificial fertility gradients i.e. inductive approach. In this approach, Ramamoorthy and Mahajan (1974) established a significant relationship between soil tests, fertilizer doses and crop yield by fitting a multiple regression of the quadratic form taking linear terms of soil and fertilizer nutrients and interaction terms of soil and fertilizer nutrients. By conducting gradient experiment, a range of soil test values are created in one and the same field for minimizing interference of other factors affecting crop yield and relate them through multiple regression with curvilinear response function**.**

$$Y = A \pm b_1 SN \pm b_2 SN^2 \pm b_3 SP \pm b_4 SP^2 \pm b_5 SK \pm b_6 SK^2 \pm b_7 FN \pm b_8 FN^2 \pm b_9 FP \pm b_{10} FP^2 \pm b_{11} FK \pm b_{12} FK^2 \pm b_{13} FN\,SN \pm b_{14} FP\,SP \pm b_{15} FK\,SK$$

where, Y - crop yield (kg ha^{-1}), A - intercept (kg ha^{-1}), b_1 to b_{15} - regression coefficients; SN, SP and SK are soil available N, P and K (kg ha^{-1}) respectively and FN, FP and FK are fertilizer N, P_2O_5 and K_2O (kg ha^{-1}) respectively.

2.1.5. Fertilizer Recommendation through STCR-based Targeted yield equations

Troug (1960) illustrated the possibility of 'Prescription method' of fertilizer use for obtaining high yields of maize using empirical values of nutrient availability from soil and fertilizer. However, Ramamoorthy *et al.* (1967) the theoretical basis and field experimental proof and validation for the fact that Liebig's 'Law of Minimum' of Plant nutrition operates equally well for N, P and K for the high yielding varieties of wheat, rice and pearl millet, although it is generally believed that this law is valid for N and not for P and K which were supposed to follow the per centage sufficiency concept of Mitscherlich and Baule and Mistcherlich and Bray. Among the various methods of formulating fertilizer recommendations, the one based on yield targeting is unique in the sense that this method not only indicates soil test based fertilizer dose but also the level of yield the farmer can hope to achieve, if good cultivation package is followed in raising the crop (Velayutham, 1979) by utilizing empirical data on nutrient availability from soil and fertilizer, he proposed the ability of fertilizer prescription method for enhancing maize yields.

The STCR based targeted yield equations used in the present day were based on previous studies done by – Ramamoorthy and Velayutham (1971). Ramamoorthy *et al*. (1967) demonstrated that Liebig's law of minimum applied equally well to N, P and K in wheat (Sonora-64) even though it only applies to mobile nutrients like N. There is a clear linear relationship between grain yield and total nutrient uptake. They've concentrated on the theoretical aspects of fertilizer recommendation for wheat *var*. Sonora-64 targeted yield. As a result, they proposed Troug's (1960) targeted yield method, in which balanced fertilization can be utilized to attain various production targets.

Ramamoorthy and Mahajan (1974) reported that the targeted yield method is used to determine the appropriate fertilizer dose. This method determines the fertilizer dose by taking into account the quantity of nutrients removed from each unit of economic produce, the fertility status of the initial soil samples, the efficiency of nutrients already present in the soil and nutrients added through fertilizer and possibly the nutrient interactions. As a result, it is based on the concept of a balanced nutrient content in the soil. In this context, the STCR trials are aimed not only at increasing yields but also at reducing fertilizer use (Singh and Sharma, 1978).

Dey (2015) reported that during the past 40 years, the STCR project has produced a number of fertilizer adjustment equations for obtaining desired yields of significant crops on various soils in various agroecological zones of the country. These equations for fertilizer adjustment have been tested in follow up and frontline demonstrations have been carried out across the nation. In these studies, rates of fertilizer application based on soil tests enabled researchers to achieve higher response ratios and benefit-cost ratios across a wide range of agroecological zones.

2.2. Fertilizer recommendation through STCR based Targeted yield equations

Ramamoorthy and Pathak (1969) confirmed that fertilizer recommendations based on targeted yield methodologies are superior to blanket doses, according to several studies. A targeted yield technique would be the most cost-effective fertilizer application. Troug (1960) established the targeted yield approach principle, which Ramamoorthy *et al*. (1967) adapted appropriately. The fertilizer dose calculated using this method ensures balanced fertilization of the crop, preserves soil fertility and reduces fluctuations in the yield. The utility of this concept has been demonstrated in experiments taken under the All-India soil test crop response correlation scheme and others (Ramamoorthy and Pathak, 1969; Tandon, 1976; Mosi *et al*., 1976 and Sekhon *et al*., 1976). Balasundaram (1978) discovered a solid phosphorus relationship based on post-harvest soil test data. Velayutham (1979) discovered equations that satisfy the twin objectives of maximizing profit from fertilizer nutrients while preserving soil fertility. Dhavan *et al*. (1989), Maragatham and Chellamuthu (2001) and Rao and Srivastava (2002) also reported similar work with post-harvest soil test values. This approach considers a nutritional requirement (NR) of a crop for producing a unit quantity of economic yield, the per centage contribution of nutrients from the soil (C_s) by a particular soil test and the per centage contribution of nutrients from additional fertilizer (C_f). As shown below, these three parameters are utilized to relate yield target (T) to soil nutrients (S) and fertilizer nutrients (F):

$$FD = \{(NR \times 100\ T) / C_f\} - \{(C_s \times STV) / C_f\}$$

When the yield target (T) is used in IPNS conditions along with the fourth parameter, the per cent contribution of nutrients from additional organic manures or biofertilizers (C_o), the equation takes on the form shown below:

$$FN = \{(NR \times 100\ T) / C_f\} - \{(C_s \times SN) / C_f\} - \{(C_o \times ON) / C_f\}$$

This methodology, known as the "Inductive cum Targeted yield strategy", when combined with inductive methodology provides the basis for the ICAR-sponsored All India Coordinated Research Project for Soil Test Crop Response Correlation Studies (AICRPSTCR). Based on this approach, fertilizer prescription equations under NPK alone and IPNS were developed for a variety of crops and field experiments were carried out in all of the project's participating centres (Rao and Srivastava, 2001a & b, Muralidharudu *et al*., 2007 and 2011). For a diversity of 41 soil-crop conditions in Tamil Nadu, the integrated fertilizer prescriptions based on soil tests and yield targets are recorded in a handbook by Santhi *et al*. (2010a).

2.3. AICRP on STCR

Troug was the first to establish the concept of a fertilizer prescription equation for a targeted yield target in 1960, as previously mentioned. Ramamoorthy established the theoretical foundation and experimental technique for Indian conditions in 1967, proving a linear link between yield and nutrient uptake. Fertilizer requirements for a specific quantity of yield of any crop can be determined based on soil efficiency and fertilizer nutrients. Following that, the ICAR launched the AICRP on soil test crop response (STCR), which aims to create soil test-based fertilizer recommendations for various crops. Dr. B. Ramamoorthy and co-workers, famous soil scientists, started the project in 1967-68 at IARI, New Delhi, with eight centres in various locations. Five more facilities were added in 1970-71. Presently, the STCR project is working with twenty-five centres. The coordinating cell of the project is at ICAR -Indian Institute of Soil Science, Bhopal.

2.4. STCR- IPNS system

All the 25 cooperating centres of AICRP on STCR have generated technologies for an integrated supply of plant nutrients involving fertilizers, organic manures and biofertilizers.

The STCR method adapts fertilizer nutrient doses to those produced by other organic sources such as FYM, green manure, composted crop wastes and bio-fertilizers including *Azospirillum* and *Phosphobacteria*, as well as those provided by the soil. Because the current demand for chemical fertilizers is 32 MT and only 22 MT are used, a 10 MT scarcity is coming, requiring the usage of chemical fertilizers alongside organics (Dey, 2015). Furthermore, organics will help to preserve soil health and production by improving the physical, chemical and biological aspects of the soil.

A field experiment was conducted by Ammal *et al*. (2020) at Arachikuppam village, Puducherry, using an integrated plant nutrient management system based on the STCR technique to generate a fertilizer prescription equation for rice. With the soil test values and the N, P and K fertilizer doses, the yield of rice grain and straw was significantly improved. According to the experiment, 1.46 kg of nitrogen, 0.60 kg of P_2O_5 and 1.12 kg of potassium were needed to produce 1 quintal of rice grains. For N, P_2O_5 and K_2O, 20.18, 21.39 and 19.52 per cent nutrient contribution of soil, 39.04, 39.39 and 70.97 per cent contribution from fertilizers and 23.06, 30.40 and 55.03 per cent contribution from organic manure. The targeted yield concept has been used to calibrate the soil test-based fertilizer adjustment equations for particular targets of rice grain yield of 7.0 and 8.0 t ha^{-1}. These fertilizer prescription equations developed for rice (*var.*) White Ponni can be used to calculate fertilizer doses formulated for a range of soil test values and targeted yield under NPK alone and IPNS (NPK + FYM).

Udaykumar and Santhi (2017) experimented on an Inceptisol for (STCR-IPNS) Soil Test Crop Response correlation studies under Integrated Plant Nutrition System for pearl millet in the Western zone of Tamil Nadu based on the targeted yield concept. N, P_2O_5 and K_2O nutrient requirement for pearl millet (NR) were reported to be 2.87, 1.27 and 2.59 kg q^{-1}, respectively. For N, P_2O_5 and K_2O, the per cent nutrient contribution from the soil (C_s) was 23.48, 32.76 and 11.10; from fertilizers (C_f), it was 47.45, 45.59 and 78.52; and from organic manure (C_o), it was 38.03, 19.28 and 37.58 respectively.

Fertilizer prescription equations (FPEs) have been developed using the fundamental data *viz.*, NR, C_s, C_f and C_o and a ready reckoner of fertilizer doses has been formulated for the desired yield targets of pearl millet for a variety of soil test values on Inceptisol. The results also showed that the prescribed fertilizer doses for pearl millet 40, 24 and 28 kg ha^{-1} of N, P_2O_5 and K_2O could be decreased when farm yard manure (FYM) was applied at 12.5 t ha^{-1} (with 24 % moisture and 0.53, 0.26 and 0.50 % NPK, respectively).

An experiment was conducted by Gayathri *et al*. (2009) soil test-based fertilizer prescription equations under the Integrated Plant Nutrition System (STCR-IPNS), were developed for potato on Ultisols. These equations were used to create nomograms for a wide range of soil test values and potato yield targets. When these equations were tested on farmer's fields, it was found that more than 90 per cent of the targets were achieved and STCR - IPNS for 40 t ha^{-1} recorded significantly higher response ratio (38.05 kg^{-1}) and benefit-cost ratio (15.3) over other treatments indicating the validity of the equations for prescribing fertilizer doses for potato.

According to Katharine *et al*. (2014), soil test-based fertilizer prescription equations (FPEs) were developed for the desired targeted yield of transgenic cotton under Integrated Plant Nutrition System (IPNS) drip fertigation on Vertic Ustropept in Tamil Nadu, South India. The results showed that the deviation recorded in the achievement of the desired target was within range of ±10 per cent, proving the validity of the FPEs. STCR treatments significantly influenced crop development and yield parameters and recorded a significantly higher yield, response ratio (RR) and benefit-cost ratio (BCR) than blanket, farmer's practice and control treatments respectively. Treatments of STCR-IPNS performed better than those using STCRNPK alone. In the STCR treatments, post-harvest soil fertility increased. STCR-IPNS for 4.0 t ha^{-1} of cotton proved its superiority over all other treatments in terms of yield, uptake, response ratio, BCR and quality parameters. This treatment increased yield by 62.4 and 65.6 per cent over the blanket and farmer practices respectively. As a result, it is possible to conclude that these FPEs could be used to prescribe soil test-based fertilizer doses for transgenic cotton on Inceptisols under drip fertigation.

A field experiment was done by Santhi *et al.* (2010) on Vertic Ustropept soils in Tamil Nadu during to determine the link between soil tests and the response of Ashwagandha to applied fertilizers under the Integrated Plant Nutrition System (STCR-IPNS) by following Ramamoorthy’s Inductive cum targeted yield model. The basic parameters, nutrient requirement, the contribution from soil, fertilizers and FYM, were computed using data on dry root yield, initial soil test values on available NPK, fertilizer and farm yard manure (FYM) doses applied and NPK uptake. It was observed that one-tonne dry root of Ashwagandha required 77.6, 31.7 and 113.3 kg of N, P_2O_5 and K_2O, respectively. The per cent contribution of nutrients from soil, fertilizer and FYM were 19.03, 31.30 and 23.14 for N; 20.26, 17.30 and 6.38 for P_2O_5; and 11.08, 62.53 and 30.39 for K_2O respectively. Using these basic parameters, fertilizer prescription equations for ashwagandha (*var.* JA 20) were developed and fertilizer dose estimates were calculated for a range of soil test values and desired yield targets under NPK alone and IPNS (NPK + FYM).

Organic or biofertilizer treatments were also used in STCR correlation studies as part of an integrated plant nutrition system (Raniperumal *et al*., 1984; Murugappan, 1985; Sumam, 1988; Swadija *et al*., 1993; Maragatham, 1995; Santhi, 1995; KAU, 1996 and Andi, 1998). The implementation of an Integrated Plant Nutrition System (IPNS) in vegetable cowpea resulted in the conservation of fertilizer nutrients. Fertilizer requirements for the same quantity of crop output varied depending on soil test findings. As a result, soil testing and balanced fertilization are becoming increasingly important for increasing crop yield (Beena *et al*., 2019).

2.5. Effect of STCR- IPNS system on crop production

Suganya and Manickam (2016) reported that the soil test crop response (STCR) strategy for targeted yield is unique in providing information on both soil test-based fertilizer dose as well as the amount of yield that can be attained with appropriate agronomic methods. As a raw resource for starch-based industries, Cassava plays a key role in the food, nutritional and employment security of the rural population around the world. Cassava is typically grown in Ultisols, Alfisols and Entisols which are poor in fertility. In terms of tuber yield and starch, the treatments differed significantly. STCR-based fertilizer application combined with composted poultry manure @ 10 t ha^{-1} resulted in maximum tuber yields of 42.50 t ha^{-1} and 49.70 t ha^{-1} for yield targets of 40 and 50 t ha^{-1}, respectively and a higher BCR (4.49). The same treatments produced the highest starch content of 26.9 and 25.4 per cent respectively. As a result, this novel nutrition approach of STCR-based IPNS for targeted yield plays vital role for balanced nutrition, sustainable crop productivity and increasing profit.

Field studies were carried out by Sherene *et al.* (2021) for two seasons under cassava in red sandy loam soils (Typic Rhodustalf) in Yethapur at the Tapioca and Castor Research Station, Yethapur, using the variety ‘Tapioca YTP-1’. To investigate the influence of STCR based integrated plant nutrient supply (IPNS) for targeted yields on growth, yield, quality and economics under irrigated conditions, eleven treatments were replicated three times in a randomized block design. The STCR-IPNS technology was used to estimate fertilizer doses based on soil test results and a targeted yield of 60 q ha^{-1} and it was compared against farmer’s practice. The exhibited STCR-IPNS method increased rice yield by 41.68 and 38.34 per cent over farmer's practices in sodic soil, respectively, for medium fine and bold rice varieties. The net return from the shown STCR-IPNS technology was found to be ₹ 42,000 and ₹ 44,000, respectively, as compared to farmers' practices of ₹ 21,000 and ₹ 17,500 for medium fine and bold rice types. For medium fine and bold rice, respectively, the benefit-cost ratios of STCR technology with farmers' practices were 2.16 and 2.25 and 1.55 and 1.46. The STCR-IPNS technology, which involves applying fertilizer doses based on initial soil test values with FYM @ 12.5 t ha^{-1} and gypsum application, was popular in altering farmers' attitudes, skills and knowledge and can be advised for achieving higher yields (i.e. up to 6 t ha^{-1}), response ratios and BCR for rice on Alathur series (Vertic Ustropept) and related soil series, particularly sodic soils of Tamil Nadu. Also, this strengthened the bonds of trust between scientists and farmers.

Reddy (2022) conducted a study on soil test crop response based integrated plant nutrition system (STCR - IPNS) to develop STCR and STCR-IPNS fertilizer prescription equations (FPEs) for achieving desired yield targets of maize. Fertilizer doses at varying soil test values, for attaining 60, 80 and 100 q ha^{-1} target grain yield of maize have been worked out based on the initial soil test values of available N, P and K and the quantities of N, P and K added through farm yard manure (FYM). The results of the experiment indicated that at both locations, the per cent achievement of the targeted yield was within ± 10 per cent variation proving the validity of the equations for prescribing integrated fertilizer doses for maize. The highest grain yield was recorded in the STCR-IPNS equation with 100 q ha^{-1} target yield recording an increase of 67 and 69 per cent over the recommended package of practices at Dharwad and Belagavi, respectively. Higher gross returns were recorded under the STCRIPNS equation with 100 q ha^{-1} target yield owing to higher grain and stover yields. While the STCR equation developed at Jabalpur with 100 q ha^{-1} target yield recorded higher net returns. The post-harvest soil available NPK indicated better build-up and maintenance of soil fertility by the soil test-based fertilizer recommendation under IPNS. Targeting 100 q ha^{-1} grain yield for maize under the STCR approach was found to be ideal in terms of yield, economics and soil fertility maintenance in the Vertisols of Karnataka. The fertilizer prescription equations developed for maize under IPNS can be recommended for Vertisols of North Karnataka for achieving a target yield of 100 q ha^{-1} with sustained soil fertility and it can be extrapolated to other agro-climatic zones of Karnataka on similar and allied soil types.

According to Magheshan and Ammal (2022) the integrated plant nutrient system (IPNS) technology, which is based on soil test crop response (STCR), adapts fertilizer doses to the demands of estimated crop yield, taking into account the crop's nutrient requirements as well as the contribution of nutrients from the soil, fertilizers and organic manures. A field experiment was conducted in Puducherry's Bahour soil series to determine the quality of the okra modified in response to the application of manure and fertilizer based on STCR. Ten treatments were used in the trial, including the control, farmer's practice, FYM alone at 12.5 t ha^{-1}, blanket suggestion, STCR-NPK alone at 160, 170 and 180 q ha^{-1} and STCR-IPNS at 160, 170 and 180 q ha^{-1}. Fruit samples were taken at the fifth, twelfth and nineteenth pickings and quality indicators were examined. The mucilage (4.54 %), protein (1.84 %), starch (4.95 %) and ascorbic acid (13.99 mg per 100 g) content of okra was improved after the application of STCR + IPNS - 180 q ha^{-1}. With the STCR-IPNS technology, crops are produced sustainably and expensive fertilizer is used judiciously.

2.6 STCR studies in Kerala

The need for alternative soil test-based suggestions against the Kerala state's existing methods was identified by Hassan *et al*. (2001). Kerala Agricultural University has developed targeted yield equations for around 25 crops since 1996 (KAU, 2018). According to the studies reported by Swadija *et al*. (1993) in rice, Swadija (1997) in cassava, Jayalakshmi (2001) in ginger, Nagarajan (2003) in coleus and Sidha (2005) in groundnut respectively produced the majority of the equations for the varied targeted yield and have been validated by the farmers in the field. For the laterite soils of Kerala, targeted yield equations have been developed for banana, turmeric and rice varieties like Aiswarya and Kanakam, sweet potato, ash gourd, bhindi, snake gourd, brinjal, chilli, pumpkin, coleus, groundnut, cucumber, bitter gourd and amaranthus. KAU (2008) conducted frontline demonstration experiments on crops such as the Nendran variety of banana, turmeric and cassava.

Lamina (2009) experimented with oriental pickling melon to test and verify the targeted yield equations developed under AICRP on the STCR centre, KAU, Vellanikkara, Kerala.

According to Sajnanath (2011), an experiment was conducted in STCR on cucumber in the laterite soils of Kerala. The targeted yield equations developed for cucumber produced the yields of 30 and 35 t ha^{-1} upon validation of STCR based fertilizer recommendations.

According to Bastin *et al*. (2013), a fertilizer level suggested for 30 t ha^{-1} is utilized and the equ ation developed for the Nendran banana variety proved that it could provide a 30-33 t ha^{-1} yield. Under the auspices of the AICRP on STCR, Kerala Agricultural University established targeted yield equations for turmeric with yield targets of 25 and 30 t in the variety Kanthi. For production targets of 20 and 25 t, targeted yield equations were developed for the first and second crops of amaranth in the varieties Kannara local and Arun (Sreelatha *et al.,* 2014).

A field experiment was carried out by Beena *et al.* (2018) on Ultisol of the STCR field, KAU, Thrissur, utilizing an integrated plant nutrient management system based on the STCR method, to develop fertilizer prescription equations for vegetable cowpea. Four essential basic parameters, including the amount of nutrients needed to produce one tonne of pod yield (NR), the contribution of nutrients from fertilizers (% CF), the contribution of nutrients from the soil (% CS) and the contribution of nutrients from organic matter (% CFYM), were obtained from soil test data, cowpea pod yield and NPK uptake by cowpea. Cowpea nutrient requirements in terms of N, P_2O_5 and K_2O to produce one tonne of pod yield were 10.82, 0.52 and 8.00 kg, respectively. The nutrient contribution from soil, fertilizer and FYM was 12.85, 14.28 and 0.65 for N; 10.53, 0.71

and 0.55 for P_2O_5 and 6.26, 2.58 and 0.84 for K_2O, respectively. Using these fundamental characteristics, a simple reckoner of fertilizer doses for different soil test values and desired yield targets of vegetable cowpea for NPK alone and NPK + FYM was developed.

2.7.1. Nutrient interactions of Nitrogen

Between N and P, there is a synergistic relationship. According to Terman *et al*. (1977), plants absorb more P when they are exposed to nitrogen. Three greenhouse pot experiments with corn (*Zea mays* L.) were conducted to study the effects of multiple rates of applied N, P and K on growth and yield-nutrient concentration trends. In young maize plants, applied N also improved P concentrations and uptake of the plants. Even at the earliest harvest, the yield response to applied K resulted primarily in the dilution of N and P concentrations. According to Kemp (1983), depending on the K levels in the soil, increasing nitrogen concentration in the soil can have varied impacts on K levels in plant tissues. When nitrogen dosages are increased, more K uptake is observed in soils that are rich in K and vice versa.

2.7.2. Nutrient interactions of P

Plant growth and N uptake were influenced by P (Sumner and Farina 1986). P and Mg are said to have a positive interaction because Mg is the activator of the Kinase enzyme, which is involved in most processes involving the transfer of the phosphate functional group. According to Murphy *et al*. (1981), luxurious uptake of the P occurs, when a higher amount of P is supplied and it can lead to micronutrient deficiencies like Fe and Zn. Smilde (1973) noticed a greater uptake of Mn due to the soil acidifying impact of P.

2.6.3. Nutrient interactions of K

Streeter (1984) reported that K facilitates the efficient utilization of nitrogen in agricultural plants because the uptake of N as NO_3^- through the plant root is an active process that is aided by K. Potassium inhibits the absorption of calcium and magnesium (Fageria, 2001). Gupta (1979) discovered a similar effect in B, where he noticed a drop in B content in plant tissues as the amount of K applied increased. When Mn is available in low amounts in soil, increasing doses of K improve Mn uptake, whereas when Mn is present in higher amounts in soil, increasing doses of K hinder Mn uptake (Ramani and Kannan, 1974). Shukla and Mukhi (1980) reported that increased K application increased Zn consumption in corn.

2.8. Effect of different nutrients in Amaranthus

2.8.1. Influence of chemical fertilization

In *Amaranthus tricolor*, Madhukar (2019) reported that the effect of NPK fertilizer on plant height may also be due to the increased decomposition of organic matter and mineralization of nutrients, particularly N and K. The effectiveness of targeted yield-based STCR treatments could be due to the balanced supply of nutrients in the required quantity based on the initial soil fertility status and differing yield targets. He also observed that the increase in stem diameter may be due to the increased availability of nutrients in the soil which enhance the nutrient absorption by the crop because the N applied through fertilizer increased the photosynthetic efficiency of leaves. The availability of more photosynthates resulted in higher stem diameter.

Akinbile *et al.* (2016) in *Amaranthus cruentus*, addition of NPK was found to improve organic material decomposition and the mineralization of nutrients, particularly N and K.

According to Kushare *et al*. (2010) the application of FYM and inorganic fertilizer in rabi grain amaranth (*Amaranthus hypochondriacus* L.), influenced the stem girth recorded at different growth stages. It was observed that stem girth was statistically higher with the application of FYM @ 10 t ha^{-1} (3.65 cm) and remained at par with the application of FYM @ 5 t ha^{-1} (3.54 cm) over control (3.16 cm). Charachimwe *et al.* (2018) did a study and observed that the pigweed *Amaranthus cruentus* responded to organic and inorganic fertilizers and they found that 400 kg ha^{-1} of NPK produced the largest mean stem girth (0.897 cm), whereas 10 t ha^{-1} of control produced the least stem girth (0.203 cm).

Dehariya (2019) observed that Amaranthus grows longer leaves when sufficient N is provided. Hewitt and Smith (1975) also found that N application promotes leaf length growth in *Amaranthus* at different levels, resulting in increased leaf yield and quality. Leafy vegetables in terms of leaf yield tend to respond well to nutrient supplies that enhance vegetative growth

Thakur *et al*. (2021) reported that optimal nutrition levels were observed to improve the leaf length of *Amaranthus* drastically. Gamel *et al.* (2004) in *Amaranthus caudatus* studied that the optimum levels of nutrients were found to significantly improve leaf length. Rana *et al.* (2006) in *Amaranthus hypochondriacus* L. reported that the optimum levels of nutrients were found to significantly improve leaf length. Dehariya *et al.* (2019) in *Amaranthus tricolor* L. did a study about leaf length and a significant difference was seen in connection to the application of N at various amounts. At the time of the final harvest, *Amaranthus* leaf length increased gradually at all doses of N application.

In *Amaranthus* sp. Hewitt and Smith (1975) stated that N stimulates leaf development and growth in plants, which is directly connected to leaf width. Khurana *et al.* (2016) reported that *Amaranthus* sp. leaf width improved with increasing N levels. It was discovered that the *Amaranthus* sp. leaf width increased continuously at several growth stages and was one of the plant's major yield-contributing factors. Dehariya (2019) observed increased leaf width in *Amaranthus* and suggests that varied doses of N application promote the increased leaf width. Dehariya (2019) in *Amaranthus tricolor* L. also found that N increased plant growth as well as the number of leaves per plant.

Chakhatrakan (2003) and Olaniyi *et al.* (2008) in vegetable amaranth reported that the increased doses of N increased the mineral nutrient contents in various plant parts of grain amaranth.

