# NUTRIENT SCHEDULING IN RAINFED SORGHUM
# (*Sorghum bicolor* L. Moench)

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# NUTRIENT SCHEDULING IN RAINFED SORGHUM
# (*Sorghum bicolor* L. Moench)

*By*

**KARTHIK TR**
**(2019-11-032)**

**THESIS**

**Submitted in partial fulfillment of the**

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**VELLAYANI, THIRUVANANTHAPURAM-695 522**

**KERALA, INDIA**

## 2021

# DECLARATION

I, hereby declare that this thesis entitled **"NUTRIENT SCHEDULING IN RAINFED SORGHUM (*Sorghum bicolor* L. Moench)"** 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.

Place : Vellayani

Date :

KARTHIK TR

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## CERTIFICATE

Certified that this thesis entitled **"NUTRIENT SCHEDULING IN RAINFED SORGHUM (*Sorghum bicolor* L. Moench)"** is a record of research work done independently by Mr. KARTHIK T R (2019-11-032) 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 him.

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# CERTIFICATE

We, the undersigned members of the advisory committee of **Mr. KARTHIK T R (2019-11-032)** a candidate for the degree of **Master of Science in Agriculture** with major in Agronomy, agree that the thesis entitled **"NUTRIENT SCHEDULING IN RAINFED SORGHUM (*Sorghum bicolor* L. Moench)"** may be submitted by Mr. KARTHIK T R (2019-11-032), in partial fulfillment of the requirement for the degree.

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*KARTHIK.T.R*

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# LIST OF ABBREVIATIONS

| Abbreviation | Expansion |
|---|---|
| % | Per cent |
| $^{o}C$ | Degree Celsius |
| BCR | Benefit -cost ratio |
| CD | Critical difference |
| cm | Centimeter |
| $cm^3$ | Cubic centimeter |
| DAE | Days after emergence |
| DAP | Days after planting |
| DAS | Days after sowing |
| DAT | Days after transplanting |
| d $Sm^{-1}$ | Deci Siemen per meter |
| EC | Electrical conductivity |
| *et al.* | Co-workers/ co- authors |
| Fig. | Figure |
| FYM | Farm yard manure |
| g | Gram |
| HI | Harvest index |
| ha | Hectare |
| K | Potassium |
| KAU | Kerala Agricultural University |
| kg $ha^{-1}$ | Kg per hectare |
| LA | Leaf area |
| LAI | Leaf area index |
| m | Meter |
| Max. | Maximum |
| mg | milli gram |
| Min. | Minimum |
| mm | Milli meter |
| N | Nitrogen |
| $NO_3^-$ | Nitrate |
| NS | Non-significant |
| P | Phosphorous |
| pH | Negative logarithm of hydrogen ion concentration |
| POP | Package of practices |
| q $ha^{-1}$ | quintals per hectare |
| RBD | Randomized block design |
| RDF | Recommended doses of fertilizer |
| RH | Relative humidity |
| ₹ | Indian rupees |
| SEm | Standard error mean |
| t $ha^{-1}$ | Tons per hectare |
| *viz.* | Namely |

# INTRODUCTION

Millets are group of small grained cereal food crops popularly known as nutri-cereals as they provide most of the nutrients required for normal functioning of human body. These wonder crops are highly tolerant to drought and other extreme conditions and are grown with low chemical inputs such as fertilizers and pesticides. Sorghum, also known as great millet or jowar is truly a versatile crop that can be grown as a grain, forage or sweet crop. This major millet has unique capacity to withstand drought or excessive soil moisture and hence known as the “crop camel”. The $C_4$ type photosynthesis pathway enables the crop to efficiently use the nutrients, radiation, and thus makes it adaptable to harsh and water-limited conditions. The deep root system architecture of sorghum further empowers it drought-tolerant. The crop has a quick growing habit and can survive even on marginal lands; hence considered to be a climate resilient crop.

Like cereals, millets also respond to nutrient application and nutrient stress is considered to be a major constraint affecting the millet productivity. Therefore efficient nutrient management approach is a key strategy to achieve higher productivity of millets especially in rainfed agriculture. Sorghum is a heavy user of major nutrients and hence application of fertilizers are essential to boost grain yield and get higher returns in this crop.

Nitrogen (N) is the vitally important plant nutrient with its major role in formation of proteins, carbohydrate utilization and promotion of vegetative growth in cereals and millets. Potassium (K) is the macronutrient most extracted by plants, and it plays an important role in photosynthesis, formation and translocation of carbohydrates. In addition to activation of numerous enzymes, K plays an important role in the maintenance of electrical potential gradients across cell membranes and the generation of turgor. Sorghum responds to the application of K under water stressed conditions (Sharma and Kumari, 1996) and under rainfed conditions potassium plays a major role in maintaining water potential and imparting drought tolerance.

Though N is the major stimulant to crop growth, for its efficient utilization, the crop must have access to an adequate amount of K from the plant-available pool of K in the soil. Hence, in order to improve N use efficiency, the balanced nutrition of N and K is important. Crop response to applied fertilizer N decreases at low K levels when the exchangeable K content of a soil is below a critical target level and there is no point in applying large quantities of N when K is limiting. Hence the ratio of N and K is important for producing higher yield with better quality of produce especially in nutrient demanding crops like sorghum.

Time of nutrient application holds importance as its rate of application, and splitting the nutrient doses and its frequency of application influence the nutrient use efficiency. Split application of N fertilizer reduces its loss and thereby improves the nitrogen use efficiency. Similarly, application of K in split doses at different stages of the crop can enhance the efficiency of its utilisation and result in higher grain yield, especially under heavy rainfall situation in cereals and millets.