The application of N significantly increased the total fresh weight of *Amaranthus* as reported by Murdiono (2019) and N needed by *Amaranthus* could be fulfilled from the supply of urea fertilizer. This was probably due to increased photosynthetic activity and there was an accumulation of carbohydrates in leaves, thus increasing the leaf’s fresh weight.

In *Amaranthus,* slower growth in plants grown in plots treated with NPK and poultry manure was observed as a drawback during the early weeks after transplanting (Oyedeji, 2014).

2.8.2 Effect of integrated plant nutrient system in *Amaranthus*

A field trial was conducted by Preetha *et al*. (2005) on amaranth (*Amaranthus tricolor* L.) with various quantities of vermicompost generated using ayurvedic pharmaceutical wastes (from Oushadhi Pharmaceuticals, Thrissur), farm yard manure (FYM) and inorganic fertilizers. Five tonnes of vermicompost mixed with 50:50:50 kg ha^{-1} of N : P_2O_5 : K_2O had the maximum vegetative yield and nutrient uptake, followed by 2.5 tonnes of vermicompost + NPK, indicating the synergistic effects of the combined application of vermicompost and chemical fertilizers in amaranth cultivation. Ramesha (2017) reported that the effect of thermochemical organic fertilizer improved the biometric characteristics of *Amaranthus.* It is an effective and efficient substitute for conventional organic manures. The fortification of thermochemical organic fertilizer with nutrients leads to increased productivity and profitability in *Amaranthus*.

During 2009-2011, an experiment was carried out by Vipitha (2016) at the College of Agriculture, Vellayani to study the growth, productivity and economics of *Amaranthus* as influenced by the performance of bio-organic composite manure and microbial consortium. T_1 (coir pith compost – 50 g, ground nut cake – 35 g and ash – 15 g) had the maximum number of leaves per plant and the highest dry matter (25.6 g $plant^{-1}$ and 1481.92 kg ha^{-1}, respectively) and T_5 (poultry manure- 50 g, ground nut cake – 30 g, rock dust- 19 g and microbial consortium – 1 g) had the highest leaf: stem ratio of 2.47. Among the treatments, T_5 had the highest yield, which was on par with T_1 and T_2 (poultry manure- 50 g, ground nut cake– 30 g, rock dust- 20 g). According to the study, an economics of such cultivation practices T_5, with a net return of ₹ 130800/- per ha and a BC ratio of 2.2, was the most cost-effective treatment.

The literature related to the impact of varying doses of inorganic fertilizers and IPNS on growth components, yield attributes, yield, total nutrient uptake by *Amaranthus*, soil available nutrient status, soil enzymatic activities, validation, the economics of developed fertilizer prescription equations and the approaches currently used for nutrient management fertilizer prescriptions have been reviewed and conferred in this chapter for further enhanced understanding of the planned research work. Yield targeting emerged as a highly promising tool among the various ways for making fertilizer recommendations according to the literature review. This method not only calculates the amount of fertilizer to apply based on a soil test but also the amount of yield a farmer can expect if good agronomic practices are used in crop production. It establishes the scientific basis for the judicious application of fertilizers. Farmers have not adopted the equations developed as part of the study on their farms. This implies the need to make these equations more widely known among farmers. To popularize the technology, we must test the equation's validity in various agroecological zones. The goal of this study is to test and evaluate the targeted yield equations developed under AICRP on STCR, Vellanikkara for Amaranthus in AEU-8, Thiruvananthapuram.

3. MATERIALS AND METHODS

The current work entitled “Evaluation of STCR based targeted yield equations of Amaranthus (*Amaranthus tricolor* L.) in southern laterite soils (AEU-8) of Kerala," was conducted in the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani during 2021-22. In this work, a field experiment based on randomized block design was carried out to test and validate the targeted yield equation produced by STCR 2014 for the cultivation of Amaranthus at (AEU-8), College of Agriculture, Vellayani, Thiruvananthapuram. The initial soil fertility status and the nutritional status of the organic manures used in the experiment were analysed. This chapter discusses the layout of the field experiment carried out, the standard procedures followed for the analysis of soil and plant samples, biometrical observations and yield data, dry matter production, and statistical analysis of the data generated.

3.1. Initial properties of soil

Soils were collected from a depth of 0 to 15 cm and it’s initial physicochemical and biological characteristics were analysed. The procedures followed for the analysis of soil samples are listed in table 1.

3.2. Nutrient status of Organic Amendment

The organic sources used in the experiment *viz*., fresh cow dung and FYM were analysed for the nutrient status of total N, P and K by following the procedures given in table 6.

3.3. Field Experiment

A field experiment in a randomized block design was conducted to assess the response of the Amaranthus crop in lateritic soils (AEU-8) grown as per the management practices based on the targeted yield equations developed by AICRP on the STCR project (Sreelatha *et al*., 2014).

3.3.1. Experimental site

3.3.1.1. Location

The field was situated at 8°5' N latitude and 76°9' E longitude and an altitude of 29 m above mean sea level located in (AEU-8) at the College of Agriculture, Vellayani, with predominant soil type as the red loam and falls under Vellayani series.

3.3.1.2. Cropping season

The crop was grown during the summer season (March 2022 to June 2022).

3.3.2. Experimental materials

3.3.2.1. Crop and Variety

Amaranthus variety Arun, with characteristic deep red coloured leaves, was used in the experiment.

3.3.2.2. Source of Seed Material

The seeds of the variety Arun were procured from Instructional Farm, College of Agriculture, Vellayani. Seedlings of Amaranthus were raised in pro trays and transplanted to the main field after 25 days of sowing.

Fig. 1: 25 DAS seedlings in the pro tray

3.3.2.3. Fertilizers and Manures

Farmyard manure, fresh cow dung and vermicompost obtained from the Animal Husbandry unit of the College of Agriculture, Vellayani were used as organic manure sources in the experiment. The liming material for the experiment was dolomite.

Table 1. Methodology of analysis of physical and chemical properties

Sl. No.	Parameter	Method	Reference
1	Bulk density	Undisturbed core sample	Blake (1965)
2	Particle density	Pycnometer method	Vadyunina and Korchagina (1986)
3	Porosity	Calculation using bulk density and particle density	Danielson and Sutherland (1986)
4	Soil texture	Bouyoucos hydrometer method	Bouyoucos (1936)
5	Water holding capacity	Core method	Guptha and Dakshinamoorthy (1980)
6	pH	Potentiometry method (w/v) (1:2.5 soil water ratio)	Jackson (1973)
7	EC	Conductivitymetry (w/v) (1:2.5 soil water ratio)	Jackson (1973)
8	Organic carbon	Walkley and Black method	Walkley and Black (1934)
8	Available N	Alkaline permanganate method	Subbiah and Asija (1956)
9	Available P	Bray No. 1 extraction and estimation using a spectrophotometer	Bray and Kurtz (1945)
10	Available K	Neutral normal ammonium acetate extraction and estimation using flame photometer	Jackson (1973)
11	Available Ca and Mg	Versanate titration method	Hesse (1971)
12	Available S	Extracted using 0.15% $CaCl_2$ and estimation turbidimetrically by $BaCl_2$ using spectrophotometer	Massoumi and Cornfield (1963)
13	Available Fe, Mn, Zn, and Cu	0.1.N HCl extraction and estimation using atomic absorption spectrophotometer	Sims and Johnson (1991)
14	Available B	Hot water extractable B estimation using spectrophotometer	Gupta (1967)

The inorganic sources of nitrogen (N), phosphorus (P), and potassium (K) were urea (46% N), rajphos (20% P_2O_5) and muriate of potash (60% K_2O) respectively.

Sulphate of Potash (SOP) was additionally applied for the organic treatments. Liming material 350 kg ha^{-1} and vermicompost 1 t ha^{-1} were applied to all treatments following each harvest by Kerala Agricultural University (KAU, 2016) Package of Practices Recommendations.

3.3.2.4. Design and Layout of experiment

Crop	:	Amaranthus
Variety	:	Arun
Spacing	:	30 cm x 20 cm
Plot size	:	1.8 x 1.2 m^2
No. of plots	:	20
Design	:	RBD
Treatments	:	5
Replications	:	4
No. of plants per plot	:	35

3.3.2.5. Treatments

Treatments T_3, T_4 and T_5 made use of the targeted yield equation below for Amaranthus with FYM created by AICRP on STCR at Vellanikara.

$$FN = 3.50T – 0.10SN – 0.19ON$$

$$FP_2O_5 = 1.44T – 2.58SP – 0.30OP$$

$$FK_2O = 1.35T – 0.06SK – 0.13OK$$

T	= Targeted yield
FN	= Fertilizer Nitrogen dose
SN	= Nitrogen contribution of soil
ON	= Nitrogen contribution of organic sources
FP_2O_5	= Fertilizer phosphorous dose
SP	= Phosphorous contribution of soil
OP	= Phosphorous contribution of organic sources
FK_2O	= Fertilizer potassium dose
SK	= Potassium contribution of soil
OK	= Potassium contribution of organic sources

While determining the number of nutrients needed for crop management, the nutrient contributions from the soil (SN, SP, SK) and organic manures (ON, OP, OK) were taken into account. The treatment combinations followed in the experiment are shown in table 2 and the field layout of the experiment is given in Fig. 2. and plate .1.

Table 2. Treatment details

T_1	POP KAU with organic manure management
T_2	POP KAU based on soil test
T_3	STCR recommendation for a targeted yield of 20 tonnes
T_4	STCR recommendation for a targeted yield of 22.5 tonnes
T_5	STCR recommendation for a targeted yield of 25 tonnes

To all treatments except T_1, a base dose of FYM and recommendations for N, P, and K based on soil tests were applied, along with need-based plant protection and control of secondary and micronutrients based on soil tests.

T_3R_4	**T_1R_4**	**T_4R_3**	**T_5R_4**	**T_2R_4**
T_2R_3	**T_3R_3**	**T_1R_3**	**T_4R_2**	**T_5R_1**
T_4R_1	**T_2R_2**	**T_5R_3**	**T_1R_2**	**T_3R_1**
T_5R_2	**T_4R_4**	**T_2R_1**	**T_3R_2**	**T_1R_1**

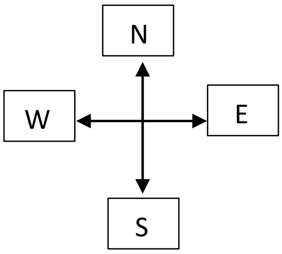

Fig. 2: Field Layout

Plate 1: Experimental site after 2^{nd} harvest

3.3.3. Crop husbandry practices

3.3.3.1. Nursery and main field preparation and sowing

Amaranthus seeds were sown in portrays containing potting mixture (soil, sand, and vermicompost in 3:1:1 proportion). The sprinkling of water was carried out at regular intervals. Seed germination was noted on the third day.

The initial soil samples were taken before field preparation and were analysed for chemical characteristics. The experimental area was thoroughly ploughed and the quantity (350 kg ha^{-1}) of dolomite was added during the initial ploughing since the soil was acidic. Plots measuring 1.8 m by 1.2 m were then constructed by building bunds that were 30 cm wide and 25 cm high. Two or three seedlings were transplanted with a spacing of 20 cm distance within the rows at each planting point. After the complete establishment of the seedlings, unwanted seedlings were removed by thinning. Among the 35 plants per plot, 16 plants per plot were selected as observational plants.

3.3.3.2. Nutrient management

The quantity of fertilizers used in each treatment is given in table 3. In treatments T_2, T_3, T_4 and T_5, Urea, Rajphos, and MOP were used as fertilizers. As a basal dose, a half-dose of N and full doses of P and K were applied.

The treatment T_1 being organic management the sources of P and K were supplied as Rajphos and Muriate of potash respectively. Here, cultural practices and post-harvest application of cow dung slurry and vermicompost to the crop were applied following (KAU, 2017). After each harvest, vermicompost was applied uniformly for vegetative growth in the successive harvests.

Table 3 lists the nutrients that chemical fertilizers from each treatment contributed. Table 4 provides the fertilizer and manure application rates for each treatment.

Table 3. Nutrient contribution from fertilizers

Treatments	N from Urea (kg ha^{-1})	P_2O_5 from Rajphos (kg ha^{-1})	K_2O MOP (kg ha^{-1})
T_1	-	-	-
T_2	128	47.5	47.15
T_3	69.883	28.688	26.928
T_4	78.633	32.288	30.303
T_5	87.383	35.888	33.678

3.3.3.3. Aftercultivation

Weeding was done manually, followed by fertilizer and manure application. The crop was irrigated on daily basis avoiding rainy days.

3.3.3.4. Incidence of Pests and Diseases

The incidence of pests and diseases were monitored and management practices were followed as per (KAU, 2016).

Table 4. Rate of application of fertilizers

Treatments	FYM (t ha^{-1})	Cow dung Slurry (kg ha^{-1})	Urea (kg ha^{-1})	Rajphos (kg ha^{-1})	MOP (kg ha^{-1})	Vermicompost (t ha^{-1})
T_1	50.05	50	-	-	-	1
T_2	50.00	-	217.3913	277.7778	83.33333	1
T_3	50.00	-	150.2341	154.6433	44.14133	1
T_4	50.00	-	168.7124	174.6433	49.14133	1
T_5	50.00	-	188.2776	194.6433	55.39133	1

3.3.3.5. Harvest

After transplanting, the first harvest was made 45 days later, the second was made 75th days after the first and the third was made 105th days after the second harvest.

3.3.4. Biometric observations

From each treatment plot, after leaving border row plants, five plants were randomly chosen as observational plants. Each observational plant was used to record the biometric characteristics of growth, and yield attributes from each treatment plot. For each treatment, the mean value of the data collected from five plants was calculated for each character. Statistical analysis was performed based on the average data from five plants per treatment plot. The information regarding the biometric observations is as follows.

3.3.4.1. Plant height

The plant height was expressed in centimeters and measured as the distance from the ground to the topmost leaf.

3.3.4.2. Stem girth

Using a twine, the main stem circumference at the collar area was measured. The mean girth was measured and recorded in centimeters.

3.3.4.3. Leaf length

The leaf length was measured for the fifth leaf and recorded in centimeters.

3.3.4.4. Petiole length

The petiole length was measured and the mean is recorded in centimeters.

3.3.4.5. Leaf width

The leaf width was measured and the mean was expressed in centimeters.

3.3.4.6. No. of branches per plant

The number of branches on each observing plant was recorded and the average was calculated.

3.3.4.7. No. of leaves per plant

The total number of leaves per plant was counted from the observational plants and expressed in centimeters.

3.3.4.8. Root length

Plants from each plot were uprooted, the root portions were separated and thoroughly washed, and the root length was measured from the base of the shortest root to its tip was recorded and expressed in centimeters.

3.3.4.9. Root weight

Plants from each plot were uprooted, the root portions were separated, and thoroughly washed and the weight of the root was recorded and measured in grams.

3.3.5. Yield Characteristics

3.3.5.1. Leaf to stem ratio

For each cutting for harvest, the ratio of the fresh weight of the total number of leaves to the fresh weight of the total number of stems was calculated. This was measured and expressed in centimeters.

3.3.5.2. Total yield per plant

Each plant yielded three cuttings. Following the transplant, the first cutting was made 30 days later, and the subsequent two were made at intervals of two weeks. The yield of cuttings was noted and given in gram plant^{-1}.

3.3.5.3. Total yield per plot

The yield from twenty plots were harvested for each cutting and total harvest was expressed in t ha^{-1}.

3.3.5.4. Leaf fresh weight

The total of harvested Amaranthus leaf fresh weight was recorded and measured in g plant $^{-1}$.

3.3.5.5. Stem fresh weight

The fresh weight of harvested stem was noted and expressed in g plant $^{-1}$.

3.3.5.6. Root fresh weight

The fresh weight of harvested root was noted and expressed in g plant $^{-1}$.

3.3.5.7. Leaf dry weight

Leaves from the observational plant from each harvest were weighed and dried in an oven at 65^0C to a consistent weight and recorded in kg ha^{-1}.

3.3.5.8. Stem dry weight

Stem from the observational plant from each harvest were weighed and dried in an oven at 65^0C to a consistent weight and recorded in kg ha^{-1}.

3.3.5.9. Root dry weight

Roots from the observational plant from each harvest were weighed and dried in an oven at 65^0C to a consistent weight and recorded in kg ha^{-1}.

3.3.6. Post-harvest soil analysis

After the 3^{rd} harvest, from each plot 0-15 cm deep soil samples were collected in polythene bags. The soil was air dried, crushed and sieved using a 2 mm sieve before being stored in an airtight container for analysis in the lab for physicochemical and biological characteristics as outlined in table.1.

3.3.6.1. Enzyme assay

The biological parameters such as dehydrogenase activity were analysed in the soil samples taken at harvest time and are listed in the table.5.

Table 5. Analytical methods followed in enzyme analysis

Sl.No.	Parameter	Method	Reference
1	Dehydrogenase activity	Colorimetric determination of 2,3,5- triphenyl formazan (TPF)	Casida *et al.* (1964)
2	Microbial biomass carbon	Chloroform fumigation extraction method	Vance *et al.* (1987)

3.3.7. Analysis of plant samples

By using the procedures outlined in Table 6 for collecting plant and fruit samples, various nutrients, including N, P, K, Cu, Zn, Fe, and Mn, were determined. Before analysis, the plant samples were dried in a hot air oven and ground into a fine powder. For the estimation of N single acid digestion was performed using sulphuric acid. For the estimation of other nutrients diacid digestion was performed using concentrated perchloric and nitric acid.

Table 6. Analytical methods followed for plant analysis

Sl.No.	Parameter	Method	Reference
1	N	Single acid digestion using sulphuric acid modified kjeldhal method	Jackson (1958)
2	P	Vanadomolybdate yellow colour Method	Piper (1966)
3	K	Flame photometry	Jackson (1958)
4	Ca and Mg	EDTA titration method	Cheng and Bray (1957)
5	S	Turbidimetric method after wet digestion using a diacid mixture	Cherin and Yen (1950)
6	Fe, Cu, Zn, and Mn	Atomic Absorption Spectrophotometry	Sims and Johnson (1991)
7	B	Azomethine H method	Gaines and Mitchell (1979)

3.3.8. Economic analysis

The economics of cultivation was determined using the cost of various inputs and produce at the time of the study.

3.3.8.1 Benefit Cost Ratio (BCR)

The formula was used to calculate the Benefit Cost Ratio:

$$BCR = \frac{\text{Gross income } (₹ \text{ ha}^{-1})}{\text{Cost of cultivation } (₹ \text{ ha}^{-1})}$$

3.4. Pesticide residue analysis

The samples were subjected to extraction, clean up, and concentration by following the methods given by Lehotay *et al*. (2005). Pesticide residues were then identified using UPLC- MS/MS and GC- MS/MS analysis.

3.5. Statistical analysis

Statistical analysis of the experimental data was performed using Analysis of Variance, and the F test was used to determine significance of mean values (Cochran and Cox, 1965). The table values were contrasted with the treatment-specific F values. The software grapes was utilised for statistical analysis (Gopinath *et al*., 2021).

4. RESULT

In order to test and validate the STCR-based targeted yield equation created under AICRP on STCR in Vellanikkara, a field experiment was conducted in Amaranthus in (AEU-8). The geo-reference of the site used to conduct the field experiment at the College of Agriculture in Vellayani was 8°5' N latitude and 76°9' E longitude. The initial soil tests substituted in the targeted yield equations determine dose of fertilizer to be applied in various treatments of the present study. Initial physico-chemical properties of the experiment site, nutrient status of manures and fertilizers used in different treatments, biometric observations on plant growth characteristics, yield parameters, initial and final soil nutrient status and plant nutrient analysis and uptake data, initial and final pesticide residue data, economic analysis of the experiment are presented through various tables from table no.7 to table no. 41.

4.1 Physicochemical properties of soil in the experimental site

Table 7 shows the initial physicochemical and biological properties of the experimental site.

The soil of the study site taxonomically belongs to clayey, kaolinitic isohyperthermic typic kandiustults (Benchmark soils of Kerala, soil survey organisation (SS and SC, 2007). It has a sandy clay loam texture, classified as Vellayani series of order ultisols, was extremely acidic (5.29) with electrical conductivity (0.16 dS m^{-1}) and contained a low level of organic carbon (0.35%). Available N content was low (219.16 kg ha $^{-1}$). The available P (40.04 kg ha^{-1}) and K (113.67 kg ha^{-1}) status were high and low respectively. The soil sample was deficient in available Ca (190.97 mg kg^{-1}), Mg (77.03 mg kg^{-1}) and S (4.76 mg kg^{-1}). Dolomite (350 kg ha^{-1}) was used to correct the soil pH during land preparation i.e., two weeks prior to the basal dose of fertilizers in accordance with (KAU, 2016). This rectified the deficiency of Ca and Mg too. Fertilizers viz., Urea, Rajphos and Muriate of Potash were applied according to the fertilizer nutrient requirement for the specific treatment as given in table 4. Since sulphur in the soil was observed to be very close to the sufficiency level, its management was taken care of with the management of phosphatic fertilizers.

Among the micronutrients, B was found to be deficient (0.09 mg kg^{-1}) and all the other micronutrients were in the sufficiency range. The deficiency was corrected with a basal application of borax (10 kg ha^{-1}) in accordance with (KAU, 2016).

Table 7. Soil properties of the experimental plot

S. No		**Content**	**Remarks**
	Mechanical analysis		
1.	Sand (%)	63.01	Sandy clay loam
2.	Silt (%)	13.82	
3.	Clay (%)	22.67	
	Physical properties		
4.	Particle density (Mg m^{-3})	2.54	-
5.	Bulk density (Mg m^{-3})	1.39	-
6.	Porosity (%)	45.26	-
	Electro-chemical properties		
7.	pH	5.29	Strongly acidic
8.	EC (dS m^{-1} at 25 °C)	0.16	Normal
9.	Organic Carbon (%)	0.35	Medium
10.	Cation Exchange Capacity (c mol (p+) kg^{-1})	4.84	Low
11.	Available N (kg ha^{-1})	219.16	Low
12.	Available P (kg ha^{-1})	40.04	High
13.	Available K (kg ha^{-1})	113.67	Low
14.	Ca (mg kg^{-1})	190.97	Deficient
15.	Mg (mg kg^{-1})	77.03	Deficient
16.	S (mg kg^{-1})	4.76	Deficient
17.	Fe (mg kg^{-1})	11.08	Sufficient
18.	Mn (mg kg^{-1})	15.34	Sufficient
19.	Zn (mg kg^{-1})	7.12	Sufficient
20.	B (mg kg^{-1})	0.09	Deficient
21.	Cu (mg kg^{-1})	3.5	Sufficient
	Biological properties		
22.	Dehydrogenase (μg TPF released g^{-1} soil per h^{-1} soil)	52.06	-
23.	Microbial biomass carbon (μg g^{-1} soil)	15.40	-

4.2. Analysis of Nutrient content of organic manures

The nutrient content of organic manures used in the experiment is given in table 8. The FYM with the nutritional content of 1.38 %N, 0.48 % P and 0.92 % K was applied as a basal dose uniformly for all the treatments for crop growth. After each harvest, vermicompost with nutrient content of 1.34% N, 0.35 %P and 1.56% K was applied uniformly to all the treatments to increase the foliage yield (KAU, 2016). Treatment T_1 being organic, cow dung slurry (CDS) with nutrient content 1.42% N, 0.52% P and 0.12 % K was applied. Table 8 lists the nutritional status of the organic manures used for crop growth.

Table 8. Nutrient content of organic manures

Organic manures	N%	P%	K%
FYM (%)	1.38	0.48	0.92
Cow dung slurry (%)	1.42	0.52	0.12
Vermicompost (%)	1.34	0.35	1.56

4.3. Weather data of the experimental location during the cropping period

The dominant weather conditions during the cropping season are presented in Fig. 2, table 9 and Appendix I. The weather conditions that prevailed during the field experiment were a hot, humid, tropical climate. During the cropping period, the mean maximum atmospheric temperature varied from 30.70 to 33.41°C is given in table-10. The corresponding mean minimum temperature of the location varied from 23.4 to 27.6°C. During the crop growing period, the relative humidity was recorded between 89.23% and 90.17%. Rainfall received during the crop growing period was 525 mm.

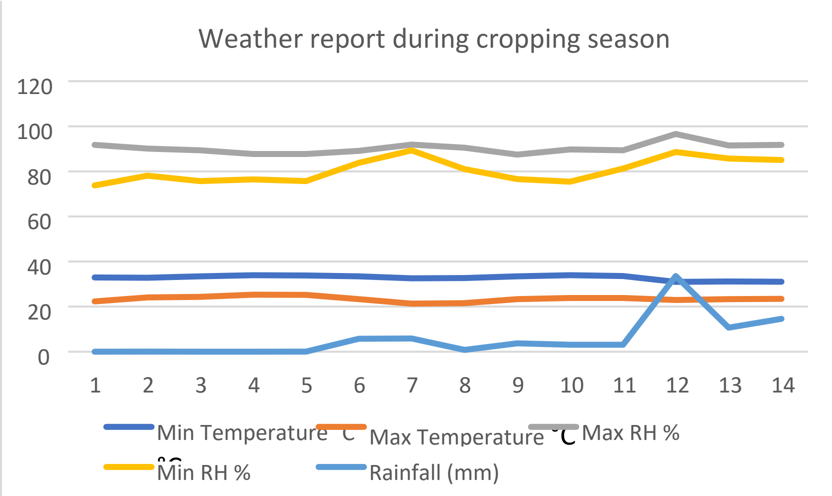

Fig.2 Weather report during cropping period March-May 2022

Table 9. Weather parameters during the crop growing period.

Month	Mean maximum atmospheric temperature (°C)	Mean minimum atmospheric temperature (°C)	Relative humidity (%)	Annual rainfall (mm)
February to May	30.70 to 33.41	23.4 to 27.6	89.23 to 90.169	525

4.4. Observations on the plant biometrics recorded

The observations of the vegetative development of the crop taken at 30 and 60 DAS are listed in tables 10 to 13.

4.4.1. Plant height (cm)

The effects of the treatments on the height of Amaranthus plant at 30 and 60 DAS, were observed to be significantly different, as shown in table 10. The plant height measured at 30 DAS followed the descending sequence: $T_5>T_4>T_3>T_2>T_1$. Treatment T_1 (17.85 cm) recorded the lowest whereas T_5 (42.17 cm) recorded the highest. The plant height measured at 60 DAS had the following sequence: $T_5>T_4>T_3>T_2>T_1$. T_1 (47.45 cm) recorded the lowest whereas T_5 (85.71 cm) recorded the highest.

Table 10. Effect of treatment on plant height and stem girth at 30 and 60 DAS

Treatments	Plant height (cm)		Stem girth (cm)	
	30DAS (mean±SD)	60 DAS (mean±SD)	30 DAS (mean±SD)	60 DAS (mean±SD)
T_1	$17.85±2.66^e$	$47.45±2.29^e$	$1.78±0.51^e$	$1.87±0.49^e$
T_2	$26.55±2.38^d$	$59.20±3.72^d$	$2.57±0.64^d$	$2.66±0.66^d$
T_3	$32.11±3.14^c$	$66.46±3.88^c$	$3.45±0.47^c$	$3.55±0.40^c$
T_4	$37.30±1.5^b$	$73.64±1.08^b$	$4.43±0.19^b$	$4.47±0.21^b$
T_5	$42.17±0.98^a$	$85.71±3.26^a$	$5.30±0.42^a$	$5.50±0.33^a$
SE (m)	1.11	2.31	0.26	0.25
CD	3.43	7.12	0.79	0.76
CV (%)	7.13	7.31	14.54	13.61

4.4.2. Stem girth (cm)

The stem girth of Amaranthus at 30 and 60 DAS, was found to be significantly different among the treatments is presented in table 10. At 30 DAS the stem girth was in the descending order: $T_5>T_4>T_3>T_2>T_1$. Treatment T_5 (5.30 cm) was the highest and T_1 (1.78 cm) was the longest. At 60 DAS the stem girth followed the sequence of $T_5>T_4>T_3>T_2>T_1$. Treatment T_5 (5.50 cm) was found to the be highest and T_1 (1.87 cm) was the lowest.

4.4.3. Leaf length (cm)

A significant difference was observed among the treatments of leaf length of Amaranthus at 30 and 60 DAS as shown in table 11. The leaf length measured at 30 DAS has owed the order of $T_5>T_4>T_3>T_2>T_1$. Treatment T_1 (9.69 cm) recorded the shortest leaf length whereas T_5 (18.84 cm) recorded the longest. The leaf length measured at 60 DAS followed the order of $T_5>T_4>T_3>T_2>T_1$. Treatment T_1 (9.84 cm) recorded the shortest leaf length whereas T_5 (18.86 cm) recorded the longest.

Table 11. Effect of treatment on leaf length and petiole length at 30 and 60 DAS

Treatments	Leaf length (cm)		Petiole length (cm)	
	30 DAS (mean±SD)	60 DAS (mean±SD)	30 DAS (mean±SD)	60 DAS (mean±SD)
T_1	9.69±1.22[e]	9.84±0.98[e]	2.34±0.24[e]	3.38±0.28[e]
T_2	11.65±0.80[d]	11.74±0.86[d]	3.83±0.37[d]	4.86±0.40[d]
T_3	13.93±1.33[c]	14.17±1.62[c]	4.80±0.66[c]	5.80±0.66[c]
T_4	16.63±1.04[b]	16.76±0.84[b]	5.79±0.39[b]	6.82±0.40[b]
T_5	18.84±1.32[a]	18.86±0.10[a]	6.80±0.44[a]	7.82±0.46[a]
SE (m)	0.54	0.55	244.00	0.23
CD	1.85	1.70	0.75	0.70
CV (%)	8.50	7.37	10.36	8.68

4.4.4. Petiole length (cm)

The petiole length of Amaranthus differed significantly among treatments at 30 and 60 DAS as listed in table 11. The order of petiole length measured at 30 DAS was: $T_5>T_4>T_3>T_2>T_1$. Treatment T_5 (6.80 cm) recorded the longest petiole length while T_1 (2.34 cm) recorded the shortest. The petiole length measured at 60 DAS was in the sequence of $T_5>T_4>T_3>T_2>T_1$. Treatment T_5 (7.82 cm) recorded the longest while T_1 (3.38 cm) recorded the shortest.

4.4.5. Leaf width (cm)

Table 12 represents the effects of the treatments on the leaf width of Amaranthus at 30 and 60 DAS respectively. However, the order of leaf width measured at 30 DAS was: $T_5>T_4>T_3>T_2>T_1$. Treatment T_1 (4.18 cm) recorded the lowest leaf width whereas T_5 (9.93 cm) recorded the highest. The leaf width at 60 DAS followed the sequence: $T_5>T_4>T_3>T_2>T_1$. Treatment T_1 (4.53 cm) recorded the smallest leaf width whereas T_5 (10.00 cm) recorded the largest.

Table 12. Effect of treatment on leaf width and number of leaves at 30 and 60 DAS

Treatments	Leaf width (cm)		Number of leaves	
	30 DAS (mean±SD)	60 DAS (mean±SD)	30 DAS (mean±SD)	60 DAS (mean±SD)
T_1	$4.18{\pm}1.41^{e}$	$4.53{\pm}1.25^{e}$	$8.45{\pm}2.45^{e}$	$18.60{\pm}2.55^{e}$
T_2	$5.82{\pm}0.43^{d}$	$6.14{\pm}0.38^{d}$	$13.85{\pm}1.97^{d}$	$23.93{\pm}1.97^{d}$
T_3	$7.32{\pm}0.68^{c}$	$7.45{\pm}0.39^{c}$	$17.32{\pm}1.14^{c}$	$27.47{\pm}1.19^{c}$
T_4	$8.68{\pm}0.35^{b}$	$8.69{\pm}0.34^{b}$	$22.65{\pm}1.86^{b}$	$32.73{\pm}1.82^{b}$
T_5	$9.93{\pm}0.20^{a}$	$10.00{\pm}0.21^{a}$	$26.75{\pm}1.34^{a}$	$36.86{\pm}1.35^{a}$
SE (m)	0.39	0.32	1.01	1.02
CD	1.21	0.99	3.10	3.16
CV (%)	10.96	9.29	11.30	7.34

4.4.6. Number of leaves per plant

As shown in table 12, the effects of the treatments on the number of leaves per plant of Amaranthus at 30 and 60 DAS were found to be significantly different. At 30 DAS the number of leaves per plant followed the order of $T_5>T_4>T_3>T_2>T_1$. Treatment T_5 (26.75) was found to be the highest whereas T_1 (8.45) was the lowest. At 60 DAS the number of leaves per plant followed the order of $T_5>T_4>T_3>T_2>T_1$. Treatment T_5 (36.86) recorded the highest whereas T_1 (18.60) recorded the least.

4.4.7. Number of branches per plant

The effects of the treatments on the number of branches per plant of Amaranthus at 30 and 60 DAS were found to be significantly different and were given in table 13. The number of branches per plant measured at 30 DAS followed descending order: $T_5>T_4>T_3>T_2>T_1$. Treatment T_5 (9.84) had the highest number of branches per plant and T_1 (3.15) recorded the least. The number of branches per plant measured at 60 DAS had the following sequence: T_5>T_4>T_3>T_2>T_1. Treatment T_1 (3.60) recorded the least number of branches per plant whereas T_5 (9.97) recorded the highest.

Table 13. Effect of treatment on number of branches and root length at 30 and 60 DAS

Treatments	Number of branches		Root length (cm)	
	30 DAS (mean±SD)	60 DAS (mean±SD)	30 DAS (mean±SD)	60 DAS (mean±SD)
T_1	$3.15±0.71^e$	$3.60±0.34^e$	$6.88±1.62^e$	$6.98±1.62^e$
T_2	$4.79±0.56^d$	$5.02±0.47^d$	$10.53±1.64^d$	$10.62±1.65^d$
T_3	$6.44±1.29^c$	$6.74±1.29^c$	$14.14±2.09^c$	$14.19±2.06^c$
T_4	$8.09±1.25^b$	$8.35±1.25^b$	$15.80±2.09^b$	$17.84±1.89^b$
T_5	$9.84±0.72^a$	$9.97±0.71^a$	$16.78±1.93^a$	$21.82±1.73^a$
SE (m)	0.53	0.46	1.01	0.94
CD	1.63	1.42	2.10	2.90
CV (%)	16.35	14.18	14.13	13.91

4.4.8. Root length (cm)

The root length of Amaranthus at 30 and 60 DAS was found to have a significant difference between the treatments as shown in table 13. The root length measured at 30 DAS had the following sequence: T_5>T_4>T_3>T_2>T_1. Treatment T_5 (16.78 cm) recorded the longest while T_1 (6.88 cm) recorded the shortest. The root length measured at 60 DAS followed the sequence of T_5>T_4>T_3>T_2>T_1. Treatment T_5 (21.82 cm) was found to be the longest while T_1 (6.98 cm) had the shortest.

4.5. Yield parameters

The leaf, stem and root were harvested at 30 and 60 DAS and were dried after taking the fresh weight of the leaf, stem and root separately. At the final harvest, plants were uprooted to record the fresh weight of leaf, stem, root, and the dry weight of leaf, stem and root respectively. Total dry matter production is presented in table 15. The yield observations including the mean of leaf to stem ratio at 30 DAS, total yield per plant and total yield per plot were recorded after each harvest and are presented in table 14.

4.5.1. Leaf to stem ratio at 30 DAS

A significant difference was observed among the treatments, on the leaf to stem ratio of Amaranthus, which is presented in table 14. The leaf to stem ratio at 30 DAS was found to be significantly different in treatments T_1 from others. The treatment T_1 was on par with T_2 and T_2 was on par with T_4 and T_5. The treatment T_2 was significantly different from T_3 and T_5. Treatments T_3, T_4 and T_5 were on par. T_3 showed a significant difference between T_1 and T_2. Treatment T_1 (2.02) had the lowest whereas T_5 (2.97) recorded the highest.

Table 14. Results on yield parameters of the crop at harvest

Treatments	Leaf to stem ratio at 30 DAS (mean±SD)	Total yield per plant (g plant $^{-1}$) (mean±SD)	Total yield (t ha^{-1}) (mean±SD)
T_1 -POP KAU with organic manure management	2.02±0.05^{c}	85.51±4.89^{e}	9.53±0.55^{e}
T_2 -POP KAU on the basis of soil test	2.26±0.17^{bc}	129.19±6.87^{d}	14.40±0.77^{d}
T_3 -STCR recommendation for targeted yield of 20 tonnes	2.95±0.17^{a}	174.68±25.30^{c}	19.47±2.82^{c}
T_4 -STCR recommendation for targeted yield of 22.5 tonnes	2.73±0.31^{ab}	196.84±4.52^{b}	21.94±0.50^{b}
T_5 -STCR recommendation for targeted yield of 25 tonnes	2.97±0.22^{a}	222.41±3.21^{a}	24.79±0.36^{a}
SE (m)	0.16	6.77	0.75
CD	0.49	20.85	2.32
CV (%)	12.23	8.37	8.37

4.5.2. Total yield per plant (g plant $^{-1}$) at harvest

The total yield per plant of Amaranthus was significantly different, as shown in table 14. The total yield per plant was recorded in the descending order of T_5>T_4>T_3>T_2>T_1. Treatment T_5 (222.41 g) had the highest and T_1 (85.51 g) recorded the lowest.

4.5.3. Total yield (t ha^{-1}) at harvest

The effects of the treatments on the total yield per plot were observed to be significantly different, as shown in table 14. The total yield per plot was in the sequence of T_5>T_4>T_3>T_2>T_1. Treatment T_1 (9.53 tonnes) showed the lowest whereas T_5 (24.79 tonnes) was found to be the highest.

4.5.4. Leaf fresh weight (g) at harvest of the crop

At each harvest, the plants were uprooted to record the leaf fresh weight. There was a significant difference among the treatments on the pooled leaf fresh weight of Amaranthus, which is presented in table 15. At the final harvest, the pooled fresh leaf weight was recorded in the following sequence: T_5>T_4>T_3>T_2>T_1. Treatment T_5 (222.41 g) was found highest whereas T_1 (85.51 g) recorded the least.

4.5.5. Shoot fresh weight (g) at harvest of the crop

At each harvest, the plants were uprooted to record the shoot fresh weight and the data were pooled. Among the treatments, a significant difference was observed in the pooled shoot fresh weight of Amaranthus, which is shown in table 15. The recorded pooled shoot fresh weight was in the following sequence of T_5>T_4>T_3>T_2>T_1. Treatment T_1 (82.22 g) recorded the least whereas T_5 (144.02 g) recorded the highest.

4.5.6. Root fresh weight (g) at harvest of the crop

The plants were uprooted to record the fresh weight of the roots at each harvest and the data was pooled. It is seen from table 15, that the treatments had significant effect on the pooled root fresh weight of the Amaranthus. At each harvest, the pooled root fresh weight recorded the following sequence of T_5>T_4>T_3>T_2>T_1. Treatment T_5 (75.09 g) had the highest and T_1 (43.52 g) recorded the least value.

4.5.7. Leaf dry weight (g) after oven drying

The pooled leaf dry weight of Amaranthus showed a significant difference among the treatments and is shown in table 15. The pooled data of leaf dry weight at final harvest exhibited the following sequence: $T_5>T_4>T_3>T_2>T_1$. Treatment T_1 (15.60 g) recorded the least whereas T_5 (28.91 g) recorded the highest.

4.5.8. Shoot dry weight (g) after oven drying

The effect of the treatments on the shoot dry weight of the Amaranthus was pooled and was observed to be significantly different, as shown in table 15. The shoot dry weight at the final harvest was in the decreasing order of $T_5>T_4>T_3>T_2>T_1$. Treatment T_5 (16.36 g) was the highest while T_1 (9.14 g) recorded the least.

4.5.9. Root dry weight (g) after oven drying

The pooled root dry weight of the Amaranthus was observed to be significantly different between the treatments, as shown in table 15. At the final harvest, the root dry weight was in the following sequence of $T_5>T_4>T_3>T_2>T_1$. Treatment T_1 (3.41g) recorded the least while T_5 (10.06 g) recorded the highest.

Table 15. The effect of treatment on dry matter production of the crop

Treatments	Fresh weight (g plant^{-1})			Dry weight (g plant^{-1})			Total dry matter production (g plant^{-1}) (mean±SD)
	Leaf (mean±SD)	Shoot (mean±SD)	Root (mean±SD)	Leaf (mean±SD)	Shoot (mean±SD)	Root (mean±SD)	
T_1	85.51±4.89^e	82.22±4.93^e	43.52±1.98^e	15.60±1.12^e	9.14±0.55^e	3.41±2.02^e	28.14±2.08^e
T_2	129.19±6.87^d	97.67±10.43^d	50.74±1.90^d	18.86±1.48^d	10.94±1.16^d	4.96±1.54^d	34.75±2.89^d
T_3	174.68±25.30^c	113.12±10.15^c	60.4±7.09^c	22.21±0.40^c	12.75±1.13^c	7.17±0.85^c	42.13±1.80^c
T_4	196.84±4.52^b	128.57±7.96^b	67.94±2.43^b	25.56±2.82^b	14.56±0.89^b	8.61±0.43^b	48.73±2.87^b
T_5	222.41±3.21^a	144.02±9.94^a	75.09±6.13^a	28.91±2.53^a	16.36±1.11^a	10.06±0.37^a	55.33±2.60s^a
SE (m)	6.77	4.985	2.32	1.06	0.55	0.47	1.29
CD	20.85	15.36	7.14	3.25	1.71	1.45	3.99
CV (%)	8.37	8.81	7.78	9.49	8.69	13.709	6.19

4.6. Nutrient content of the soil during harvest time

At the time of harvest, soil samples collected from all the treatment plots were analysed for physical, chemical and biological characteristics and are presented in tables 16, 17, 18, 19, 20 and 21.

4.6.1. Effect of treatments on the soil physical properties

The effect of treatments on soil physical properties *viz.*, such as particle density, bulk density, porosity and water holding capacity and are presented in table 16.

4.6.1.1. Particle density

The treatments didn't have a significant difference with respect to particle density. Treatment T_4 (2.42 Mg m^{-3}) recorded the highest and T_1 (2.39 Mg m^{-3}) was the least.

4.6.1.2. Bulk density

There was no significant difference among the treatments for the bulk density. The bulk density of treatment T_1 (1.20 Mg m^{-3}) was the lowest while T_4 (1.30 Mg m^{-3}) was the highest.

4.6.1.3. Porosity

Among the treatments, there was no significant difference found with respect to porosity. Among the treatments, T_1 (49.90%) found to be more porous whereas T_4 (46.28%) had the least.

4.6.1.4. Water holding capacity

It was observed that the water holding capacity was significantly different among the treatments T_1 and T_4. The treatments T_2, T_3 and T_5 were on par and significantly different from treatment pair T_1 and T_4. Treatment T_4 had the lowest water holding capacity (44.14%), while T_1 (46.50%) was found to have the highest.

Table. 16. Physical characteristics of soil after application of treatments

Treatments	Particle density (Mg m^{-3}) (mean±SD)	Bulk density (Mg m^{-3}) (mean±SD)	Porosity (%) (mean±SD)	Water holding capacity (%) (mean±SD)
T_1	2.39±0.12	1.20±0.12	49.90±2.39	46.50±1.44^{a}
T_2	2.40±0.16	1.28±0.16	46.96±3.27	44.95±1.52^{b}
T_3	2.41±0.20	1.29±0.20	46.64±3.84	44.56±1.46^{b}
T_4	2.42±0.13	1.30±0.13	46.28±2.58	44.14±1.67^{c}
T_5	2.41±0.16	1.29±0.16	46.49±3.04	44.28±1.56^{b}
SE (m)	0.09	0.09	1.68	0.78
CD	NS	NS	NS	2.34
CV (%)	7.12	13.46	7.11	6.87

4.6.2. Electrochemical characteristics of the soil after harvest of the crop

The effect of various treatments on the electrochemical properties, the macronutrients content, the content of secondary nutrients and micronutrients of soils are presented in tables 17, 18, 19 and 20 respectively.

4.6.2.1. pH of the soil

There was no significant difference among the treatments with respect to the pH of the soils. The initial soil pH was 5.29 and it was increased after the experiment. Treatment T_1 (5.69) was found to be the lowest while T_2 (5.41) was recorded as the highest pH.

Table 17. Soil chemical properties after harvest of the crop

Treatments	pH (mean±SD)	EC (dS m^{-1}) (mean±SD)	CEC (cmol kg^{-1}) (mean±SD)	OC (%) (mean±SD)
T_1	5.69±0.59	0.21±0.01	4.91±0.22	$0.72±0.01^{a}$
T_2	5.41±0.25	0.22±0.03	4.86±0.25	$0.50±0.01^{c}$
T_3	5.64±0.55	0.22±0.01	5.05±055	$0.70±0.02^{a}$
T_4	5.61±0.26	0.21±0.01	4.97±0.26	$0.59±0.05^{b}$
T_5	5.49±0.22	0.22±0.01	5.12±0.59	$0.60±0.09^{b}$
SE (m)	0.21	0.01	0.21	0.02
CD	NS	NS	NS	0.07
CV (%)	7.69	6.50	8.59	7.88

4.6.2.2. EC of the soil

In the case of EC, no significant difference was observed due to the effect of treatments. The initial EC of the soil was found to be 0.16 dS m^{-1}. EC was found higher for T_1, T_3 and T_5 (0.22 dS m^{-1}) whereas T_2 and T_4 (0.21 dS m^{-1}) recorded to be the lowest.

4.6.2.3. Cation exchange capacity

There was no significant difference for CEC among the treatments. CEC in the initial samples was 4.84 (c mol kg^{-1}). The lowest CEC was recorded in T_2 (4.86 c mol kg^{-1}) and the highest was observed in T_5 (5.12 c mol kg^{-1}).

4.6.2.4. Organic carbon

It was noticed that the soil OC content for the two treatment pairs (T_1, T_3) and (T_4, T_5) differed significantly among the two pairs and also were found to be on par among themselves respectively. The initial OC of the experimental soil was 0.35%. The treatment, T_2 showed a significant difference for the treatment pairs (T_1, T_3) and (T_4,

T_5). The highest and lowest OC content were recorded in T_1 (0.72 %) and T_2 (0.50 %) respectively.

4.6.2.5. Available nitrogen of the soil

The available nitrogen status of the soil among the treatments was found to show a significant difference and is presented in table 18. In the initial soil samples available N was 119.16 kg ha^{-1} and was higher in all the treatment plots after the experiment. The descending order of the available N content among the treatments at harvest was: $T_5>T_4>T_3>T_2>T_1$. Treatment T_1 (232.95 kg ha^{-1}) and T_5 (374.11 kg ha^{-1}) were found to be the lowest and highest respectively.

Table 18. Effect of treatments on soil macronutrient content after crop harvest

Treatments	Available Nutrients (kg ha^{-1})		
	N (mean±SD)	P (mean±SD)	K (mean±SD)
T_1	232.95±31.50^{e}	56.97±1.70^{d}	78.70±6.07^{e}
T_2	273.24±5.65^{d}	49.67±1.57^{e}	89.59±0.27^{d}
T_3	313.53±2.02^{c}	64.27±1.90^{c}	111.59±6.07^{b}
T_4	353.82±29.44^{b}	71.57±7.78^{b}	109.19±6.44^{c}
T_5	374.11±32.43^{a}	78.87±1.87^{a}	127.99±10.18^{a}
SE (m)	12.02	2.13	3.50
CD	37.03	6.57	10.78
CV (%)	7.67	6.64	6.06

4.6.2.6. Available phosphorus of the soil

There was a significant difference between all the treatments for phosphorous content. The initial available P was found to be 24 kg ha^{-1}. The effect of treatments followed the order of $T_5>T_4>T_3>T>_1T_2$. The highest available phosphorous content was in the treatment T_5 (78.87 kg ha^{-1}) and the lowest was in T_2 (49.67 kg ha^{-1}).

4.6.2.7. Available potassium of the soil

Among the treatments, the K content showed significant differences. The available K in the initial sample was 213 kg ha^{-1}. Available K content followed the sequence of T_5>T_3>T_4>T_2>T_1. Treatment T_1 (78.70 kg ha^{-1}) was found low while T_5 (127.99 kg ha^{-1}) was found to be the highest value.

4.6.2.8. Secondary nutrients of the soil at harvest

The secondary nutrient content of the soil samples collected at harvest is presented in table 19.

The exchangeable Ca showed no significant difference among the treatments at the time of harvest. The initial Ca content of the soil was 190.97 mg kg^{-1} (Table 7). The Ca content of the soil in all the treatments was higher than the corresponding initial level. The highest soil Ca content was found in the treatment T_3 (319.01 mg kg^{-1}), whereas in T_5 (315.31 mg kg^{-1}) it was the lowest.

Table 19. Effect of treatments on soil secondary nutrient content after crop harvest

Treatments	Ca (mg kg^{-1})	Mg (mg kg^{-1})	S (mg kg^{-1})
T_1	317.27±5.91	122.12±1.37	$4.01±0.12^{a}$
T_2	318.28±5.52	120.74±2.86	$3.27±0.33^{b}$
T_3	319.01±51.51	125.42±17.97	$3.79±0.29^{a}$
T_4	317.10±3.36	126.43±0.43	$2.59±0.08^{c}$
T_5	315.31±5.29	125.39±12.85	$2.26±0.24^{c}$
SE (m)	12.27	5.53	0.13
CD	NS	NS	0.39
CV (%)	7.73	8.91	8.04

There was no significant difference in exchangeable Mg content among the treatments. The initial value of Mg was 77 mg kg^{-1}. Treatment T_2 (120.74 mg kg^{-1}) recorded the least and T_4 (126.43 mg kg^{-1}) recorded the highest.

The available S content of the soil of T_1 was found to show a significant difference from those of treatment T_2, T_4 and T_5. The treatment T_2 was also significantly different from others. However, the two treatment pairs (T_1, T_3) and (T_4, T_5) were on par respectively. Treatment T_1 (4.01 mg kg $^{-1}$) recorded the highest while T_5 (2.26 mg kg^{-1}) had the lowest.

4.6.2.9. Micronutrients of soil at harvest

In table 20, the estimation values of the micronutrient content of the soil at harvest are presented. All the micronutrients showed a significant difference among the treatments.

4.6.2.9.1. Iron

There was no significant difference among the treatments with respect to the iron content of soil at the time of harvest. The Fe content of the soil at harvest followed the descending order of $T_3>T_5>T_4>T_1>T_2$. The highest Fe content was found in treatment T_3 (17.93 mg kg^{-1}) whereas T_2 (17.55 mg kg^{-1}) had the lowest.

Table. 20. Effect of treatments on available micronutrients at the time of harvest

Treatments	Fe (mg kg $^{-1}$) (mean±SD)	Mn (mg kg $^{-1}$) (mean±SD)	Zn (mg kg $^{-1}$) (mean±SD)	Cu (mg kg $^{-1}$) (mean±SD)	B (mg kg $^{-1}$) (mean±SD)
T_1	17.68±0.53	2.80±0.54^{c}	1.14±0.21^{d}	1.12±0.02^{c}	0.50±0.02^{a}
T_2	17.55±0.48	5.61±0.19^{a}	1.95±0.13^{a}	1.67±0.02^{a}	0.43±0.04^{bc}
T_3	17.93±2.45	3.60±0.19^{b}	1.76±0.15^{b}	1.35±0.14^{b}	0.48±0.04^{ab}
T_4	17.73±0.61	3.21±0.16^{bc}	1.36±0.11^{c}	1.22±0.20^{bc}	0.46±0.08^{abc}
T_5	17.91±0.50	2.97±0.40^{c}	0.95±0.08^{e}	1.16±0.02^{c}	0.41±0.05^{c}
SE (m)	0.94	0.17	0.07	0.06	0.02
CD	NS	0.52	0.24	0.19	0.05
CV (%)	7.49	9.29	13.16	9.37	7.42

4.6.2.9.2. Manganese

The Mn content in treatment T_1 was significantly different from others and was on par with T_5. Similarly, treatment T_2 too was significantly different from other treatments. Treatment T_3 was found to be significantly different from others but was on par with T_4. Treatment T_4 was on par with T_5 Mn content was in the descending sequence of $T_2>T_3>T_4>T_5>T_1$. Treatment T_1 (2.80 mg kg^{-1}) was recorded to be low while T_2 (5.61 mg kg^{-1}) was found to be high.

4.6.2.9.3. Zinc

A significant difference was found among all the treatments for the Zn content of the soil at harvest. The order of Zn content was: $T_2>T_3>T_4>T_1>T_5$. Treatment T_2 (1.95 mg kg^{-1}) was superior and T_5 (0.95 mg kg^{-1}) recorded the least.

4.6.2.9.4. Copper

The soil Cu content followed a similar trend as that of Mn content in the soil. Treatment T_2 (1.67 mg kg^{-1}) was superior and T_1 (1.12 mg kg^{-1}) recorded the least.

4.6.2.9.5. Boron

At harvest, there exists a significant difference among all the treatments with respect to the B content of the soil. Treatment T_1 was significantly different from T_2 and T_5 but was on par with the treatment pair (T_3, T_4). T_3 was on par with treatment pair T_2 and T_4 whereas T_4 was on par with treatment pair T_2 and T_5. T_5 was on par with T_2. Initial value of soil B 0.09 mg kg^{-1}. The treatment T_1 (0.50 mg kg^{-1}) was recorded as higher content whereas T_5 (0.41 mg kg^{-1}) was the least.

4.6.3. Biological properties of the soil at harvest

The results of the soils at harvest, from all the treatments, were collected to analyse the activity of dehydrogenase enzyme and microbial biomass carbon are shown in table 21.

4.6.3.1. Dehydrogenase enzyme activity

There was no significant difference among the treatments with respect to dehydrogenase activity. The descending order of the treatments: $T_1>T_3>T_4>T_5>T_2$. Treatment T_3 (52.62 g of TPF released g^{-1} soil per hour) had the lowest activity while T_1 (64.08 g of TPF released g^{-1} soil per hour) was the highest.

Table 21. Biological properties after application of treatments.

Treatments	Dehydrogenase activity (µg of TPF released g^{-1} h^{-1}soil) (mean±SD)	Microbial biomass carbon (µg g^{-1} soil) (mean±SD)
T_1-POP KAU with organic manure management	64.08±10.65	124.35±0.65
T_2- POP KAU based on soil test	59.03±1.91	119.45±0.91
T_3-STCR recommendation for a targeted yield of 20 tonnes	52.62±0.68	114.67±0.68
T_4-STCR recommendation for a targeted yield of 22.5 tonnes	54.68±9.96	112.45±0.96
T_5-STCR recommendation for a targeted yield of 25 tonnes	53.16±14.16	113.12±4.16
SE (m)	4.56	4.56
CD	NS	NS
CV (%)	16.08	7.80

4.6.3.2. Microbial biomass carbon

The soil MBC didn't show any significant difference between the treatments. The highest microbial biomass carbon was in the treatment T_1 (124.35 µg g^{-1} soil) whereas the lowest was in T_4 (112.45 µg g^{-1} soil). The descending order of soil MBC followed the sequence of $T_1>T_2>T_3>T_4>T_5$.

4.7. The nutrient content of the plant at harvest

The primary, secondary and micronutrient content of shoot, root and leaf samples of all the treatments at the time of harvest were analysed. This section describes the results of the plant analysis are presented in tables 22 to 30 and the techniques used are given in table 6.

4.7.1. Primary and secondary content of the shoot

In tables 22 and 23 the primary and secondary nutrient content of the above ground portion (shoot) are given.

4.7.1.1. Nitrogen

The content of nitrogen varied significantly among all the treatments. The descending order of the nitrogen content was: $T_5>T_4>T_3>T_2>T_1$. The treatment T_1 (3.43%) was found to be the lowest and T_5 (6.54%) was found to be the highest of all other treatments.

Table 22. The effect of treatment on the primary nutrient content of shoot

Treatments	N (%) (mean±SD)	P (%) (mean±SD)	K (%) (mean±SD)
T_1	3.43±0.36^e	0.37±0.03^e	0.37±0.02^e
T_2	4.22±0.25^d	0.40±0.01^d	1.89±0.34^d
T_3	4.99±0.62^c	0.43±0.02^c	2.17±1.13^c
T_4	5.76±0.28^b	0.46±0.01^b	3.23±0.31^b
T_5	6.54±0.46^a	0.49±0.02^a	5.24±0.23^a
SE (m)	0.22	0.01	0.09
CD	0.68	0.03	0.25
CV (%)	8.82	6.34	6.27

4.7.1.2. Phosphorus

The P content showed differed significantly in all the treatments. The treatments followed the order: $T_5>T_4>T_3>T_2>T_1$. The treatment T_5 (0.49%) recorded the highest P content whereas T_1 (0.37%) recorded the lowest P content.

4.7.1.3. Potassium

The K content of the shoot showed a significant difference among all the treatments. The effect of treatments on the K concentration was in the sequence: $T_5>T_4>T_3>T_2>T_1$. Treatment T_1 (0.37%) recorded the least whereas T_5 (5.24%) was highest over all other treatments.

4.7.1.4. Calcium

It was noticed that the Ca content of the shoot sample for treatment pair T_1 and T_5 showed a significant difference from the rest of the treatments and also were found to be on par with each other. The two treatment pairs (T_2, T_4) and (T_3, T_4) were on par respectively. These two treatment pairs differed significantly among themselves. Treatment T_2 (10.23 mg kg^{-1}) was found to be the highest and T_1 (6.64 mg kg^{-1}) was recorded to be the lowest.

Table 23. The effect of treatments on the secondary nutrient content of shoot

Treatments	Ca (mg kg^{-1}) (mean±SD)	Mg (mg kg^{-1}) (mean±SD)	S (%) (mean±SD)
T_1	$6.64±1.35^{c}$	$0.22±0.02^{d}$	0.31±0.02
T_2	$10.23±0.38^{a}$	$0.41±0.03^{a}$	0.31±0.02
T_3	$8.80±0.28^{b}$	$0.36±0.04^{ab}$	0.30±0.02
T_4	$8.90±0.52^{ab}$	$0.31±0.06^{bc}$	0.23±0.02
T_5	$7.45±0.86^{c}$	$0.26±0.06^{cd}$	0.30±0.03
SE (m)	0.43	0.02	0.01
CD	1.34	0.07	NS
CV (%)	10.34	14.28	7.59

4.7.1.5. Magnesium

The treatment T_1 was significantly different from other treatments but was on par with T_5. The treatment T_2 was significantly different from other treatments but was on par with T_3. T_3 was significantly different from others but was on par with T_4. T_4 was significantly different from others but was on par with T_5. The lowest Mg content was in the treatment T_1 (0.22 mg kg^{-1}) whereas T_2 (0.41 mg kg^{-1}) had the highest.

4.7.1.6. Sulphur

It was noticed that the S content of the shoot sample did not show a significant difference among the treatments. The highest content of S was found to be high in T_1 and T_2 (0.31 mg kg^{-1}) and the lowest in T_4 (0.29 mg kg^{-1}).

4.7.1.7. Micronutrient content in shoot

Table 24 presents the effect of treatments of micronutrients in the shoot. The micronutrient content of the shoot revealed that there was a significant difference between the treatments.

4.7.1.7.1. Iron content

It was noticed that the Fe content of the shoot sample for treatment pair T_1 and T_2 showed a significant difference from the rest of the treatments and also were found to be on par with each other. However, T_3 was on par with T_2. The treatment T_5 was on par with treatment pair T_4 and T_3. The treatments effect on Fe content of shoot followed the order: $T_5>T_4>T_3>T_2>T_1$. The treatment T_5 (38.64 mg kg^{-1}) was the highest whereas T_1 (30.29 mg kg^{-1}) was found to be the least.

4.7.1.7.2. Copper content

It was noticed that the Cu content of the shoot sample for treatment T_1 showed a significant difference from the rest of the treatments. T_2 was on par with T_1 whereas T_1 was on par with T_3. However, treatment pair T_4 and T_5 were significantly different from others and also were on par among themselves. The Cu content of shoot between the treatments followed the sequence of $T_2>T_1>T_3>T_4>T_5$. It was found that treatment T_4 (2.05 mg kg^{-1}) was inferior and T_2 (4.60 mg kg^{-1}) was superior to others.

Table 24. Effect of treatments on micronutrient content in shoot

Treatments	Fe (mg kg^{-1}) (mean±SD)	Cu (mg kg^{-1}) (mean±SD)	Zn (mg kg^{-1}) (mean±SD)	Mn (mg kg^{-1}) (mean±SD)	B (mg kg^{-1}) (mean±SD)
T_1	30.29±3.22^{c}	4.00±0.46^{ab}	24.53±1.96^{ab}	10.81±1.07^{b}	1.64±0.10^{a}
T_2	33.04±3.0^{bc}	4.60±0.52^{a}	27.09±2.45^{a}	12.81±0.13^{a}	1.77±0.11^{a}
T_3	35.79±1.97^{ab}	3.56±0.67^{b}	23.02±1.81^{b}	9.72±0.66^{b}	1.81±0.11^{a}
T_4	38.54±2.18^{a}	2.05±0.31^{c}	19.40±0.83^{c}	5.44±0.35^{d}	0.63±0.12^{c}
T_5	38.64±1.71^{a}	2.56±0.54^{c}	17.23±1.52^{c}	6.72±1.06^{c}	1.01±0.11^{b}
SE (m)	1.32	0.28	0.91	0.38	0.06
CD	4.06	0.85	2.80	1.16	0.18
CV (%)	7.47	16.51	8.16	8.28	8.45

4.7.1.7.3. Zinc content

The significant difference with respect to zinc content of shoot was noticed to be in similar pattern as to that of the Cu content in the shoot. The effect of treatments on Zn content of shoot followed the order: $T_2>T_1>T_3>T_4>T_5$. Treatment T_2 (27.09 mg kg^{-1}) was found to be higher than others while T_5 (17.23 mg kg^{-1}) was found to be lower than others.

4.7.1.7.4. Manganese content

The treatments T_2, T_4 and T_5 were significantly different from treatment pair T_1 and T_3 while this treatment pair T1 and T_3 were on par for the Mn content in shoot. The Mn content of shoot between the treatments followed the sequence of $T_2>T_1>T_3>T_5>T_4$. The lowest Mn was recorded in T_4 (5.44 mg kg^{-1}) whereas T_2 (12.81 mg kg^{-1}) recorded the highest.

4.7.1.7.5. Boron content

With respect to B content of shoot, the treatments T_4 and T_5 were significantly different from others. It is seen that T_1, T_2 and T_3 were on par among themselves. The effect of treatments on B content of shoot followed the order: $T_3>T_2>T_1>T_5>T_4$. The T_3

(1.81 mg kg^{-1}) recorded a higher B content and T_4 (0.63 mg kg^{-1}) had a lower B content among the treatments.

4.7.2. Primary and secondary nutrient content in root

The results of the primary, secondary and micronutrient content of the roots are presented in tables 25 to 27.

4.7.2.1. Major nutrients

4.7.2.1.1. Nitrogen

All the treatments were found to be significantly different for shoot nitrogen content. The effect of treatments on the nitrogen concentration followed the order: $T_5>T_4>T_3>T_2>T_1$. Among the treatments, T_5 (3.82%) had the highest N content whereas T_1 (1.36%) had the lowest.

Table 25. Effect of treatments on primary nutrients of the root

Treatments	N (%) (mean±SD)	P (%) (mean±SD)	K (%) (mean±SD)
T_1	1.36±0.30^e	0.34±0.03^e	1.60±0.32^e
T_2	1.85±1.70^d	0.41±0.01^d	3.62±0.19^d
T_3	2.34±0.26^c	0.54±0.05^b	4.55±0.19^c
T_4	2.83±0.13^b	0.47±0.03^c	6.58±0.34^b
T_5	3.82±0.33^a	0.62±0.04^a	7.84±0.35^a
SE (m)	0.13	0.02	0.16
CD	0.39	0.06	0.49
CV (%)	10.43	8.54	6.48

4.7.2.1.2. Phosphorus

The effect of different treatments on P content exhibited a significant difference. The order among different treatments was: $T_5>T_4>T_3>T_2>T_1$. Treatment T_1 (0.34%)

was found to be inferior among other treatments and T_5 (0.62%) was found to be superior.

4.7.2.1.3. Potassium

The K content among different treatments varied significantly. The effect of treatments on K content followed the sequence of $T_5>T_4>T_3>T_2>T_1$. The highest K content was recorded in T_5 (7.84%) whereas the lowest was in T_1 (1.60%).

4.7.2.2. Secondary nutrients

4.7.2.2.1. Calcium

It was noticed that the Ca content of root samples for treatment pair T_2 and T_5 showed a significant difference from the rest of the treatments and also were found to be on par with each other. Treatment T_5 (4.07 mg kg^{-1}) was the least while T_1 (6.07 mg kg^{-1}) was recorded the highest.

4.7.2.2.2. Magnesium

In the case of Mg content of the root, all the treatments were found to be significantly different. The effect of treatments on the magnesium concentration was in the order of $T_2>T_4>T_5>T_3>T_1$. Among the treatments T_1 (0.14 mg kg^{-1}) had the highest Mg concentration and T_4 (0.09 mg kg^{-1}) had the least.

4.7.2.2.3. Sulphur

There was no significant difference in S content among the treatments. The lowest S content was recorded in T_3 (0.28 mg kg^{-1}) and the highest was in T_1 (0.32 mg kg^{-1}).

4.7.2.3. Micronutrient content in root

4.7.2.3.1. Iron content

It was noticed that the Fe content of root samples for the two treatment pairs (T_1, T_3) and (T_4, T_5) differed significantly among the two pairs and also was found to be on par among themselves respectively. The treatment, T_2 showed a significant difference for the treatment pairs (T_1, T_3) and (T_4, T_5). The treatments effect on Fe content of root followed the order: $T_2>T_1>T_3>T_5>T_4$. The highest and lowest were recorded in T_2 (29.23 mg kg^{-1}) and T_4 (16.03 mg kg^{-1}) respectively.

Table 26. Effect of treatments on secondary nutrient content of the root

Treatments	Ca (mg kg^{-1}) (mean±SD)	Mg (mg kg^{-1}) (mean±SD)	S (%) (mean±SD)
T_1	$6.07±0.16^{d}$	$0.14±0.04^{e}$	0.32±0.03
T_2	$4.31±0.27^{b}$	$0.11±0.02^{a}$	0.31±0.02
T_3	$5.99±0.37^{a}$	$0.12±0.01^{d}$	0.28±0.03
T_4	$5.89±0.34^{c}$	$0.09±0.01^{b}$	0.30±0.02
T_5	$4.07±0.37^{b}$	$0.10±0.02^{c}$	0.29±0.02
SE (m)	0.14	0.01	0.01
CD	0.53	0.02	NS
CV (%)	6.48	10.96	8.21

Table 27. Effect of treatments on micronutrient content of root

Treatments	Fe (mg kg^{-1}) (mean±SD)	Cu (mg kg^{-1}) (mean±SD)	Zn (mg kg^{-1}) (mean±SD)	Mn (mg kg^{-1}) (mean±SD)	B (mg kg^{-1}) (mean±SD)
T_1	$25.12±2.08^{b}$	$3.19±0.42^{b}$	$12.12±1.52^{c}$	$7.13±1.07^{b}$	$2.78±0.11^{a}$
T_2	$29.32±1.66^{a}$	$4.02±0.42^{a}$	$16.93±1.82^{b}$	$10.58±0.13^{a}$	$2.77±0.13^{a}$
T_3	$23.02±1.64^{b}$	$3.02±0.20^{b}$	$21.064±2.47^{a}$	$6.83±0.66^{b}$	$2.62±0.17^{a}$
T_4	$16.03±2.16^{c}$	$1.30±0.20^{d}$	$19.03±1.96^{ab}$	$4.03±0.35^{c}$	$1.00±0.14^{c}$
T_5	$18.03±1.22^{c}$	$2.26±0.20^{c}$	$13.78±0.83^{c}$	$4.83±1.06^{c}$	$1.79±0.14^{b}$
SE (m)	0.10	0.14	0.91	0.38	0.06
CD	3.07	0.42	2.80	1.16	0.23
CV (%)	8.93	9.92	10.88	11.29	6.88

4.7.2.3.2. Copper content

The copper content in root followed a similar trend as that of Mn content in shoot. The Cu content in root samples varied from 1.30 to 4.02 mg kg^{-1}. The Cu content of root between the treatments followed the sequence of $T_2>T_1>T_3>T_5>T_4$. The treatment T_1 (1.30 mg kg^{-1}) was inferior and T_5 (4.02 mg kg^{-1}) was superior.

4.7.2.3.3. Zinc content

It was noticed that the Zn content of root samples for treatment pair T_1 and T_5 showed a significant difference from the rest of the treatments and also were found to be on par with each other. The zinc content of treatment T_3 which was on par with T_4 was significantly different from others. However, T_4 was on par with the treatment T_2 and which also differed significantly from other treatments T_1 and T_5. The effect of treatments on Zn content of root followed the order: $T_3>T_4>T_2>T_5>T_1$. The highest Zn content was recorded in T_3 (21.06 mg kg $^{-1}$) and the lowest was recorded in T_1 (12.12 mg kg $^{-1}$).

4.7.2.3.4. Manganese content

The Mn content exhibited a similar pattern as observed in the case of Fe content of root. The Mn content of root between the treatments followed the sequence of $T_2>T_1>T_3>T_5>T_4$. Treatment T_4 (4.03 mg kg $^{-1}$) was found to be lower than others while T_2 (10.58 mg kg $^{-1}$) was recorded as the highest in Mn content of root.

4.7.2.3.5. Boron content

The boron content in root sample followed a similar trend as that B content in shoot. The B content of the roots varied from 1.00 to 2.78 mg kg^{-1}. The effect of treatments on B content of root followed the order $T_1>T_2>T_3>T_5>T_4$. The highest and lowest B content was recorded in T_5 (2.78 mg kg $^{-1}$) and T_1 (1.00 mg kg $^{-1}$) respectively.

4.7.3. Primary and secondary nutrient content in leaf

The results of primary, secondary and micronutrient analysis of the leaf samples are presented in tables 28 to 30.

4.7.3.1. Primary nutrients in leaf

4.7.3.1.1. Nitrogen

A significant difference among the treatments was observed for the N content of leaf samples. The order of treatment effect was $T_5>T_4>T_3>T_2>T_1$. The nitrogen content was recorded to be the highest in T_5 (4.92%) and the lowest in T_1 (2.30%).

Table 28. Effect of treatments on primary nutrient content of the leaf samples

Treatments	N (%) (mean±SD)	P (%) (mean±SD)	K (%) (mean±SD)
T_1	2.30 ± 0.23^e	0.41 ± 0.03^e	2.10 ± 0.16^e
T_2	2.96 ± 0.36^d	0.44 ± 0.01^d	2.59 ± 0.22^d
T_3	3.61 ± 0.57^c	0.57 ± 0.02^c	3.24 ± 0.19^c
T_4	4.27 ± 0.25^b	0.65 ± 0.01^b	4.13 ± 0.11^b
T_5	4.92 ± 0.18^a	0.73 ± 0.02^a	4.71 ± 0.24^a
SE (m)	0.18	0.01	0.10
CD	0.55	0.03	0.32
CV (%)	9.93	6.93	6.15

4.7.3.1.2. Phosphorus

P content of the leaf samples among the treatments showed a significant difference and followed a similar pattern to that of N content of the leaf. The effect of treatments on P content of leaf too followed the descending order: $T_5>T_4>T_3>T_2>T_1$. The lowest P content was recorded in T_1 (0.41%) while the highest was in T_5 (0.73%).

4.7.3.1.3. Potassium

It can be inferred that the potassium content in the leaf samples showed a significant difference among the treatments. The K content in the leaf sample was in the descending order: $T_5>T_4>T_3>T_2>T_1$. K content was recorded to be the highest in T_5 (4.71%) and was found to be the lowest in T_1 (2.10%).

4.7.3.2. Secondary nutrients in leaf

4.7.3.2.1. Calcium

The Ca content in leaf found to be on par for the treatments T_1, T_2 and T_4. Also, the treatments T_3 and T_5 were on par and differed significantly from others. The effect of treatments was in the decreasing order of $T_1>T_2>T_4>T_5>T_3$. Treatment T_1 (9.50 mg kg^{-1}) recorded the lowest value while the highest content was observed in T_5 (11.12 mg kg^{-1}).

Table 29. Effect of treatments on the secondary nutrient content of the leaf samples

Treatments	Ca (mg kg^{-1}) (mean±SD)	Mg (mg kg^{-1}) (mean±SD)	S (%) (mean±SD)
T_1	11.12±0.30[a]	0.55±0.04[a]	0.32±0.03
T_2	10.99±1.08[a]	0.50±0.04[b]	0.31±0.04
T_3	9.50±1.16[b]	0.35±0.03[bc]	0.31±0.03
T_4	10.85±0.71[a]	0.47±0.04[c]	0.32±0.02
T_5	9.53±0.18[b]	0.45±0.02[b]	0.32±0.01
SE (m)	0.36	0.02	0.01
CD	1.10	0.05	NS
CV (%)	6.85	7.00	7.1

4.7.3.2.2. Magnesium

With respect to Mg content in the leaf samples, it was observed that T_1 was significantly different from others. Treatment T_2 was on par with treatment pair T_5 and T_3. Treatment pair T_4 and T_3 were on par with each other. The highest magnesium content was observed in T_1 (0.55 mg kg^{-1}) whereas T_3 (0.35 mg kg^{-1}) was found to contain the least Mg content.

4.7.3.2.3. Sulphur

There was no significant difference among the treatments for S content of the leaf sample. The range of S content varied from 0.31% to 0.32%.

4.7.3.3. Micronutrient content of leaf

There was a significant difference observed among the treatments with respect to micronutrient content in the leaf sample.

4.7.3.3.1. Iron content

The Fe content of the leaf was on par for the treatment pair T_1 and T_5 and was significantly different from other treatments. The treatments effect on Fe content of leaf followed the order: T_2>T_3>T_4>T_5>T_1. The highest iron content in leaf sample was recorded in T_2 (41.40 mg kg^{-1}). The T_1 (22.63 mg kg^{-1}) recorded the lowest.

Table 30. Effect of treatments on micronutrient content in leaf sample

Treatments	Fe (mg kg^{-1}) (mean±SD)	Cu (mg kg^{-1}) (mean±SD)	Zn (mg kg^{-1}) (mean±SD)	Mn (mg kg^{-1}) (mean±SD)	B (mg kg^{-1}) (mean±SD)
T_1	22.63±1.47^{d}	3.90±0.24^{a}	15.55±1.52^{c}	10.97±0.66^{b}	1.01±0.08^{b}
T_2	41.40±1.19^{a}	4.33±0.61^{a}	22.13±1.81^{b}	13.81±0.13^{a}	1.48±0.15^{a}
T_3	36.29±3.32^{b}	3.10±0.27^{b}	26.68±2.47^{a}	6.03±0.35^{d}	1.37±0.12^{a}
T_4	31.54±3.82^{c}	1.39±0.21^{d}	24.53±1.96^{ab}	12.07±1.07^{b}	1.38±0.07^{a}
T_5	23.79±2.79^{d}	2.00±0.16^{c}	17.13±0.83^{c}	7.70±1.06^{c}	0.66±0.13^{c}
SE (m)	1.52	0.15	0.91	0.38	0.05
CD	4.67	0.46	2.80	1.16	0.17
CV (%)	9.74	10.02	8.57	7.45	9.23

4.7.3.3.2. Copper content

It was inferred that the Cu content in leaf sample of the treatment pair T_1 and T_2 showed a significant difference among the treatments T_3, T_4 and T_5. However, treatment pair T_1 and T_2 were found to be on par with each other. The Cu content of leaf between the treatments followed the sequence of $T_2>T_1>T_3>T_5>T_4$. The highest and lowest Cu content was observed in T_2 (4.33 mg kg^{-1}) and T_4 (1.39 mg kg^{-1}) respectively.

4.7.3.3.3. Zinc content

The Zn content in the leaf was found to show a similar pattern as that of Zn in the root sample. The effect of treatments on Zn content of leaf followed the order: $T_3>T_4>T_2>T_5>T_1$. The highest Zn content in the leaf sample was recorded in treatment T_3 (26.68 mg kg^{-1}) and lowest was recorded in T_1 (15.55 mg kg^{-1}).

4.7.3.3.4. Manganese content

It was noticed that the Mn content of leaf samples for treatment pair T_1 and T_4 were found to be on par with each other and also were significantly different from others. The Mn content of leaf between the treatments followed the sequence of $T_2>T_4>T_1>T_5>T_3$. The highest and lowest Mn content was recorded in T_2 (13.81 mg kg^{-1}) and T_3 (6.03 mg kg^{-1}) respectively.

4.7.3.3.5. Boron content

The B content in the leaf was noticed to record a similar pattern as that of B content in the root sample. The effect of treatments on B content of leaf followed the order: $T_2>T_4>T_3>T_1>T_5$. The highest B content was observed in T_2 (1.48 mg kg^{-1}) and lowest was found in T_5 (0.66 mg kg^{-1}).

4.8. Nutrient Uptake of the plant

The nutrient uptake values was computed separately in the shoot, root, and leaf portions respectively for all the treatments. It is evident from the data that all the treatments differed significantly for the nutrient uptake. The nutrient uptake is expressed in kg ha^{-1}.

4.8.1. Nitrogen

The results of the nitrogen uptake of plant parts as well as the total uptake are given in table 31. In the case of plant nitrogen uptake, all the treatments differed significantly.

The shoot nitrogen uptake showed a significant difference among all the treatments. The treatment T_5 (20.54 kg ha^{-1}) showed the highest nitrogen uptake and the lowest nitrogen uptake was observed in T_1 (10.76 kg ha^{-1}). The N uptake in shoot was in the order: T_5>T_4>T_3>T_2>T_1.

In terms of nitrogen uptake by the root, there was a significant difference among all the treatments. T_5 (12.04 kg ha^{-1}) showed the highest nitrogen uptake in root and T_1 showed the least (4.23 kg ha^{-1}). The N uptake in root was in the order: T_5>T_4>T_3>T_2>T_1.

A perusal of the data on nitrogen uptake by leaf indicated a significant difference among all the treatments. The treatment T_1 (7.24 kg ha^{-1}) was found to show lower N content in leaf whereas T_5 (15.47 kg ha^{-1}) recorded to show the highest N content in leaf. The N uptake in leaf was in the order T_5>T_4>T_3>T_2>T_1.

As depicted in table 31 the total nitrogen uptake by plant showed that there was a significant difference among all the treatments. The treatment T_5 (48.05 kg ha^{-1}) was recorded as the highest and T_1 (22.23 mg kg^{-1}) recorded as the lowest. The total N uptake was in the order T_5>T_4>T_3>T_2>T_1.

4.8.2. Phosphorus

There was a significant difference among the treatments for phosphorus uptake by the shoot and the results are presented in table 32.

It was observed that the phosphorus uptake in shoot showed a significant difference between all the treatments. The P uptake by shoot was recorded to be the highest in T_5 (2.43 kg ha^{-1}) and the lowest was observed in T_1 (1.28 kg ha^{-1}). The P uptake in shoot was in the order T_5>T_4>T_3>T_2>T_1.

Table 31. Effect of treatments on nitrogen uptake of the crop

Treatment	Nitrogen uptake (kg ha^{-1})			
	Shoot (mean±SD)	Root (mean±SD)	Leaf (mean±SD)	Total (mean±SD)
1	10.76±0.59^{e}	4.23±0.87^{e}	7.24±0.67^{e}	22.23±1.05^{e}
2	13.21±0.43^{d}	5.80±0.50^{d}	9.27±1.02^{d}	28.28±1.39^{d}
3	15.66±1.05^{c}	7.34±0.74^{c}	11.33±1.63^{c}	34.33±2.26^{c}
4	18.13±1.33^{b}	8.87±0.20^{b}	13.43±1.56^{b}	40.43±3.06^{b}
5	20.54±1.27^{a}	12.04±1.55^{a}	15.47±1.17^{a}	48.05±3.84^{a}
SE (m)	0.52	0.49	0.63	1.35
CD	1.61	1.52	1.93	4.16
CV (%)	6.66	12.87	11.01	7.80

There was a significant difference among all the treatments for Phosphorous uptake by root. The treatment T_1 (0.78 kg ha^{-1}) was observed to show the lowest P uptake by root and the highest was recorded by T_5 (1.55 kg ha^{-1}). The P uptake in root was in the order $T_5>T_4>T_3>T_2>T_1$.

The phosphorus uptake by leaf showed a significant difference among all the treatments. The highest P uptake was recorded in the treatment T_5 (2.15 kg ha^{-1}) and the lowest was recorded in T_1 (1.27 kg ha^{-1}). The P uptake in leaf was in the order $T_5>T_4>T_3>T_2>T_1$.

The total P uptake showed a significant difference among all the treatments. The lowest total P uptake was observed in T_1 (3.33 kg ha^{-1}) and the highest P uptake was observed in T_5 (6.13 kg ha^{-1}). The total P uptake was in the order $T_5>T_4>T_3>T_2>T_1$.

Table 32. Effect of treatments on phosphorus uptake

Treatment	Phosphorus uptake (kg ha^{-1})			
	Shoot (mean±SD)	Root (mean±SD)	Leaf (mean±SD)	Total (mean±SD)
T_1	1.28 ± 0.09^{e}	0.78 ± 0.08^{e}	1.27 ± 0.14^{e}	3.33 ± 0.27^{e}
T_2	1.58 ± 0.13^{d}	0.97 ± 0.03^{d}	1.49 ± 0.03^{d}	4.03 ± 0.15^{d}
T_3	1.87 ± 0.11^{c}	1.16 ± 0.08^{c}	1.71 ± 0.08^{c}	4.73 ± 0.23^{c}
T_4	2.15 ± 0.33^{b}	1.36 ± 0.21^{b}	1.93 ± 0.17^{b}	5.44 ± 0.70^{b}
T_5	2.43 ± 0.18^{a}	1.55 ± 0.09^{a}	2.15 ± 0.16^{a}	6.13 ± 0.38^{a}
SE (m)	0.09	0.06	0.07	0.20
CD	0.29	0.19	0.20	0.62
CV (%)	10.10	10.57	7.59	8.52

4.8.3. Potassium

The potassium uptake influenced by different treatments is presented in table 33. The details of the K uptake showed a significant difference between all the treatments.

The K uptake by shoot showed a significant difference among all the treatments. The treatment T_5 (13.15 kg ha^{-1}) showed highest K content and the lowest was observed in T_1 (4.60 kg ha^{-1}). The K uptake in shoot was in the order $T_5 > T_4 > T_3 > T_2 > T_1$.

With respect to K uptake by root there was a significant difference among all the treatments. The K content in treatment T_1 (5.02 kg ha^{-1}) was recorded to be the lower and T_5 (24.61 kg ha^{-1}) recorded to be higher.

There was a significant difference among all the treatments for K uptake in leaf samples. The highest K uptake by leaf was shown in T_5 (7.98 kg ha^{-1}) and the lowest was shown in T_1 (5.42 kg ha^{-1}).

The total K uptake exhibited a significant difference among all the treatments. The lowest total K uptake was observed in T_1 (15.04 kg ha^{-1}) and the highest was in T_5 (45.74 kg ha^{-1}). The total K uptake was in the order $T_5 > T_4 > T_3 > T_2 > T_1$.

Table 33. Effect of treatments on potassium uptake

Treatment	Potassium uptake (kg ha^{-1})			
	Shoot (mean±SD)	Root (mean±SD)	Leaf (mean±SD)	Total (mean±SD)
T_1	4.60±0.07^{d}	5.02±1.01^{e}	5.42±0.16^{e}	15.04±0.90^{e}
T_2	8.26±0.08^{d}	11.36±0.63^{d}	6.06±0.20^{d}	25.68±0.74^{d}
T_3	9.74±0.25^{c}	14.27±0.56^{c}	6.70±0.17^{c}	30.71±0.57^{c}
T_4	10.96±1.39^{b}	20.69±2.25^{b}	7.34±0.59^{b}	38.98±4.20^{b}
T_5	13.15±1.59^{a}	24.61±1.78^{a}	7.98±0.72^{a}	45.74±3.80^{a}
SE (m)	0.39	0.67	0.21	1.14
CD	1.22	2.08	0.64	3.52
CV (%)	8.44	8.87	6.17	7.31

4.9. Pesticide residue analysis

The incidence of leaf webber was observed during the cropping period. Foliar spray of flubendamide was suggested. After the harvest, soil and leaf samples were analysed for the pesticide residue. The mean values of the pesticide analysis recorded in soil sample were T_1 (0.33), T_2 (0.94), T_3 (0.74), T_4 (0.89) and T_5 (0.42) respectively. The pesticide residue levels in leaf sample were found to be below the detectable level.

4.10. Correlation Studies

Correlation was worked out among yield parameters, biometric observations, soil nutrient status at harvest stage, nutrient content in plants and nutrient uptake with yield.

4.10.1. Correlation between biometric observations and yield

Correlation of biometric observations and yield of the crop at 30 and 60 DAS are presented in tables 34 and 35 respectively. From the results, it was revealed that yield was positively correlated with all the biometric observations recorded at 30 and 60 DAS respectively. A positive correlation was recorded at 30 DAS for plant height (0.934***), stem girth (0.934***), leaf length (0.917***), petiole length (0.934***), leaf width (0.913***), number of leaves (0.952***), number of branches (0.881***), root length (0.91***) respectively with yield.

At 60 DAS a positive correlation was recorded for plant height (0.91***), stem girth (0.914***), leaf length (0.9***), petiole length (0.926***), leaf width (0.924***), number of leaves (0.889***), number of branches (0.896***), root length (0.841***) respectively with yield.

Table 34. Correlation analysis of biometric observations with yield at 30 DAS

	Plant height (cm)	Stem girth (cm)	Leaf length (cm)	Petiole Length (cm)	Leaf Width (cm)	Number of leaves	Number of branches	Root length (cm)	Yield ($t\ ha^{-1}$)
Plant height (cm)	1								
Stem girth (cm)	0.899***	1							
Leaf length (cm)	0.935***	0.907***	1						
Petiole length (cm)	0.968***	0.901***	0.962***	1					
Leaf width (cm)	0.953***	0.881***	0.914***	0.962***	1				
Number of leaves	0.952***	0.971***	0.914***	0.94***	0.919***	1			
Number of branches	0.913***	0.918***	0.892***	0.913***	0.927***	0.952***	1		
Root length (cm)	0.914***	0.9***	0.926***	0.924***	0.889***	0.896***	0.841***	1	
Yield ($t\ ha^{-1}$)	0.934***	0.934***	0.917***	0.934***	0.913***	0.952***	0.881***	0.91***	1

*** Correlation is significant at 0.001 level (two tailed)
** Correlation is significant at 0.01 level (two tailed)
* Correlation is significant at 0.05 level (two tailed)

Table 35. Correlation analysis of biometric observations with yield at 60 DAS

	Plant height (cm)	Stem girth (cm)	Leaf length (cm)	Petiole length (cm)	Leaf width (cm)	Number of leaves	Number of branches	Root length (cm)	Yield ($t\ ha^{-1}$)
Plant height (cm)	1								
Stem girth (cm)	0.934***	1							
Leaf length (cm)	0.934***	0.899***	1						
Petiole length (cm)	0.917***	0.935***	0.907***	1					
Leaf width (cm)	0.934***	0.968***	0.901***	0.962***	1				
Number of leaves	0.913***	0.953***	0.881***	0.914***	0.962***	1			
Number of branches	0.952***	0.952***	0.971***	0.914***	0.94***	0.919***	1		
Root length (cm)	0.881***	0.913***	0.918***	0.892***	0.913***	0.927***	0.952***	1	
Yield ($t\ ha^{-1}$)	0.91***	0.914***	0.9 ***	0.926***	0.924 ***	0.889***	0.896***	0.841***	1

*** Correlation is significant at 0.001 level (two tailed)
** Correlation is significant at 0.01 level (two tailed)
* Correlation is significant at 0.05 level (two tailed)

4.10.2. Correlation between yield parameters and yield

The correlation between yield parameters and yield of the crop is presented in table 37. A positive correlation was recorded for leaf to stem ratio (0.883***), leaf fresh weight (0.732***), shoot fresh weight (0.885***), root fresh weight (0.854***), leaf dry weight (0.925***), shoot dry weight (0.886), root dry weight (0.859***) respectively with yield.

Table 36. Correlation analysis of yield parameters with yield

	Leaf to stem ratio	Leaf fresh weight (g)	Shoot fresh weight (g)	Root fresh weight (g)	Leaf dry weight (g)	Shoot dry weight (g)	Root dry weight (g)	Yield ($t\ ha^{-1}$)
Leaf to stem ratio	1							
Leaf fresh weight (g)	0.77***	1						
Shoot fresh weight (g)	0.92***	0.854***	1					
Root fresh weight (g)	0.906*	0.589**	0.868***	1				
Leaf dry weight (g)	0.941***	0.733***	0.872***	0.854***	1			
Shoot dry weight (g)	0.921**	0.852***	1***	0.871***	0.874***	1		
Root dry weight (g)	0.911***	0.598**	0.874***	1***	0.86***	0.877***	1	
Yield ($t\ ha^{-1}$)	0.883***	0.732***	0.885***	0.854***	0.925***	0.886***	0.859***	1

*** Correlation is significant at 0.001 level (two tailed)
** Correlation is significant at 0.01 level (two tailed)
* Correlation is significant at 0.05 level (two tailed)

4.10.3. Correlation between soil nutrient status and yield

The yield was positively correlated with soil nutrient status. The results between soil nutrient status and yield are presented in table 37. The soil N content showed a significant difference and was positively correlated with yield (0.817***). The soil P content exhibited a significant and positive correlation with yield (0.759***). The K content of the soil was also significantly and positively correlated with yield (0.803***). The soil N content followed by K and P was recorded to have descending order of positive correlation with yield.

Table 37. Correlation coefficients between soil nutrient status and yield

	Soil N	Soil P	Soil K	Yield (t ha^{-1})
Soil N	1			
Soil P	0.768***	1		
Soil K	0.747***	0.927***	1	
Yield (t ha^{-1})	0.817***	0.759***	0.803***	1

*** Correlation is significant at 0.001 level (two tailed)
** Correlation is significant at 0.01 level (two tailed)
* Correlation is significant at 0.05 level (two tailed)

4.10.4. Correlation between nutrient content in shoot, leaf with yield

The results for correlation between the nutrient content of shoot and leaf with the yield of the crop are presented in table 38. A significantly positive correlation was exhibited by the N (0.864*), P (0.932) and K (0.925***) content of leaf as well as by N (0.877***), P (0.897***) and K (0.895***) content of shoot with yield of the crop respectively.

Table 38. Correlation coefficients between nutrient content and leaf yield

	N% in leaf	P% in leaf	K% in leaf	N% in shoot	P% in shoot	K% in shoot	Yield (t ha^{-1})
N% in leaf	1						
P% in leaf	0.915***	1					
K% in leaf	0.933***	0.972***	1				
N% in shoot	0.911***	0.925***	0.917***	1			
P% in shoot	0.905***	0.958***	0.927***	0.943***	1		
K% in shoot	0.919***	0.953***	0.952***	0.92***	0.925***	1	
Yield (t ha^{-1})	0.864***	0.932***	0.925***	0.877***	0.897***	0.895***	1

*** Correlation is significant at 0.001 level (two tailed)
** Correlation is significant at 0.01 level (two tailed)
* Correlation is significant at 0.05 level (two tailed)

4.10.5. Correlation between yield and nutrient uptake

Table 39 presents the results of correlation between the N, P and K uptake and yield of the crop. A positive correlation was exhibited for total N uptake with yield (0.887***). There was a significant positive correlation for total P uptake with yield (0.872***). However, total K uptake was significantly and positively correlated with yield (0.919***). The highest positive correlation with yield was shown by total K uptake followed by N and P total uptake.

Table 39. The correlation coefficient between nutrient uptake and yield

	Total N	Total P	Total K	Yield (t ha^{-1})
Total N	1			
Total P	0.966***	1		
Total K	0.983***	0.971***	1	
Yield (t ha^{-1})	0.887***	0.872***	0.919***	1

*** Correlation is significant at 0.001 level (two tailed)
** Correlation is significant at 0.01 level (two tailed)
* Correlation is significant at 0.05 level (two tailed)

4.11. Economics of cultivation

Table 40 presents the results of the benefit cost analysis of various treatments. The highest and lowest cost of cultivation was recorded in T_1 and T_2 respectively. The results of BC ratio suggests that T_5 was highest in comparison with other treatments. Net returns, as well as BC ratio, was highest in T_5 followed by T_4, T_3, T_2 and T_1.

Table 40. Economics of cultivation

Treatments	Total cost of cultivation/ ha (Rs)	Total benefit/ ha (Rs)	Actual profit/ ha (Rs)	BC ratio
1	81500.00	95300	13800	1.17
2	61138.73	144000	82861.27	2.40
3	61447.63	194700	133252.40	3.17
4	64918.79	219400	154481.21	3.38
5	70141.97	247900	177758.03	3.53

5. DISCUSSION

In soil and plant nutrition, minimal environmental degradation and sustained crop productivity, balanced nutrition are the main concerns. Every year, India requires approximately 7-9 million tonnes of new food grains to meet the dietary needs of its increasing population (Ramya, 2017). Despite the need for improved productivity to achieve food security for the world's growing population, the fertilizer recommendations followed previously should be reconsidered. This can be achieved by implementing both economically and environmentally effective management approaches, such as the Soil Test Crop Response, which promotes balanced nutrition, soil health and long-term crop productivity. The results of the research project "Evaluation of STCR based targeted yield equations of Amaranthus (*Amaranthus tricolor* L.) in southern laterite soils (AEU-8) of Kerala" are discussed in this chapter in context of other studies based on the existing literature. Amaranthus is a popular vegetable crop cultivated in Kerala. The primary goal of every intensive agriculture system is to maximise productivity per unit area of land. The application of adequate amount of fertilizer is a useful approach to enhance crop yield. The soil's inherent fertility level and the nutrient content of the organic manures should be considered while determining the amount of fertilizer to be applied.

The targeted yield equation has been developed for the laterite soils of Kerala for the Amaranthus crop. This equation should be tested in various agroecological units to increase its applicability in normal field situations. The primary goal of this study was to test and validate the targeted yield equations developed for Amaranthus in (AEU-8). The instructional farm, located in the College of Agriculture, Vellayani was selected as the experimental site. The targeted yield equations were verified in this study for three levels of yield targets, while they were also compared with organic manure management and conventional KAU POP recommendation based on soil test results. Biometric observations and yield parameters were recorded for the crop in order to correlate the efficacy of treatments based on post-harvest soil and plant analysis for various parameters. Plant analysis was done individually for root, shoot, and leaf to study plant nutrient uptake.

5.1. Biometric observations

The biometric observations recorded during the crop growth period *viz.*, plant height, stem girth, leaf length, petiole length, leaf width, number of leaves per plant, number of branches per plant and root length are presented in tables 11 to 14. The effect of treatments on the biometric observations is given in fig 3 to 9. All the biometric observations showed a significant difference.

The effect of treatments for plant height is given in table 11 and in fig 3. It can be seen that there was a continuous increase in plant height with the influence of treatment on the development of crop from the vegetative to harvest stage. With the increment in yield targets, plant height increased accordingly in all STCR treatments, possibly due to a corresponding increase in fertiliser dosage based on yield targets. The plant height at 30 and 60 DAS recorded the highest for treatment T_5 and was significantly different from others. The effect of treatments on plant height recorded at 30 and 60 DAS followed the order of $T_5>T_4>T_3>T_2>T_1$. In *Amaranthus caudatus*, Nyankanga (2012) confirmed that, inorganic fertiliser and manure application considerably boosted crop growth when compared to the control plot i.e., the plot with no fertilizer. This could be attributed to higher soil N availability as a result of inorganic fertiliser application, resulting in increased N uptake and thus faster crop growth. However, N release from manure happens over time after mineralization. In Amaranthus, similar findings were reported by Pang and Letey (2000), Hartemink *et al.* (2000) and Eghball *et al.* (2002). They found that N supplied by inorganic fertiliser was rapidly available, while N supplied by manure was released slowly. Arpita (2021) reported that in chickpeas when combined with vermicompost the contribution, of N and P not only increased the plant height but also increased several metabolic processes, resulting in higher apical growth, cell elongation and shoot development, as it provided additional nutrients and enhanced nutrient availability with a balanced fertiliser. In chickpeas, similar findings have been reported by Jadhav *et al.* (2009), Tripathi *et al.* (2013), Kumar *et al.* (2015) and Singh *et al*. (2018). In (*Amaranthus tricolor* L.), Madhukar (2019) and Akinbile *et al.* (2016) in *Amaranthus cruentus* reported that the effect of NPK fertilizer on plant height may also be due to increased decomposition of organic matter and mineralization of nutrients, particularly N and K. The effectiveness of targeted yield based STCR treatments could be due to the balanced supply of nutrients in required quantity based on the initial soil fertility status and differing yield targets. In this study also, all targeted based STCR treatments recorded much taller plants than T_1 and T_2 treatments indicating the possibility of increased performance of the crop with respect to biometric characters such as plant height with increased application of nutrients to the crop based on the targeted yield equation.

The data observed in table 11 and fig 4 showed that the effect of treatment on stem girth of Amaranthus at 30 and 60 DAS was recorded maximum in T_5. The effect of treatments on stem girth recorded at 30 and 60 DAS followed the order of $T_5>T_4>T_3>T_2>T_1$. In Amaranthus, Madhukar (2019) observed that the increase in stem diameter may be due to the increased availability of nutrients in the soil which enhance the nutrient absorption by the crop because the N applied through fertilizer increased photosynthetic efficiency of leaves. The availability of more photosynthates resulted in higher stem diameter. Similar results were reported by Kushare *et al.* (2010) and Charachimwe *et al.* (2018) in Amaranthus.

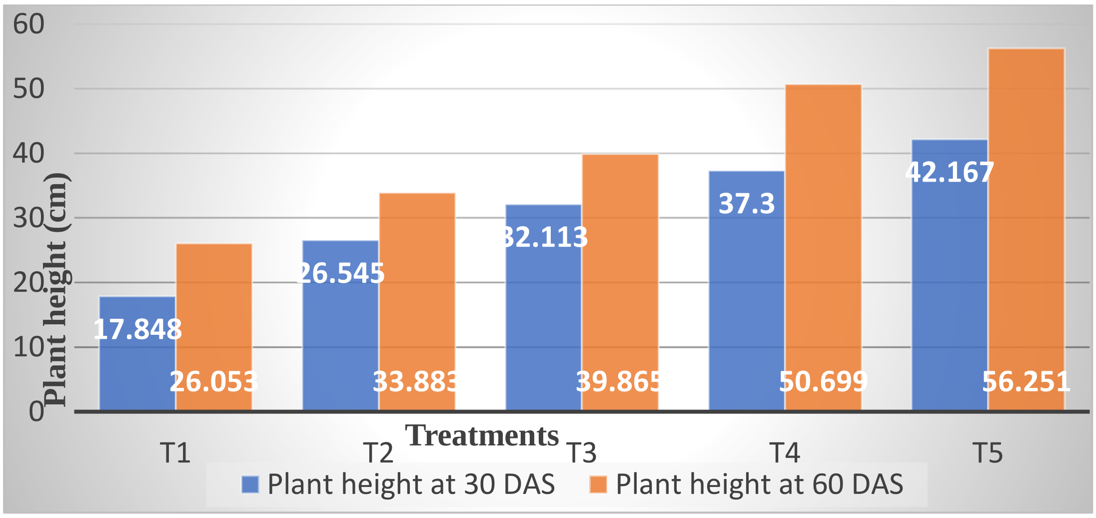

Fig. 3 Effect of treatments on plant height at 30 and 60 DAS

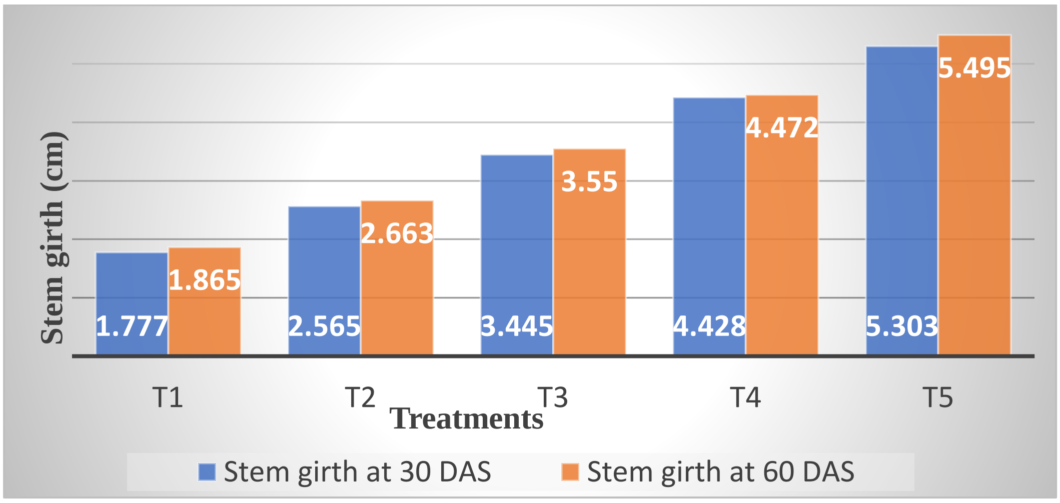

Fig. 4 Effect of treatments on stem girth at 30 and 60 DAS

The effect of treatments on leaf length recorded at 30 and 60 DAS is given in table 12 and fig 5. Treatment T_5 recorded the maximum leaf length at 30 and 60 DAS. The effect of treatments on leaf length recorded at 30 and 60 DAS followed the order of $T_5>T_4>T_3>T_2>T_1$. Dehariya (2019) reported that Amaranthus grow its leaves longer when N is applied in adequate quantities. Hewitt and Smith (1975) also found that N application promotes leaf length growth in Amaranthus at different levels, resulting in increased leaf yield and quality. Leafy vegetables in terms of leaf yield tend to respond well to nutrient supplies that enhance vegetative growth. The leaf length of Amaranthus increased significantly at different phases of growth, which was revealed to be essential for yield contributing factors of Amaranthus. Moreover, an appropriate dose of N promotes the growth and development of *Amaranthus*. Thakur (2021) reported that the optimal nutrition levels were observed to boost the leaf length of Amaranthus drastically. Gamel *et al.* (2004) in *Amaranthus caudatus* L.; Rana *et al.* (2006) in *Amaranthus hypochondriacus* L. and Dehariya *et al.* (2019) in *Amaranthus tricolor* L. reported similar observations with respect to leaf length.

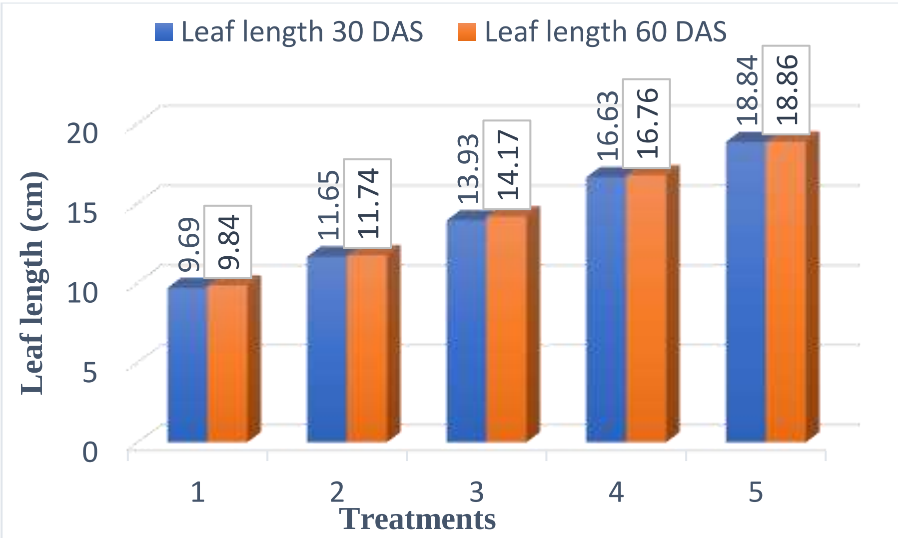

Fig. 5. Effect of treatments on leaf length at 30 and 60 DAS

Different doses of N exhibited a significant difference in leaf width of *Amaranthus*. The data from table 12 and fig 6 revealed that the increased doses of N application in T_3, T_4 and T_5 exhibited a corresponding increase in leaf width. The effect of treatments on leaf width recorded at 30 and 60 DAS was observed to be in the order of $T_5>T_4>T_3>T_2>T_1$. The results of the study suggests that varied doses of N application promote increased leaf width in Amaranthus (Dehariya, 2019). And in *Amaranthus* it is in agreement with the findings of Hewitt and Smith (1975) stated that N stimulates leaf development and growth in plants, which is directly connected to leaf width. Khurana *et al.* (2016) too reported that Amaranthus leaf width improved with increasing N levels.

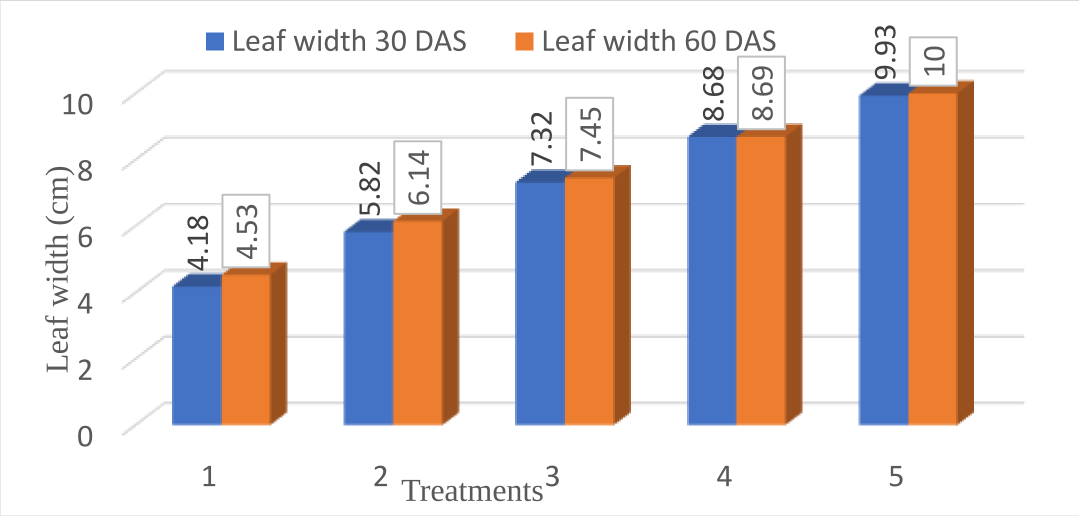

Fig .6. Effect of treatments on leaf width at 30 and 60 DAS

Treatment T_5 recorded the maximum number of leaves per plant at 30 and 60 DAS. The data for number of leaves per plant is given in table 13 and fig 7. The effect of treatments on number of leaves recorded at 30 and 60 DAS followed the order of $T_5>T_4>T_3>T_2>T_1$. Devidas (2020) noted that in safflower it is probable that increased number of leaves is due to the application of fertilizers through SSNM with the STCR equation approach, which provides a judicious amount of nutrients to the plant, increasing cell elongation throughout the crop growth period. More photosynthetic activities and optimal nutrient availability were attributed to an increase in the number of leaves per plant, which in turn increased the number of functional leaves. Maheshbabu *et al.* (2008) in soybean, Naik *et al.* (2007) in safflower and Deshmukh (2008) in chilli, observed that the number of leaves per plant was greatly increased by fertilizer management using the STCR equation. Variations in the number of leaves are bound to have an impact on the overall performance of Amaranthus because the leaves were considered to be the plant's photosynthetic organ (Miah *et al.*, 2013). According to Dehariya (2019) in *Amaranthus tricolor* L. it was found that N increased plant growth as well as the number of leaves per plant. Chweya (1984) reported that increased N supplied through various treatments enhanced mean fresh weight and thus total leaf yield in kale plants. In crops like kale and collard, Kanampiu (1987) also found that leaf production increased as doses of N were increased. According to Fritz and Habben (1973) higher N application boosted leaf fresh weight lettuce. The number of leaves per plant increased as the N fertilizer rate increased (Khurana *et al.*, 2016). Chakhatrakan (2003) and Olaniyi *et al.* (2008) too reported a similar trend in vegetable amaranth.

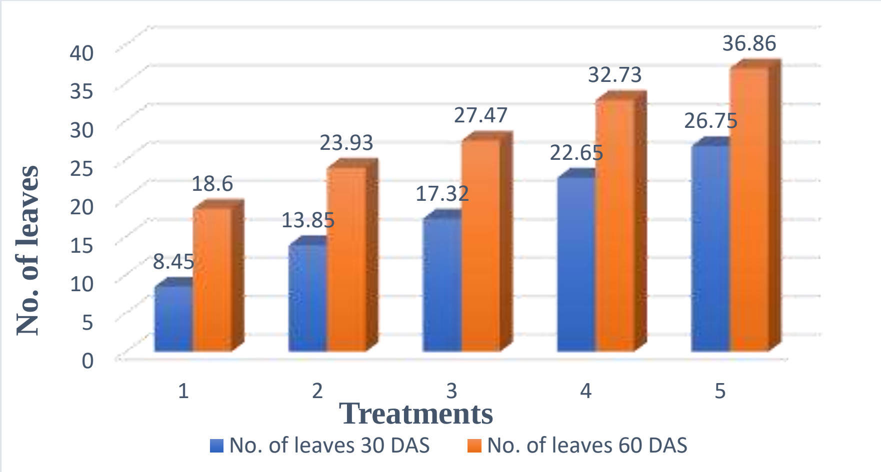

Fig .7. Effect of treatments on number of leaves at 30 and 60 DAS

The data for the number of branches per plant is given in table 13 and fig 8. The effect of treatment on the number of branches per plant of Amaranthus at 30 and 60 DAS was maximum in T_5. The effect of treatments on the number of branches recorded at 30 and 60 DAS followed the order of $T_5>T_4>T_3>T_2>T_1$. Devidas (2020) observed that the number of branches per plant of safflower increased with fertilizer treatment based on the STCR equation + ZnSO4 @ 25 kg ha $^{-1}$ + S @ 10 kg ha^{-1}. The addition of balanced nutrition in the yield target approach enhances the uptake of essential nutrients and boosts the activities of cell elongation, cell multiplication and metabolic activities, resulting in an increase in all growth parameters. Similar results were reported by Gudadhe *et al.* (2011), Patil *et al.* (2016), Patil *et al.* (2018b) and Yogeeshappa *et al.* (2018) in cotton, soybean, groundnut and French bean respectively.

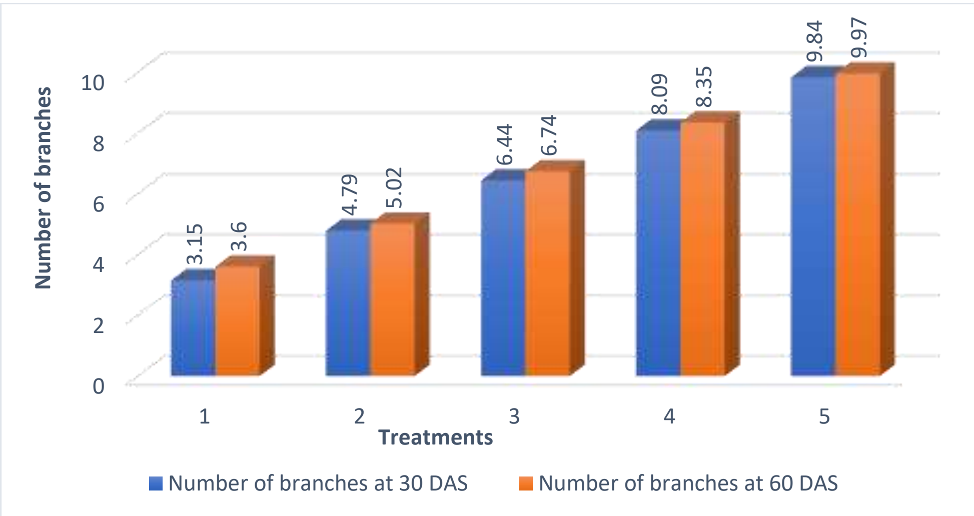

Fig .8. Effect of treatments on number of branches at 30 and 60 DAS

Table 13 and fig 9 represent the data for root length recorded at 30 and 60 DAS was noticed highest in treatment T_5 and was significantly different from others. The effect of treatments on root length recorded at 30 and 60 DAS followed the order of T_5>T_4>T_3>T_2>T_1. Devidas (2020) and Vijaypriya *et al.* (2005) stated that the increase in root length showed that nutrients from fertilisers were available during safflower growth. The root length improved with increasing fertilizer doses at all growth phases, causing a significant increase in targeted yield up to 90 DAS.

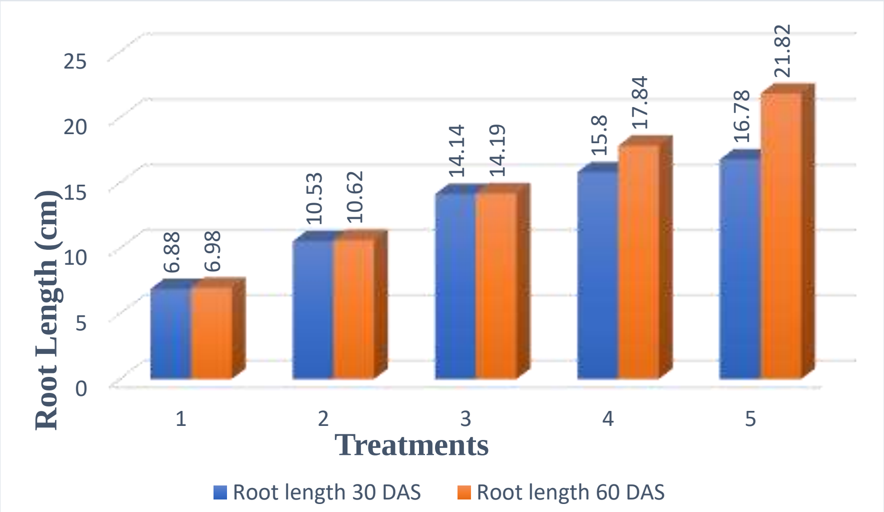

Fig .9. Effect of treatments on root length at 30 and 60 DAS

5.2. Yield parameters

The effect of treatments on the crop yield parameters, which include (leaf to stem ratio at 30 DAS, total yield per plant and the total yield per plot) are presented in table 15 show a significant variation in the crop yield. The targeted yield equations are mainly a function of yield attributes and are arrived at also by considering the levels of responses shown by yield contributing factors which are modified by different treatments applied. Therefore, by improving yield qualities and careful fertilizer management, yield can be increased drastically.

The leaf to stem ratio at 30 DAS was maximum in T_5 and the minimum was found in T_1. The effect of treatments on leaf to stem ratio recorded at 30 DAS followed the order of T_5>T_3>T_4>T_2>T_1. The leaf to stem ratio at 30 DAS was found to be significantly lower in treatment T_1. The treatment T_1 was also on par with T_2 and T_2 was on par with T_4 and T_5. The treatment T_2 was significantly different from T_3 and T_5. Treatments T_3, T_4 and T_5 were on par. T_3 showed significant difference with T_1 and T_2. Murdiono (2019) reported that the application of N significantly increased the total fresh weight of Amaranthus and N needed by Amaranthus could be fulfilled from the supply of urea fertilizer. This was probably due to increased photosynthetic activity and there was an accumulation of carbohydrates in leaves, thus increasing the leaf fresh weight. N being an integral part of chlorophyll and is hence directly involved in dry matter accumulation through photosynthesis. N led to increased leaf to shoot fresh ratio. In shallot, Napitupulu and Winarto (2010) stated that, N led to increase in the carbohydrate accumulation and thus enhancing leaf to shoot fresh weight.

The total yield per plant was found to be maximum in T_5 and minimum in T_1. The total yield per plant (pooled sum of 3harvests taken during 3months of cropping season) of Amaranthus were significantly different. The total yield per plant was recorded in the descending order of $T_5>T_4>T_3>T_2>T_1$. The total yield increased progressively from T_1 to T_5. This might be due to increasing levels of NPK application in the crop. Sundaresh (2019) stated that range and mean values on cabbage yield by cabbage revealed that the highest cabbage yield and nutrient uptake with respect to NPK were recorded from treatment receiving highest nutrient dose L_1 strip followed by L_2 strip and L_3 strip which received lowest nutrient respectively. The decreasing order in cabbage yield, N uptake, P_2O_5 uptake and K_2O uptake by cabbage crop followed the trend $L_3<L_2<L_1$. This is mainly associated with low available N content in soil, as per Liebig's 'Law of minimum', crop yield is proportional to the amount of the most limiting essential nutrient, that is essential macro-nutrient N (Liebig,1855).

The effect of the treatments on the total yield per plot observed to be significantly different, as shown in table 15 and fig 10. Total yield i.e. leaf, stem and root. The levels of NPK decided as per yield targets of STCR equation might significantly improve the transfer of photosynthates to sink and enhanced the values of yield attributes and finally resulting in higher yield. Tiwari (2020) observed similar results for yield parameters in soyabean. The increase of yield in soyabean might be due to adequate and regular supplying capacity of nutrients from the soil and resulting in the translocation of nutrients to the sink. Tiwari (2020) attributed that the increase in yield to enhanced N utilization throughout the crop growing season resulting in better crop performance and increased crop yield. The results are in close agreement with the findings of Singh *et al.* (2001), Jadhav *et al.* (2011), Yagoub *et al.* (2015) in soyabean, whereas Sharma and Verma (2011) and Nwokwu (2020) in rajma and cowpea respectively. Bodkhe and Syed (2014) revealed that the maximum increase in yield attributing characteristics of soybean was due to applied NPK fertilizers based on soil test in the recommended practice. In Amaranthus, all the above similar findings have been justifying the fact that yield targeting is determined by the level of response shown by yield contributing factors which can be modified by different treatments applied. Therefore, judiciously increasing the fertilizer and manure management yield can be increased and optimized considerably using STCR based targeted yield equations.

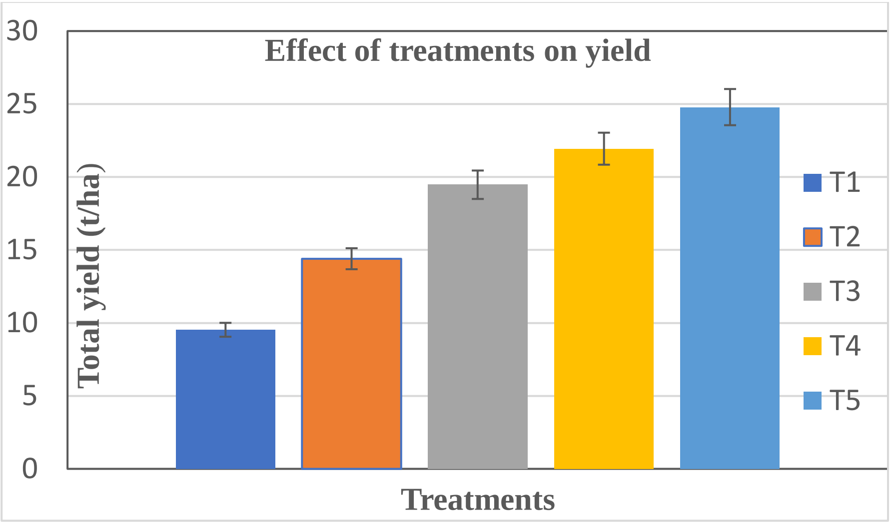

Fig. 10. Effect of treatments on Total yield per plot at 30, 60 and 90 DAS

Initial harvest at 30 DAS produced a lower yield and this might be due to poor mineralization of the N applied through fertilizers as observed in fig 11. In Amaranthus, slower growth of plants in NPK and poultry manure-fertilized soil was observed during the early weeks after transplanting (Oyedeji, 2014). This could be due to initial physiological changes associated with transplanting and transplant shock. After transplanting, similar observations were reported by Murthy and Sahu (1979) in rice, Mckee (1981) in tomato, Khahra *et al.* (1990) in maize and Agbaje and Olofintoye (2002) in sorghum. This effect was resolved during the later weeks after transplanting (4–6 WAT) as N, P and K release after mineralization significantly enhanced the growth parameters (leaf number, length and breadth, plant height, branching, and stem girth) in the three *Amaranthus species*. Oyedeji (2014) stated that in *Amaranthus,* the higher response of the crop to NPK is indicative of the ease of dissolution of nutrients in the inorganic fertilizer being in a more soluble form.

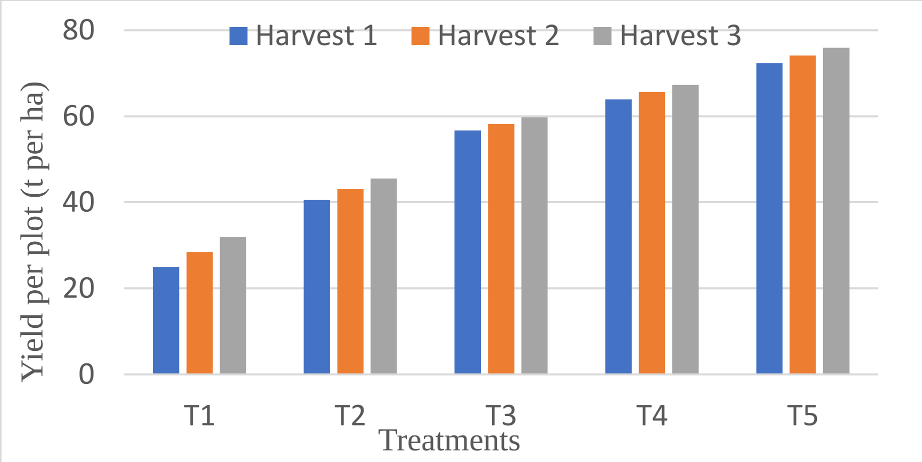

Fig. 11. Effect of treatments on first, second and third harvests

The yield observations indicate that the targeted yield can be obtained with fertiliser application based on the targeted yield equations. From the experiment, a yield of 19.47, 21.94 and 24.79 t ha^{-1} were obtained against the three targeted yields *viz.*, 20, 22.5 and 25 t ha^{-1} respectively. In percentage terms the yield targets obtained were 97.35, 97.51 and 99.16 per cent respectively. Hence, all the three targeted yields were achieved. Thus, the equations were verified and proved to be valid in (AEU- 8) where 25 tonnes of *Amaranthus* can be successfully harvested by following STCR based targeted yield equations for nutrient management and following POP for irrigation, pest, and disease management. STCR treatments were shown to be the best treatment in all yield parameters considered against the standard POP under both conventional management and organic agriculture. This observation was in line with the results of Babatola *et al*. (2002) in okra where it was stated that increasing fertiliser application increased crop growth and yield. Targeted yield equations were developed for the first and second crops of *Amaranthus* in varieties Kannara local and Arun for yield targets 20 and 25 tonnes (Sreelatha *et al.*, 2014). The use of an integrated plant nutrient system (IPNS) resulted in the saving of fertilizer nutrients in the vegetable *Amaranthus*. The fertilizer requirements varied with the soil test values for the same level of crop production. Patel *et al.* (2001) obtained a yield of 10,12,16 and 20 q ha^{-1} respectively in a field trial to check the validity of the targeted yield equation for pigeon peas against the respective targets. Lamina (2009) in oriental pickling, was able to obtain a targeted yield of 30 t ha^{-1} but was unable to achieve a yield of 45t ha^{-1} while using the targeted yield equations. Fertilizer application as per the targeted yield of 4 t ha^{-1} produced maximum number of pods, grains, grain weight per plant and thousand grain weight in chickpeas, which was high when compared to recommended blanket fertilizer dose (Shinde *et al.*, 2000). In cucumber, similar findings were in line with observations made by Waseem *et al*. (2008) reported that providing an appropriate amount of nutrients increased the overall vigour of the crop which eventually increased the number of fruits per vine. Sajnanath (2011) stated that a maximum yield target of 41 t ha^{-1} was obtained in cucumber using targeted yield equations.

5.3. Dry matter production

The dry matter production progressively increased from T_1 to T_5 as presented in table 16 and fig 12. The total dry matter production was highest in T_5 (55.33 g $plant^{-1}$) and lowest in T_1 (28.14 g $plant^{-1}$). Tiwari (2020) observed that varying quantities of NPK application under the STCR strategy had a significant effect on dry matter accumulation of soybean at 30, 45, 60, 75 DAS and at crop harvest. Among the targeted yield based STCR treatments the increase in dry matter production may be attributed to the increase in the application of NPK fertilizers based on the targeted yield equation along with FYM. At all crop growth stages, a considerable improvement in dry matter accumulation of soyabean was noticed with each consecutive increment of varied doses of NPK nutrients. The progressive increase in dry matter accumulation could be attributed to the cumulative effect of all growth characteristics and increasing NPK levels, which increased plant height, leaf area, and leaf area index, factors of higher chlorophyll per unit area, improving accumulation and transport of nutrients in soyabean. Menaria (2005), Jamili *et al*. (2017) and Chirde *et al.* (2019) also observed synergistic impact of NPK treatment in fennel and soyabean respectively.

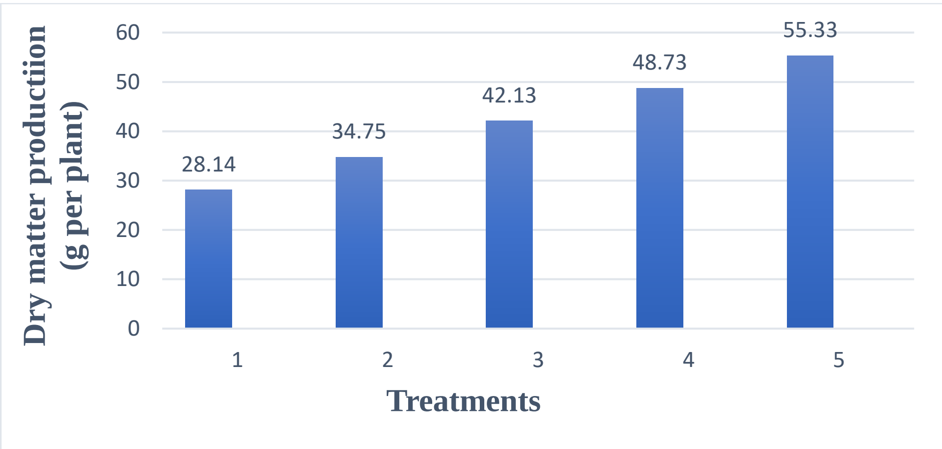

Fig. 12. Effect of treatments on dry matter production

5.4. Post-Harvest Soil analysis

The physical properties like particle density, bulk density, porosity (table 17) and the electrochemical properties like pH, EC and CEC of the post-harvest soil (table 18) didn't change significantly after the crop harvest. However, the electrochemical properties were higher than the initial soil test values. Water holding capacity was observed to show a significant difference and was highest in T_1. In T_1, the quantity of organic matter added was the highest (50.05 kg ha^{-1}) as a part of the organic management. And this might have been contributed to significantly higher water holding capacity of this treatment. Similarly, the OC content (table 18) differed significantly among the treatments and increased (fig 13). Similar observations were made by Apoorva (2008) in ragi. In comparison to the initial OC, the combined use of organic manure and chemical fertilisers elevated the OC in post-harvest soil were reported by Singh and Swarup (2000) and Phogat *et al*. (2004).

The available N content of the soil among the different treatments varied significantly (table 19) and fig.14. The available N after harvest varied from 232 (T_1) to 374 (T_5) kg ha^{-1} in comparison to the initial available N content of the soil (119 kg ha^{-1}). The overall N content of all treatments increased after crop harvest. Sharma and Sharma (2002) reported that combined application of NPK fertilisers and FYM increased the N status of the soil.

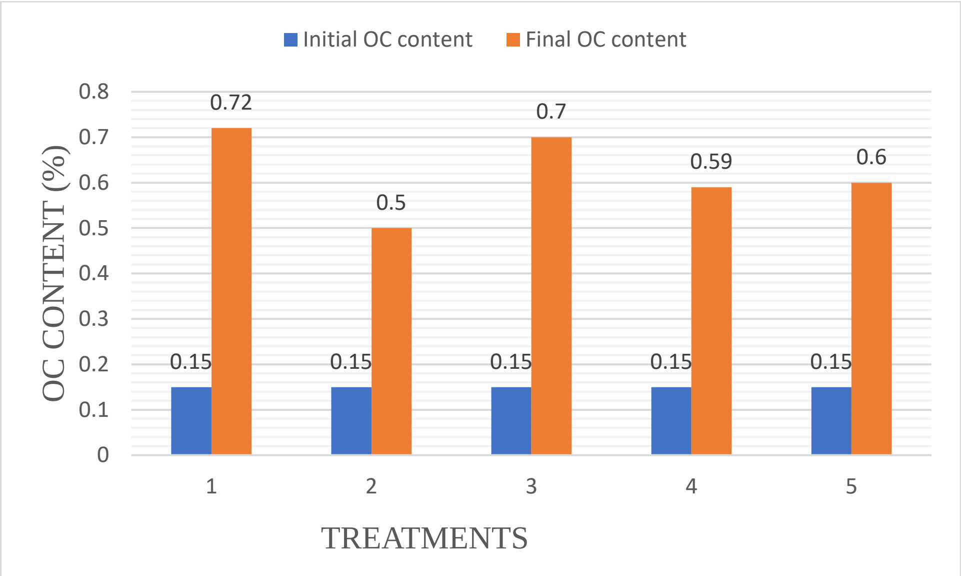

Fig. 13. Effect of treatments on OC in post-harvest soil

Similar results were obtained in pearl millet (Kanchana, 2020). Organic manure, such as FYM, when combined with other nutrients, improved nutrient mineralization and as a result, increased available nutrient status in the soil. This efficiently supplied a balanced nutritional environment in both the rhizosphere and the plant system, resulting in better mineralization by soil microorganisms, which increased the available N in the soil after crop harvest. In pearl millet, similar trend was reported by Dwivedi *et al.* (2016) and Jakhar *et al.* (2018).

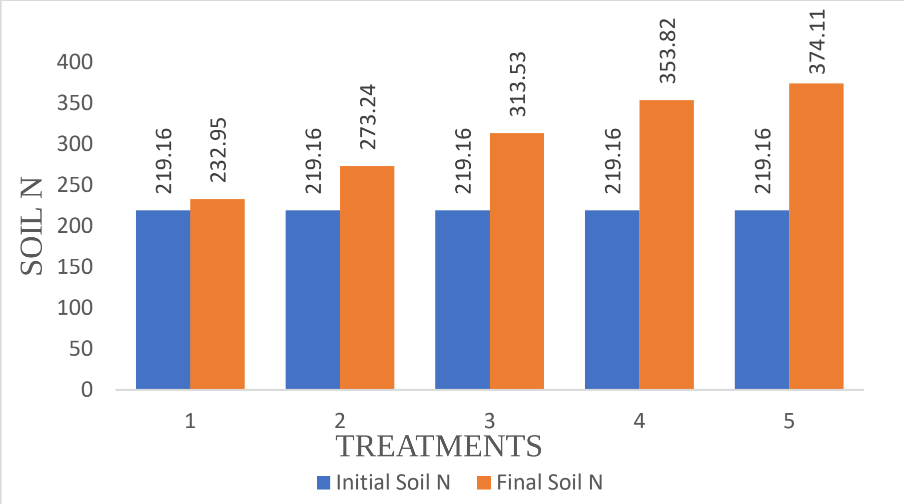

Fig. 14. Effect of treatments on available N after crop harvest

From table 19 and fig. 15 it can be seen that the available P in post-harvest soil ranged from 49.67 (T_1) to 78.87 kg ha^{-1} (T_5). The initial available P was found to be 24 kg ha^{-1}. There was a significant difference between all the treatments. Ram *et al.* (2016) made similar observations. P may be more readily available in the soil as a result of the production of organic acids during FYM decomposition, which speeds up mineralization (Dhakal *et al.*, 2016). By solubilizing and mobilising native soil fixed P, the combined action of FYM with P fertilisers increased the soil available P (Amruth *et al.*, 2018) and thus the availability of P from organic manures such as FYM can be increased to all phases of crop growth (Parihar *et al.*,2013). Singh *et al.* (2020) suggested that only a portion of the combined application of inorganic fertilisers and FYM will be utilized but the residual effect of FYM will enhance the soil available P, soil fertility and productivity.

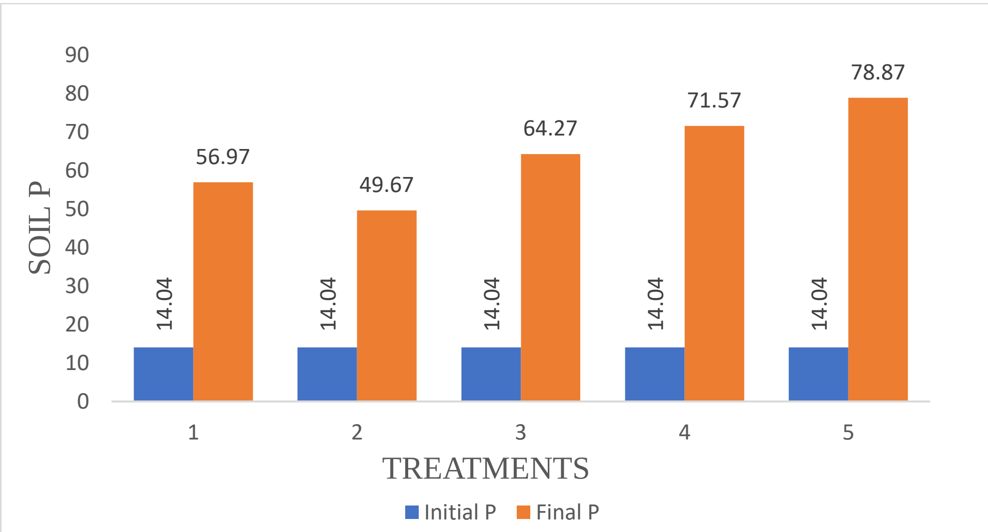

Fig. 15. Effect of treatments on available P after crop harvest

The results given in table 19 and fig.16 shows that the available K in soil samples ranged from (T_1) 78.70 to (T_5) 127.99 kg ha^{-1}. The available K in the initial sample was 213 kg ha^{-1}. The highest value of available K was observed in T_5 and lowest value was observed in T_1. It was noted that there was an increase in soil available K along with increase in yield target levels. Similar findings were observed by Kanchana (2020) in pearl millet. The addition of FYM to inorganic fertilisers may enhance the CEC of the soil. This may be responsible for retaining more exchangeable K and thereby increased the availability of K (Binjola *et al.*, 2017). Tomar *et al.* (2018) confirmed that the use of NPK fertilisers, in combination with FYM, increased soil available K status by lowering K fixation due to organic matter interaction with clay, as well as directly adding to the available pools of K in the soil.

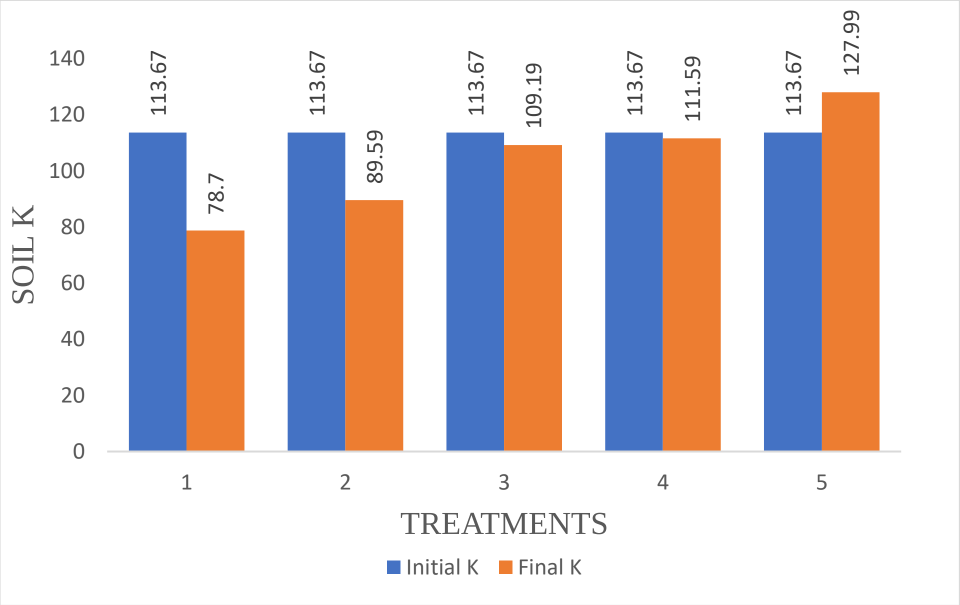

Fig. 16. Effect of treatments on available K after crop harvest

From the table 20 it can be seen that there was no significant difference between the treatments with respect to secondary nutrients. However, there was a slight increase in Ca and Mg content of soil samples at harvest which might be to the incorporation of dolomite to the soil at the time of land preparation as a liming material for correcting the soil acidity. Babu *et al.* (2007) in sugarcane and Sharma and Subehia (2014) in rice and wheat respectively confirmed an increase in Ca and Mg content in soil after the application of FYM.

The data for the micronutrient content of post-harvest soil samples is given in table 21. Except in the case of Fe content, all the other micronutrients showed significant difference between all the treatments. The Mn content in soil was significantly different among the treatments. Mn content was in the descending sequence of $T_2>T_3>T_4>T_5>T_1$. A significant difference was found among all the treatments for Zn content of the soil at harvest and followed the order: $T_2>T_3>T_4>T_1>T_5$. The soil Cu content followed the similar trend as that of Mn content in soil. The treatments followed the sequence of $T_2>T_3>T_4>T_5>T_1$. The deficiency of B content was corrected with a basal application of borax (10 kg ha^{-1}) in accordance with (KAU, 2016). The B levels in soil had been increased as compared to the initial level (0.44 mg kg^{-1}).

5.5. Biological properties

The results of dehydrogenase activity and MBC of the soil after the harvest of the crop are presented in the table 21. There was no significant difference among the treatments with respect to dehydrogenase activity. The highest dehydrogenase activity was observed in T_1 (64.08 μg of TPF released g^{-1} soil 24 h^{-1}) and the lowest was in T_3 (52.62 μg of TPF released g^{-1} soil 24 h^{-1}). The use of cow dung slurry and FYM together may have resulted in higher results in T_1. The soil MBC didn't show any significant difference between the treatments. The highest microbial biomass carbon was in the treatment T_1 (124.35 μg g^{-1} soil) whereas the lowest was in T_4 (112.45 μg g^{-1} soil). The greater soil MBC content in T_1 (organic manure) may be due to the release of mineralizable and readily hydrolyzable carbon from organic manure application, which resulted in higher microbial activity and higher soil MBC. Rani (2020) too reported a higher MBC content due to application of higher quantity of organic manure. The readily available carbon component of FYM encouraged the growth of microbial biomass, which improved soil MBC. Bohem *et al.* (2005) observed that farmyard manure increased microbial biomass in soil. The combined use of organic manure and chemical fertilisers had similar effects on soil MBC (Patil and Puranik, 2001).

5.6. Plant analysis

The macro, secondary and micronutrient content of root, shoot and leaf was analysed separately and presented in table 23 to 31.

5.6.1. Nutrient content in plant samples

For macronutrients, nutrient content of the leaf, shoot and root respectively showed a similar trend. T_5 (25 t ha^{-1}), recorded the greatest yield compared to other treatments and was found to have the highest N, P and K contents in leaf, shoot and root respectively. When the nutrient percentages are compared the highest percentage of nutrient was observed in N followed by K and P. The lowest nutrient percentage was observed in T_1 which had the lowest yield. The nutrient content of plant portions enhanced as fertiliser dosage was increased. The significant increase in N, P and K content in leaf, shoot of Amaranthus with the application of varied doses of STCR based targeted yield could be due to improved nutrient supplying capacity of soil. When organic manure is added to soil, complex nitrogenous compounds slowly breakdown and make steady N, P and K supply throughout growth period of crop which might be attributed to more nutrient availability. The increase in N, P and K content in leaf, shoot and root with the application of fertilizers might be due to improved nutritional environment in the rhizosphere as well as in the plant system leading to enhanced translocation of N, P and K in plant parts which increased the uptake of nutrient in all parts of plant. Similar finding had been reported by Mali *et al.* (2015) who reported positive influence of fertilizers and FYM on N content in grain and straw of wheat. Sawarkar *et al*. (2013), Jat *et al*. (2014) and Sharma *et al*. (2016) in soyabean-wheat, pearl millet and wheat respectively reported similar positive influence of combined effect of inorganic fertilizer and organic manure.

The analysis of secondary nutrients in the plant samples for shoot, root and leaf showed a significant difference among the treatments. Nibin (2019) stated that the better plant growth might have resulted due to release of secondary nutrients from dolomite residual effect of FYM. The significant difference for Ca and Mg content in plant samples might be to the incorporation of dolomite to the soil before the cropping period as a liming material for correcting the acidity of the soil. However, the analysis of S content in the plant samples for shoot, root and leaf didn't show any significant difference among the treatments.

The order of micronutrients in the shoot samples. The treatments effect on Fe content followed the order: $T_5>T_4>T_3>T_2>T_1$. The Cu content of shoot between the treatments followed the sequence of $T_2>T_1>T_3>T_4>T_5$. The effect of treatments on Zn content of shoot followed the order: $T_2>T_1>T_3>T_4>T_5$. The Mn content of shoot between the treatments followed the sequence of $T_2>T_1>T_3>T_5>T_4$. The effect of treatments on B content of shoot followed the order: $T_3>T_2>T_1>T_5>T_4$.

The effect of treatments on micronutrients in root samples followed the order. The treatments effect on Fe content followed the order: $T_2>T_1>T_3>T_5>T_4$. The Cu content between the treatments followed the sequence of $T_2>T_1>T_3>T_5>T_4$. The effect of treatments on Zn content followed the order: $T_3>T_4>T_2>T_5>T_1$. The Mn content between the treatments followed the sequence of $T_2>T_1>T_3>T_5>T_4$. The effect of treatments on B content followed the order $T_1>T_2>T_3>T_5>T_4$.

The Fe content followed the order: $T_2>T_3>T_4>T_5>T_1$. The Cu content between the treatments followed the sequence of $T_2>T_1>T_3>T_5>T_4$. The effect of treatments on Zn content followed the order: $T_3>T_4>T_2>T_5>T_1$. The Mn content between the treatments followed the sequence of $T_2>T_4>T_1>T_5>T_3$. The effect of treatments on B content followed the order: $T_2>T_4>T_3>T_1>T_5$. The significant difference in micronutrients might be attributed to the residual effect of FYM applied. However, Frageria (2001) reported that if significant amounts of P are provided, luxury uptake of P may occur, this effect increases the P to Fe ratio De kock (1965) and P to Zn ratio respectively in plant tissues (Loneragan, 1979a) (Loneragan, 1982b). Smilde (1973) observed a positive interaction between P and Mn, which might be due to acidifying effect of soil P and thereby increase Mn uptake (Jackson, 1976). Tisdale et al. (1997) reported that organic manures can provide chelating agents which improve the solubility of micronutrients and thereby enhance the micronutrient content of the plants.

5.6.2. Primary nutrient uptake by the crop

The macro nutrient uptake of root, shoot and leaf are presented in table 32 to 34 and fig 17 to 19. The nutrient uptake for primary nutrients were also studied. The highest uptake of primary nutrients and highest yield were observed in T_5. The lowest uptake of nutrient was observed in T_1 which yielded the least. Kanchana (2020) reported the relationship between nutrient content and yield is represented by the total nutrient uptake, which relates plant uptake of N, P and K in proportion to their availability in the root zone and the plant growth. In the current experiment, treatment T_5 (STCR based targeted yield 25 t ha $^{-1}$) recorded the highest total N, P and K uptake with values of 48.05, 6.13 and 45.74 kg ha^{-1} respectively. It was observed that as yield targets were increased, the total N, P and K uptake also increased. All of the STCR treatments had significantly greater total N, P and K uptake than the other treatments, which could be attributed to increased nutrient content and total yield (Chandrakanth, 2015). According to Preetha (2003) the ability of different crops to nutrient uptake is a better index of a crop response to fertilisers. The ability of plant to uptake nutrients depends on the amount of nutrients that are present in the soil. Therefore, higher dry matter production can be connected to increased nutrient uptake. The maximum dry matter production and nutrient uptake were both recorded by the treatment T_5. James *et al*. (1967) confirmed that by applying vermicompost, the rate of metabolic activity and the rate of cell division of the microbes increased. This led to a higher uptake of nutrients, and increased N uptake. To obtain optimum yield of the crops, NPK fertilisers must be used in a balanced way. The reactions to N are more obvious in vegetable crops like *Amaranthus*. However, P and K are also necessary for the growth of high-quality vegetables. These results revealed that the fertilizer application can have a direct effect on nutrient uptake and thereby improve the yield of the crop as long as the supplied nutrient is well within the optimum range of crop as suggested by Mitscherlich equation (Mitscherlich, 1909). Similar findings were reported by Swadija (1997), Nagarajan (2003), Cheraghi *et al.* (2012) and Barker (2012).

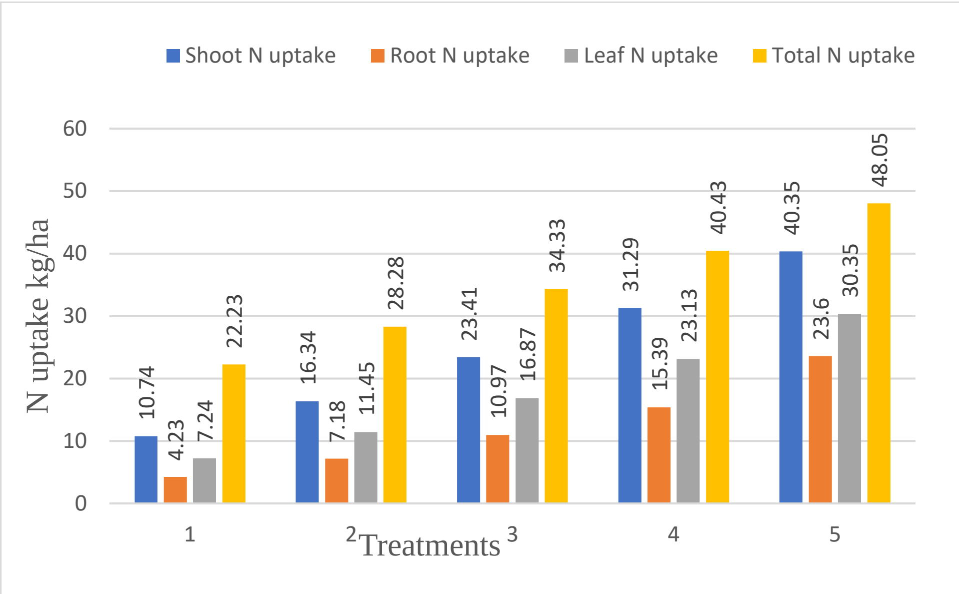

Fig .17. Effect of treatments on total N uptake

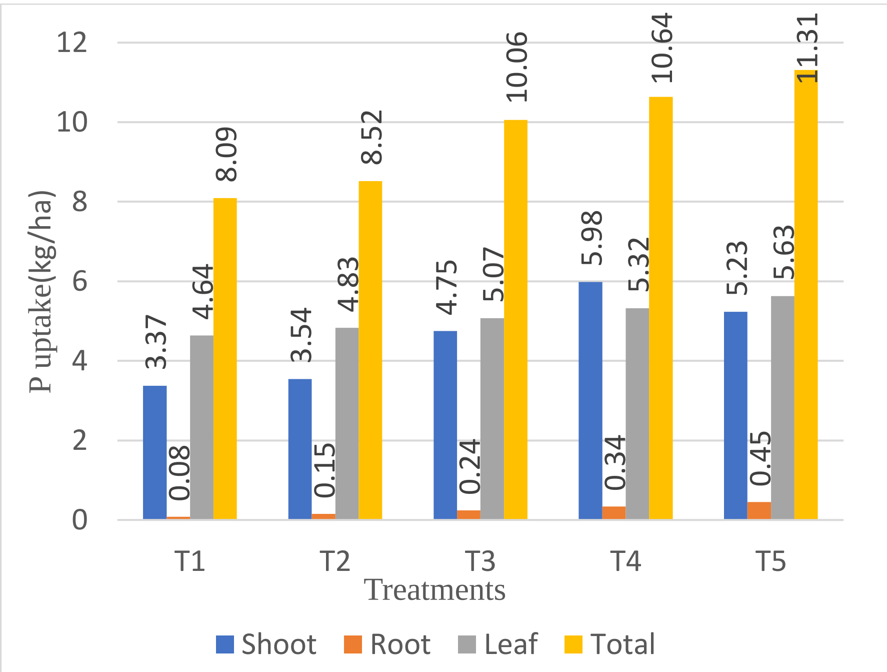

Fig .18. Effect of treatments on total uptake on P

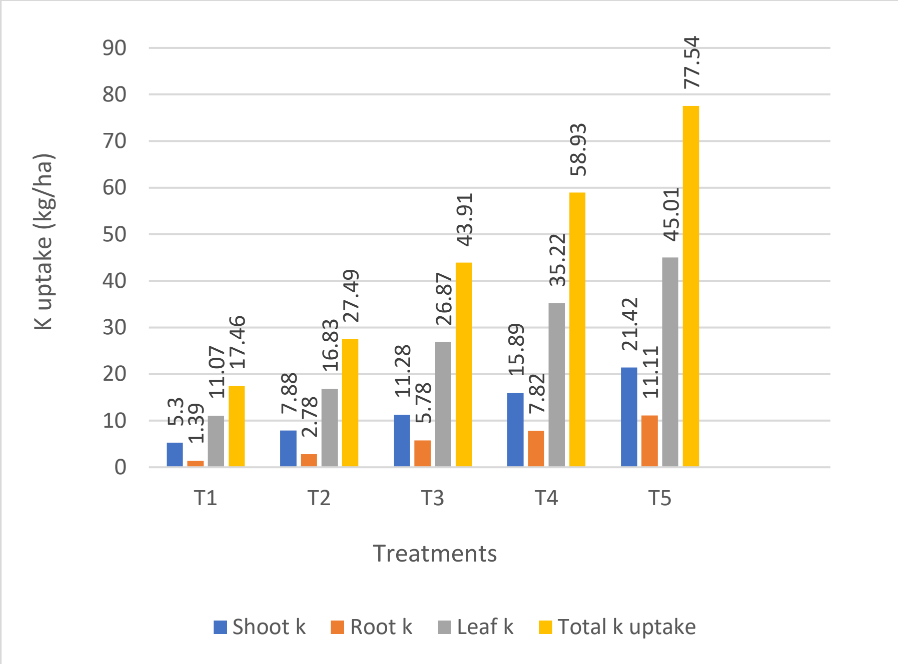

Fig .19. Effect of treatments on total K uptake

5.7. Correlation Studies

Correlation of biometric observations and yield of the crop at 30, 60 and 90 DAS are presented in tables 35 and 36 respectively. From the results it was revealed that yield was positively correlated with all the biometric observations recorded at 30 and 60 DAS respectively. At 30 and 60 DAS yield was positively correlated with plant height, stem girth, leaf length, petiole length, leaf width, number of leaves, number of branches, root length respectively.

Correlation of yield parameters and yield of the crop are presented in table 37. The correlation studies between yield parameters and yield. Yield was positively correlated with leaf to stem ratio, leaf fresh weight, stem fresh weight, root fresh weight, leaf dry weight, stem dry weight, root dry weight respectively.

The results between soil nutrient status and yield are presented in table 38. The correlation studies between yield and soil nutrient status of the crop shows that yield showed significantly positive correlation with soil nutrient status of N, P and K respectively. Among the primary nutrients, the highest positive correlation was exhibited by soil available N followed by available K and P.

The results for correlation between yield and the nutrient content of shoot, leaf is presented in table 39. Significantly positive correlation was exhibited by yield with the N, P and K content of leaf and shoot respectively.

Table 40 presents the results of correlation between the plant N, P and K uptake and yield. The correlation between nutrient uptake and yield showed a positive correlation with uptake of all primary nutrients. The highest correlation coefficient was exhibited by K followed by N and P uptake respectively.

5.8. Economics of the cultivation

Table 41 presents the results of the benefit cost analysis of various treatments. The highest and lowest cost of cultivation was recorded in T_1 and T_2 respectively. The BC ratio was the highest for T_5 which recorded the highest yield. Among all the treatments in T_1 recorded the lowest BC ratio and lowest yield respectively. The cost of cultivation was highest for T_1 due to the labour charges incurred during the application of cow dung slurry, as well as the higher cost of inputs.

The study concluded that the yield targets can be achieved using the targeted yield equations developed for (*Amaranthus tricolor.* L) in (AEU- 8). The highest dry matter production was achieved in T_5 suggests that judicious application of fertilizers can result in positive response to yield. The crop responded positively to higher fertilizer doses in T_5 which was observed in the results obtained while analysing the nutrient content of the crop and the nutrient uptake studies. There was a significant difference between the treatments when the plant Ca, Mg and micronutrient content was studied. The nutrients were maintained in a sufficiency range. While considering the economic aspect too, T_5 showed a superiority over the treatments. The STCR based targeted yield equations for (*Amaranthus tricolor.* L) can be adopted in (AEU-8) as the yield targets can be achieved with optimum use of fertilizers without compromising the soil quality and yield.

6. SUMMARY

The current work, entitled "Evaluation of STCR-based targeted yield equations of Amaranthus (*Amaranthus tricolor* L.) in southern laterite soils (AEU-8) of Kerala," was conducted in the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani from the period March 2022 to June 2022. In this work, a field experiment based on randomized block design was carried out to test and validate the targeted yield equation produced by STCR 2014 for the cultivation of *Amaranthus* at (AEU-8), Instructional farm, College of Agriculture, Vellayani, Thiruvananthapuram.

Use of STCR based targeted yield fertilizer management by using inorganic fertilizers in combination with FYM can minimize fertilizer requirements, saving fertilizer nutrients in a cost-effective and long-term way while increasing *Amaranthus* production and fertility. It is considered as sustainable method of crop production as it ensures judicious application of fertilizers without compromising the yield of the crop. Targeted yield equations developed under AICRP on STCR is an efficient strategy to provide fertilizer prescriptions. An advantage is that the farmers can predict the yield of the crop and provide fertilizer accordingly while using the equation. These equations developed in the research stations has to be test verified in farmer's field prior to wide scale adoption by the farming community. Fertilizer efficiency may be enhanced, with the added advantage of lesser chemical fertilizer usage. Therefore, it can be inferred that soil test crop response based targeted yield approach can be considered as a promising strategy for proposing optimum fertilizer recommendation in *Amaranthus* for similar type of soil and climatic conditions in (AEU-8) laterite soils of Kerala.

The five treatments used in the experiment were the organic and conventional package of practices based nutrient management as T_1 and T_2 and three levels of Soil test crop response (STCR) based on targeted yield with T_3, T_4 and T_5 having nutrient management for a targeted yield of 20, 22.5 and 25 t ha^{-1}. The following equation targeted yield equation used in the study was developed by All India Co-ordinated Research Project on STCR at the College of Horticulture, Kerala Agricultural University, Vellanikkara:

The targeted yield equations used in the study is:

FN = 3.50T – 0.10SN – 0.19ON
FP_2O_5 = 1.44T – 2.58SP – 0.30OP
FK_2O = 1.35T – 0.06SK – 0.13OK

T	= Targeted Yield
FN	= Fertilizer Nitrogen dose
SN	= Nitrogen contribution of Soil
ON	= Nitrogen contribution of Organic sources
FP2O5	= Fertilizer Phosphorous dose
SP	= Phosphorous contribution of Soil
OP	= Phosphorous contribution of Organic sources
FK_2O	= Fertilizer Potassium dose
SK	= Potassium contribution of Soil
OK	= Potassium contribution of Organic sources

The primary goals of the experiment were to test and validate the targeted yield equation developed under AICRP on STCR for Amaranthus in southern laterites of AEU-8. In the experiment, post-harvest soil quality was also examined by analyzing the physicochemical and biological properties of the soil. To better understand how different plant parts uptake nutrients, the nutritional content of various plant parts was examined. Studies of correlation between several parameters and yield were conducted. The following is a summary of the experiment's findings:

- When the vegetative characters of the crop recorded at intervals 30 and 60 DAS during the growing season it was noticed that the treatment T_5 showed a superiority and the treatment T_1 observed to be inferior over the other treatments.
- When the yield parameters of the crop were studied it was found to be maximum in T_5 (2.97) and minimum in T_1 (2.02). The total yield per plant in treatment T_5 (222.41 g) had the highest and T_1 (85.51 g) recorded the lowest. The total yield per plot in treatment T_1 (9.53 tonnes) showed the lowest whereas T_5 (24.79 tonnes) was found to be the highest. The yield targets were achieved for all the three STCR treatments. T_5 recorded a maximum yield of (24.79 t ha^{-1}) followed by T_4 (21.94 t ha^{-1}) and T_3 (19.47 t ha^{-1}). The yield achieved for treatments T_1 and T_2 were (9.53 t ha^{-1}) and (14.40 t ha^{-1}) respectively.
- While considering the fresh weight of the plant samples the leaf, shoot and root weights were highest in T_5 and lowest in T_1. The total shoot weight of (144.02 g) were observed in T_5 which is the highest and (82.2 g) observed in T_1 was the lowest. The root fresh

weight was highest in T_5 (75.09 g) and lowest in T_1 (43.52 g). The leaf weight in treatment T_5 (222.41 g) was found highest whereas T_1 (85.51 g) recorded the least. The dry weight of plant samples were recorded for shoot, root and leaf respectively. The shoot dry weight in treatment T_5 (16.36 g) was the highest while T_1 (9.14 g) recorded the least. When the dry weight of root was recorded, treatment T_1 (3.41g) recorded the least while T_5 (10.06 g) recorded the highest. The dry weight in leaf in treatment T_1 (15.60 g) recorded the least whereas T_5 (28.91 g) recorded the highest. There was significant difference among the treatments. The highest dry matter production was observed in T_5 (55.33 g) and lowest was recorded in T_1 (28.14 g).

- When the physical properties of the post-harvest soil samples were analysed there was no significant difference among the treatments while considering the particle density, bulk density, porosity and porosity. The treatment T_4 (44.14%) had the lowest water holding capacity, while T_1 (46.50%) had the highest. The pH in treatment T_1 (5.69) was found to be the lowest while T_2 (5.41) was recorded as the highest. The EC was found higher for T_1, T_3 and T_5 (0.22 dS m^{-1}) whereas T_2 and T_4 (0.21 dS m^{-1}) recorded to be low. The lowest CEC was recorded in T_2 (4.86 c mol kg $^{-1}$) and the highest was observed in T_5 (5.12 c mol kg^{-1}). The highest and lowest OC content were recorded in T_1 (0.72 mg kg^{-1}) and T_2 (0.50 mg kg^{-1}) respectively.
- Observations on available nitrogen in treatment T_1 (232.95 kg ha $^{-1}$) and T_5 (374.11 kg ha^{-1}) were found to be the lowest and highest respectively. The highest phosphorus content in soil was recorded in treatment T_5 (78.87 kg ha^{-1}). Lowest residual phosphorus content was found in treatment T_2 (49.67 kg ha^{-1}). Analysis of soil for potassium content of soil was recorded maximum in treatment T_5 (127.99 kg ha^{-1}) and lowest K content in T_1 (78.70 kg ha^{-1}).
- The analysis of secondary nutrients in soil suggests that there was no significant difference for Ca and Mg. The Ca content in soil was highest in T_3 (319.01 mg kg^{-1}) and lowest in T_5 (315.31 mg kg^{-1}). The Mg content in soil was highest in T_4 (126.43 mg kg^{-1}) and lowest in T_2 (120.74 mg kg^{-1}). The highest S content in soil was observed in T_1 (4.01 mg kg^{-1}) and lowest in T_5 (2.26 mg kg^{-1}).
- The micronutrients in post harvest soil samples were analysed. The Fe content in soil showed no significant difference among all treatments. The highest Fe content was recorded in T_3 (17.93 mg kg $^{-1}$) and lowest was recorded in T_2 (17.55 mg kg $^{-1}$). The Fe content was in the order $T_3 > T_5 > T_4 > T_1 > T_2$. The Mn content in soil also showed

significant difference in all treatments. Highest Mn content was observed in T_2 (5.61 mg kg^{-1}) and lowest was recorded in T_4 (2.80 mg kg^{-1}). The Mn content was in the order $T_2>T_3>T_4>T_5>T_1$. The order of Zn content was: $T_2>T_3>T_4>T_1>T_5$. Treatment T_2 (1.95 mg kg^{-1}) was superior and T_5 (0.95 mg kg^{-1}) recorded the least.

- The order of Cu content was: $T_2>T_3>T_4>T_1>T_5$. Treatment T_2 (1.67 mg kg^{-1}) was superior and T_1 (1.12 mg kg^{-1}) recorded the least.
- The B content in treatment T_1 (0.50 mg kg^{-1}) was recorded as higher content whereas T_5 (0.41 mg kg^{-1}) was the least.
- There was no significant difference among the treatments with respect to dehydrogenase activity. The descending order of the treatments: $T_1>T_3>T_4>T_5>T_2$. Treatment T_3 (52.62 g of TPF released g^{-1} soil per hour) had the lowest activity while T_1 (64.08 g of TPF released g^{-1} soil per hour) was the highest.
- The soil MBC didn't show any significant difference between the treatments. The highest microbial biomass carbon was in the treatment T_1 (124.35 μg g^{-1} soil) whereas the lowest was in T_4 (112.45 μg g^{-1} soil). The descending order of soil MBC followed the sequence of $T_1>T_2>T_3>T_4>T_5$.
- The macro and secondary nutrient content of shoot, root and leaf samples were analysed separately. The results showed a similar trend in all the cases. The primary nutrient content in all plant samples were in the order $T_5>T_4>T_3>T_2>T_1$. The highest N, P and K contents were observed in T_5 and the lowest was in T_1 . When the nutrient percentages are compared the highest percentage of nutrients were observed in K followed by N and P. The lowest nutrient percentages were observed in T_1 which has the lowest yield.
- The results of the micronutrients didn't follow similar trend in the plant samples. The order of micronutrients in the shoot samples is given below. The treatments effect on Fe content followed the order: $T_5>T_4>T_3>T_2>T_1$. The Cu content of shoot between the treatments followed the sequence of $T_2>T_1>T_3>T_4>T_5$. The effect of treatments on Zn content of shoot followed the order: $T_2>T_1>T_3>T_4>T_5$. The Mn content of shoot between the treatments followed the sequence of $T_2>T_1>T_3>T_5>T_4$. The effect of treatments on B content of shoot followed the order: $T_3>T_2>T_1>T_5>T_4$.
- The effect of treatments on micronutrients in root samples is given below. The treatments effect on Fe content followed the order: $T_2>T_1>T_3>T_5>T_4$. The Cu content between the treatments followed the sequence of $T_2>T_1>T_3>T_5>T_4$. The effect of treatments on Zn content followed the order: $T_3>T_4>T_2>T_5>T_1$. The Mn content

between the treatments followed the sequence of $T_2>T_1>T_3>T_5>T_4$. The effect of treatments on B content followed the order $T_1>T_2>T_3>T_5>T_4$.

- The effect of micronutrients in the leaf samples is given below. The Fe content followed the order: $T_2>T_3>T_4>T_5>T_1$. The Cu content between the treatments followed the sequence of $T_2>T_1>T_3>T_5>T_4$. The effect of treatments on Zn content followed the order: $T_3>T_4>T_2>T_5>T_1$. The Mn content between the treatments followed the sequence of $T_2>T_4>T_1>T_5>T_3$. The effect of treatments on B content followed the order: $T_2>T_4>T_3>T_1>T_5$.
- The highest uptake of primary nutrients were observed in T_5 which yielded the highest yield. The lowest uptake of primary nutrients were observed in T_1 which yielded the least. These results reveals that the fertilizer application can have a direct effect on nutrient uptake and thereby improve the yield of the crop as long as the supplied nutrient is well within the optimum range of crop as suggested in the Mistcherlich equation.
- Correlation between biometric observations and yield was worked out to understand the contribution of these observations to total yield of the crop. At 30 and 60 DAS yield was positively correlated with plant height, stem girth, leaf length, petiole length, leaf width, number of leaves, number of branches and root length respectively. This shows that plants with more number of leaves and highest plant height produced a higher yield.
- The correlation studies between yield and yield parameters revealed that Yield was positively correlated with leaf to stem ratio, leaf fresh weight, stem fresh weight, root fresh weight, leaf dry weight, stem dry weight and root dry weight respectively.
- The correlation studies between yield and soil nutrient status of the crop show that yield showed a significantly positive correlation with soil nutrient status of N, P and K respectively. Among the primary nutrients, the highest positive correlation was exhibited by soil available N followed by available K and P.
- When the correlation was worked out between yield and nutrient status of the crop there was a significantly positive correlation was exhibited by yield with the N, P and K content of leaf and shoot respectively.
- The correlation between nutrient uptake and yield showed a positive correlation with uptake of all primary nutrients. The highest correlation coefficient was exhibited by potassium, followed by nitrogen and phosphorous.
- The highest BC ratio was recorded in T_5 which states the superiority of this treatment on comparison to other treatments.

- The study concluded that the yield targets can be achieved using the targeted yield equations developed for (*Amaranthus tricolor.* L) in (AEU- 8). The highest dry matter production was achieved in T_5 suggests that judicious application of fertilizers can result in positive response to yield. The crop responded positively to higher fertilizer doses in T_5 which was observed in the results obtained while analysing the nutrient content of the crop and the nutrient uptake studies. There was a significant difference between the treatments when the plant Ca, Mg and micronutrient content was studied. The nutrients were maintained in a sufficiency range. While considering the economic aspect too, T_5 showed a superiority over the treatments. The STCR based targeted yield equations for (*Amaranthus tricolor.* L) can be adopted in (AEU-8) as the yield targets can be achieved with optimum use of fertilizers without compromising the soil quality and yield.

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"EVALUATION OF STCR BASED TARGETED YIELD EQUATIONS OF AMARANTHUS (*Amaranthus tricolor* L.) IN SOUTHERN LATERITE SOILS (AEU-8) OF KERALA"

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ABSTRACT

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ABSTRACT

The current work, entitled "Evaluation of STCR-based targeted yield equations of Amaranthus (*Amaranthus tricolor* L.) in southern laterite soils (AEU-8) of Kerala," was conducted in the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani from the period March 2022 to June 2022. In this work, a field experiment based on randomized block design was carried out to test and validate the targeted yield equation produced by STCR 2014 for the cultivation of *Amaranthus* at (AEU-8), Instructional farm, College of Agriculture, Vellayani, Thiruvananthapuram.

The five treatments used in the experiment were the organic and conventional package of practices based nutrient management as T_1 and T_2 and three levels of Soil test crop response (STCR) based on targeted yield with T_3, T_4 and T_5 having nutrient management for a targeted yield of 20, 22.5 and 25 t ha^{-1}. The following equation targeted yield equation used in the study was developed by All India Co-ordinated Research Project on STCR at the College of Horticulture, Kerala Agricultural University, Vellanikkara:

$$FN = 3.50T - 0.10SN - 0.19ON$$

$$FP_2O_5 = 1.44T - 2.58SP - 0.30OP$$

$$FK_2O = 1.35T - 0.06SK - 0.13OK$$

Where, FN, SN and ON are fertilizer nitrogen dose which was added through fertilizer, soil available nitrogen and nitrogen contribution of organic sources respectively. FP_2O_5, SP and OP are fertilizer phosphorus dose which is added through fertilizer, soil available phosphorus and phosphorous contribution of organic sources respectively. FK_2O, SP and OP are fertilizer potassium dose which is added through fertilizer, soil available potassium and potassium contribution of organic sources respectively.

The nutritional status of organic manures used in the experiment and initial soil fertility levels of the field were analysed to calculate the quantity of fertilizer dose in T_3, T_4 and T_5. Biometric observations, yield parameters, pre-and post-harvest physicochemical properties of soil and the nutrient content in shoot, root, leaf and dry matter production were recorded to study their effect on yield.

Among all the treatments T_5 recorded the highest values for biometric observations and yield parameters. The treatment T_5 recorded a yield of 24.79 t ha^{-1}. Similarly, the dry matter

production, number of leaves per plant and height of the plants were 55.33 g $plant^{-1}$, 36.86 and 42.17 cm respectively. The plant height and the number of branches per plant and the dry matter production too were the highest for this treatment (T_5).

The post-harvest analysis of soil physical properties such as particle density, bulk density and porosity showed no significant difference among the treatments. However, a significant difference was found in water holding capacity and was highest in T_1. The treatment T_1 recorded the lowest level of macronutrients while the highest level was recorded in T_5. All the treatments resulted in an increase in the organic carbon content of the soil after the experiment. Thus, treatments had negligible influence on overall soil health status as indicated by an insignificant difference among the treatments with respect to dehydrogenase activity and the microbial biomass carbon of the post-harvest soil samples.

The lowest uptake of macronutrients was observed in T_1 which recorded the lowest yield. The highest uptake of macronutrients was observed in T_5 which recorded the highest yield. This suggests that among the treatments higher levels of fertilizer application for the targeted yield range of 20 to 25 t ha^{-1} have a direct influence on nitrogen, phosphorous and potassium uptake and therefore an increase in crop production. There was a significant difference between the treatments with respect to secondary and micronutrient content of soil and plant respectively. These nutrients were maintained within a sufficiency range by application of amendments and organic matter.

The biometric parameters and yield were positively correlated. Also, a positive correlation was observed between yield parameters and yield. There was a positive correlation for yield with the post-harvest soil nutrient status of nitrogen, phosphorus and potassium respectively. The yield showed a significantly positive correlation with the nutrient content of the leaf and shoot. Similarly, a positive correlation was observed between yield and plant nitrogen, phosphorus and potassium uptake. The economics of cultivation indicate that treatment T_5 had the highest profit and benefit cost ratio compared to the other treatments.

It can be concluded that the Soil test crop response-integrated plant nutrient system based targeted yield equation with organic manure management for cultivating *Amaranthus tricolor* can be adopted and extended to agro ecological unit 8 of Trivandrum district of Kerala, India with a yield target of 25 t ha^{-1}. Therefore, the present study confirmed the possibility of optimizing of the yield of *Amaranthus* sustainably with nutrient management alone using targeted yield equations.

സംഗ്രഹം

"കേരളത്തിലെ തെക്കൻ ലാറ്ററൈറ്റ് മണ്ണിൽ (AEU-8) ക്കാ ചീരകൃഷി യി (*Amaranthus tricolor* L.) അഖിലേന്ത്യ ഏകോപിത ഗവേഷണ പരിപാടി (AICRP on STCR), 2014 അടിസ്ഥാനമാക്കിയുള്ള ടാർഗെറ്റു ചെയ്ത വിളവിനായുള്ള ഉരുത്തിരിച്ചെടുത്ത വിളവ് സമവാക്യം കാർഷിക കോളേജിലെ സോയിൽ സയൻസ് ആൻഡ് അഗ്രികൾച്ചറൽ കെമിസ്ട്രി വകുപ്പിൽ കൃഷിയിട നിരീക്ഷണത്തിലൂടെ പരീക്ഷിച്ചുറപ്പിച്ചു. ചീരകൃഷിക്കായി സോയിൽ ടെസ്റ്റ് ക്രോപ്പ് റെസ്പോൺസ് സ്റ്റഡീസ് സംബന്ധിച്ച് അഖിലേന്ത്യ ഏകോപിത ഗവേഷണ പരിപാടി (AICRP on STCR), 2014 ൽ ഉരുത്തിരിച്ചെടുത്ത സമവാക്യം 2022 മാർച്ച് മുതൽ 2022 ജൂൺ വരെയുള്ള കാലയളവിൽ ഇൻസ്ട്രക്ഷണൽ ഫാം, കോളേജ് ഓഫ് അഗ്രികൾച്ചർ, വെള്ളായണി, തിരുവനന്തപുരം (AEU-8) എന്ന സ്ഥലത്ത് പരിശോധിക്കുന്നതിനും സാധൂകരിക്കുന്നതിനുമായി ക്രമരഹിതമായ ബ്ലോക്ക് രൂപകൽപ്പനയെ അടിസ്ഥാനമാക്കിയുള്ള ഒരു ഫീൽഡ് പരീക്ഷണം നടത്തി.

പരീക്ഷണത്തിൽ ഉപയോഗിച്ച അഞ്ച് ചികിത്സാരീതികൾ ടി1, ടി2 എന്നിങ്ങനെയുള്ള പോഷക മാനേജ്മെന്റിന്റെ ജൈവവും പരമ്പരാഗതവുമായ പാക്കേജും ടി3, ടി4, ടി5 എന്നിവ STCR വിളവ് സമവാക്യം ഉപയോഗിച്ച് ടാർഗെറ്റുചെയ്ത വിളവ് അടിസ്ഥാനമാക്കിയുള്ള മൂന്ന് ലക്ഷ്യമിടുന്ന 20, 22.5, 25 ടൺ ഹെക്ടർ-1 വിളവ് ആണ്. പഠനത്തിൽ ഇനിപ്പറയുന്ന സമവാക്യം ടാർഗെറ്റുചെയ്ത വിളവ് സമവാക്യം ഉപയോഗിച്ചു.

$$FN = 3.50T - 0.10SN - 0.19ON$$

$$FP_2O_5 = 1.44T - 2.58SP - 0.30OP$$

$$FK_2O = 1.35T - 0.06SK - 0.13OK$$

ഇവിടെ, FN, SN, ON എന്നിവ യഥാക്രമം വളം, മണ്ണിൽ ലഭ്യമായ നൈട്രജൻ, ജൈവ സ്രോതസ്സുകളുടെ നൈട്രജൻ സംഭാവന എന്നിവയിലൂടെ ചേർത്ത വളം നൈട്രജൻ ഡോസ് ആണ്. FP_2O_5, SP, OP എന്നിവ യഥാക്രമം വളം, മണ്ണിൽ ലഭ്യമായ ഫോസ്ഫറസ്, ജൈവ സ്രോതസ്സുകളുടെ ഫോസ്ഫറസ് സംഭാവന എന്നിവയിലൂടെ ചേർക്കുന്ന വളം ഫോസ്ഫറസ് ഡോസുകളാണ്. FK_2O, SP, OP എന്നിവ യഥാക്രമം

വളം, മണ്ണിൽ ലഭ്യമായ പൊട്ടാസ്യം, ജൈവ സ്രോതസ്സുകളുടെ പൊട്ടാസ്യം സംഭാവന എന്നിവയിലൂടെ ചേർക്കുന്ന വളം പൊട്ടാസ്യം ഡോസാണ്.

T_3, T_4, T_5 എന്നിവയിലെ രാസവളത്തിന്റെ അളവ് കണക്കാക്കാൻ പരീക്ഷണത്തിൽ ഉപയോഗിക്കുന്ന ജൈവവളങ്ങളുടെ പോഷക നിലയും കൃഷിയിടത്തിലെ പ്രാരംഭ മണ്ണിന്റെ ഫലഭൂയിഷ്ഠതയും വിശകലനം ചെയ്തു. ബയോമെട്രിക് നിരീക്ഷണങ്ങൾ, വിളവ് പാരാമീറ്ററുകൾ, വിളവെടുപ്പിന് മുമ്പും ശേഷവും മണ്ണിന്റെ ഭൗതിക രാസ ഗുണങ്ങൾ, തണ്ട്, വേര്, ഇല, ഉണങ്ങിയ പദാർത്ഥങ്ങളുടെ ഉൽപാദനത്തിലെ പോഷകങ്ങളുടെ അളവ് എന്നിവ വിളവിൽ ചെലുത്തുന്ന സ്വാധീനം പഠിക്കാൻ രേഖപ്പെടുത്തി.

മറ്റ് പരീക്ഷണ ഘടകങ്ങളെ അപേക്ഷിച്ച് T_5 ബയോമെട്രിക് നിരീക്ഷണങ്ങൾക്കും വിളവ് പാരാമീറ്ററുകൾക്കും ഏറ്റവും ഉയർന്ന മൂല്യങ്ങൾ രേഖപ്പെടുത്തി. T_5 പരീക്ഷണ ഘടകം ഹെക്ടർ-1 24.79 ടൺ വിളവ് രേഖപ്പെടുത്തി. അതുപോലെ, ഉണങ്ങിയ പദാർത്ഥത്തിന്റെ ഉത്പാദനം, ഒരു ചെടിയുടെ ഇലകളുടെ എണ്ണം, ചെടികളുടെ ഉയരം എന്നിവ യഥാക്രമം 55.33 ഗ്രാം ചെടി-1, 36.86, 42.17 സെ.മീ. ചെടിയുടെ ഉയരവും ഒരു ചെടിക്ക് ശാഖകളുടെ എണ്ണവും ഉണങ്ങിയ പദാർത്ഥത്തിന്റെ ഉൽപാദനവും ഈ പരീക്ഷണ ഘടകത്തിൽ ഉയർന്നു കണ്ടു (T_5).

വിളവെടുപ്പിനു ശേഷമുള്ള മണ്ണിന്റെ ഭൗതിക ഗുണങ്ങളായ കണികാ സാന്ദ്രത, ബൾക്ക് ഡെൻസിറ്റി, പോറോസിറ്റി എന്നിവയുടെ വിശകലനം വിവിധ പരീക്ഷണ ഘടകങ്ങളിൽ കാര്യമായ വ്യത്യാസമൊന്നും സൃഷ്ടിച്ചില്ല. എന്നിരുന്നാലും, പരീക്ഷണ ഘടകങ്ങൾ മണ്ണിലെ ജല സംഭരണ ശേഷിയിൽ കാര്യമായ വ്യത്യാസം സൃഷ്ടിക്കുന്നതായി കണ്ടെത്തി. ഏറ്റവും ഉയർന്നത് T_1 ലാണ്. T_1 പരീക്ഷണ ഘടകങ്ങൾ മാക്രോ ന്യൂട്രിയന്റുകളുടെ ഏറ്റവും താഴ്ന്ന നില രേഖപ്പെടുത്തിയപ്പോൾ ഏറ്റവും ഉയർന്ന അളവ് T5 ൽ രേഖപ്പെടുത്തി. എല്ലാ ചികിത്സകളും പരീക്ഷണത്തിന് ശേഷം മണ്ണിലെ ജൈവ കാർബണിന്റെ അളവ് വർദ്ധിപ്പിക്കുന്നതിന് കാരണമായി. അതിനാൽ, ഡീഹൈഡ്രജനേസ് പ്രവർത്തനവും വിളവെടുപ്പിനു ശേഷമുള്ള മണ്ണിന്റെ സാമ്പിളുകളുടെ മൈക്രോബയൽ ബയോമാസ് കാർബണും സംബന്ധിച്ച പരീക്ഷണ ഘടകങ്ങൾ തമ്മിലുള്ള നിസ്സാരമായ വ്യത്യാസം സൂചിപ്പിക്കുന്നത് പരീക്ഷണ ഘടകങ്ങൾ മൊത്തത്തിലുള്ള മണ്ണിന്റെ ആരോഗ്യനിലയിൽ കാര്യമായ സ്വാധീനം ചെലുത്തുന്നില്ല .

ഏറ്റവും കുറഞ്ഞ വിളവ് രേഖപ്പെടുത്തിയ ടി1 ൽ മാക്രോ ന്യൂട്രിയന്റുകളുടെ ഏറ്റവും കുറഞ്ഞ ആഗിരണം നിരീക്ഷിക്കപ്പെട്ടു. ഏറ്റവും

ഉയർന്ന വിളവ് രേഖപ്പെടുത്തിയ ടി5 ൽ മാക്രോ ന്യൂട്രിയന്റുകളുടെ ഏറ്റവും ഉയർന്ന ഉപഭോഗം നിരീക്ഷിക്കപ്പെട്ടു. 20 മുതൽ 25 ടൺ ഹെക്ടർ ഹെക്ടർ വരെയുള്ള വിളവെടുപ്പിന് ഉയർന്ന തോതിലുള്ള രാസവളപ്രയോഗം നൈട്രജൻ, ഫോസ്ഫറസ്, പൊട്ടാസ്യം എന്നിവയുടെ ആഗിരണത്തിൽ നേരിട്ട് സ്വാധീനം ചെലുത്തുന്നുവെന്നും അതിനാൽ വിള ഉൽപ്പാദനം വർദ്ധിക്കുമെന്നും ഇത് സൂചിപ്പിക്കുന്നു. മണ്ണിന്റെയും ചെടിയുടെയും യഥാക്രമം ദ്വിതീയവും സൂക്ഷ്മപോഷകവും സംബന്ധിച്ച പരീക്ഷണ ഘടകം തമ്മിൽ കാര്യമായ വ്യത്യാസമുണ്ട്. മൺ മാറ്റചേരുവകൾ (soil amendments) ഓർഗാനിക് വസ്തുക്കളും ഉപയോഗിച്ച് ഈ പോഷകങ്ങൾ മതിയായ പരിധിക്കുള്ളിൽ നിലനിർത്തി.

ബയോമെട്രിക് പാരാമീറ്ററുകളും വിളവും ക്രിയാത്മകമായി ബന്ധപ്പെട്ടിരിക്കുന്നു. കൂടാതെ, വിളവ് പാരാമീറ്ററുകളും വിളവും തമ്മിൽ നല്ല പരസ്പരബന്ധം നിരീക്ഷിക്കപ്പെട്ടു. യഥാക്രമം നൈട്രജൻ, ഫോസ്ഫറസ്, പൊട്ടാസ്യം എന്നിവയുടെ വിളവെടുപ്പിനു ശേഷമുള്ള മണ്ണിലെ പോഷക നിലയുമായി വിളവിന് നല്ല ബന്ധമുണ്ട്. വിളവ് ഇലയുടെയും ചിനപ്പുപൊട്ടലിന്റെയും പോഷക ഘടകങ്ങളുമായി കാര്യമായ നല്ല ബന്ധം കാണിച്ചു. അതുപോലെ, വിളവും ചെടികളുടെ നൈട്രജൻ, ഫോസ്ഫറസ്, പൊട്ടാസ്യം എന്നിവയും തമ്മിൽ നല്ല ബന്ധം നിരീക്ഷിക്കപ്പെട്ടു. കൃഷിയുടെ സാമ്പത്തികശാസ്ത്രം സൂചിപ്പിക്കുന്നത്, മറ്റ് ചികിത്സകളെ അപേക്ഷിച്ച് T5 ചികിത്സയ്ക്ക് ഏറ്റവും ഉയർന്ന ലാഭവും ആനുകൂല്യ ചെലവും അനുപാതം ഉണ്ടെന്നാണ്.

ചീര കൃഷി ചെയ്യുന്നതിനായി മണ്ണ് പരിശോധന വിള പ്രതികരണം-സംയോജിത സസ്യ പോഷക സമ്പ്രദായം അടിസ്ഥാനമാക്കിയുള്ള ലക്ഷ്യാധിഷ്ഠിത വിളവ് സമവാക്യവും ജൈവവള പരിപാലനവും സ്വീകരിക്കുന്നതുവഴി ഹെക്റ്റർ പ്രതി ൨൫ (25) ടൺ വിളവ് നേടാം എന്നതിനാൽ, തിരുവനന്തപുരം ജില്ലയിലെ കാർഷിക പരിസ്ഥിതി യൂണിറ്റ് 8 ലേക്ക് പരിപാലിക്കാൻ സുസ്ഥിരമായി സാധിക്കും എന്ന് നിലവിലെ പഠനം സ്ഥിരീകരിച്ചു.

APPENDIX I

Week	Temperature(°C)		RH (%)		Rain
No.	Max.	Min.	Avg Max	Avg Min	(mm)
9	33.0	22.3	91.8	73.8	-
10	32.8	24.1	90.1	78.1	0.1
11	33.4	24.4	89.3	75.7	-
12	33.9	25.3	87.7	76.4	-
13	33.8	25.2	87.7	75.7	0.1
14	33.5	23.4	89.1	83.7	5.7
15	32.5	21.3	91.9	89.3	5.9
16	32.7	21.6	90.5	81.0	0.8
17	33.4	23.3	87.4	76.6	3.7
18	33.9	23.9	89.7	75.4	3.0
19	33.6	23.8	89.3	81.3	3.1
20	31.1	22.9	96.6	88.6	33.6
21	31.2	23.3	91.4	85.7	10.7
22	31.4	23.4	91.7	85.1	13.9
23	31.4	23.5	91.3	88.1	2.6
24	31.5	23.0	91.3	87.6	10.9
25	31.9	23.8	90.3	85.7	2.3
26	31.6	23.4	92	88.2	6.5

Fig.1 Weather data during (March-June 2022)