The crop sorghum has recently gained popularity in Kerala with the introduction of millet villages in the State. Sorghum can be cultivated as a rainfed crop in kharif and also during summer season in Southern Kerala which receives adequate summer and pre monsoon showers. However, appropriate agro techniques especially the nutrient management practices to match the current fertility status of Kerala soils are lacking and hence the scientific investigation on the response of sorghum to N and K which are often limiting in Kerala soils is highly relevant.

With this background, the present study was proposed with the following objectives;

- To standardise the nutrient schedule for rainfed sorghum
- To workout the economics of cultivation of the crop

# 2. REVIEW OF LITERATURE

Millets are important food crops in the dry and semi dry areas and are cultivated on large scale in these areas owing to tolerance to abiotic and biotic stress situation especially the dry condition. Millets respond to the application of nutrients and higher yield is achieved by balanced application of nitrogen and potassium. Nitrogen and potassium is found to have a positive interaction and yield response to potassium application in cereals and millets depends to a great extent on level of nitrogen nutrition. In nutrient demanding crops like sorghum, nitrogen and potassium ratios often influence the yield and quality parameters through their interactions on uptake of nutrients and assimilation of metabolites. When nitrogen and potassium are applied as split doses at different stages, the crop can utilise it properly than when applied as a single dose and hence time of application of these nutrients is also significant for formulating the schedule of application of nutrients. In this chapter a detailed research work done on the effect of nutrient ratios and time of application of major nutrients on various cultivation aspects of sorghum and similar crops are presented.

## 2.1 EFFECT OF NUTRIENT RATIOS

### 2.1.1 Effect of nutrient ratios on growth and growth attributes

Sorghum is a nutrient demanding crop and responds well to the application of fertilizers. Application of total recommended dose of fertilizers to the crop resulted in greater plant height and growth of the crop and the descending the level of fertilizes reduced the growth of sorghum as reported by Jat *et al*. (2013). Kumar *et al.* (2018) observed that supply of nutrients soil test basis produced higher growth of sorghum in terms of plant height and leaf length at each specific stage of the crop. Patil *et al*. (2018) demonstrated that, in rabi sorghum, the total nutrient supply through inorganic fertilizers enhanced the plant growth in terms of plant height, number of leaves per plant and dry matter accumulation in contrast to the control.

Significance of N: K ratios with respect to the growth and growth attributes has been reported by many researchers. In a study conducted at Kerala Agricultural

University on upland rice, Gopalakrishnan (2005) reported that NK ratio of 100:50 ($N:K_2O$ in kg $ha^{-1}$) resulted in the highest plant height, tiller number and dry matter production compared to 80:40, 80:60, 100:75, 120:60 or 120:90 NK ratios. According to Wells and Wood (2007), optimum N:K ratios favor healthy plant growth and development whereas imbalance of N and K supply is detrimental to plant growth. Barik *et al.* (2017) reported that higher plant height was obtained with the application of 100 kg N and 80 kg K per ha than with the application of 50 kg N and 60 kg K per ha and the control in sweet sorghum.

Akram *et al.* (2007) found that the plant height of sorghum was enhanced with the application of both phosphorous and potassium together in comparison with the phosphorous and potassium alone. Rao *et al*. (2014) reported a marked increase in the tiller production of kharif rice with 25 per cent increase in P and K doses. Significantly higher plant height and number of tillers per hill were produced in finger millet with the application of P and K in 1:1 ratio (75 :75 kg $ha^{-1}$) compared to the application of same at the rate of 75: 62.5 kg $ha^{-1}$ at 30, 60 and 90 DAS (Sundaresh, 2016).

According to Beuchamp and Hamilton (1970), the highest dry matter yield was produced in corn with the application of N and P in the highest ratio. Ravikovitch and Yoles (1971) reported that growth of fox tail millet decreased sharply under saline conditions when N-P treatments were not applied and while application of phosphorus at higher rates with moderate levels of nitrogen significantly improved the plant growth. Response of fox tail millet to low nitrogen and phosphate by respective reduction and enhancement of its root system has been pointed out by Nadeem *et al*. (2020).

Ratios of major nutrients N, P and K have profound influence in growth of sorghum as reported by several workers. Meena *et al.* (2017) investigated the effect of varied nutrient ratios on the growth of sorghum. The result of the study indicated that the nutrient ratio 2:1:1 as 100: 50: 50 kg $ha^{-1}$ of N: $P_2O_5$: $K_2O$ enhanced the plant height, stem diameter, leaf number per plant and dry matter accumulation over the same ratio as 80: 40: 40 and 60: 30: 30 kg $ha^{-1}$ of N: $P_2O_5$: $K_2O$ and control. Verma *et al*. (2017) conducted an experiment on sorghum to assess the effect of fertility levels on the growth of the crop and reported that 125 per cent recommended dose of fertilizers (RDF) in 2.5:1.25:1.25 ratio of N: $P_2O_5$: $K_2O$ resulted in the highest plant height and dry matter accumulation which was followed by the level 100 per cent (80: 40: 40 kg $ha^{-1}$ or 2:1:1 ratio of N: $P_2O_5$: $K_2O$), 75 per cent and 50 per cent RDF. Ajeigbe *et al*. (2018) conducted an experiment on sorghum (*Sorghum bicolor* (L). Moench) with different levels of nitrogen application along with same quantity of P and K. In their experiment it was observed that application of 80 kg N $ha^{-1}$ had influenced the plant growth and development in terms of plant height, LAI at different growth stages when compared with the application of 100 kg N $ha^{-1}$ and the control. In an experiment conducted on fodder sorghum, Aditi *et al*. (2019) reported that 100 per cent RDF (80: 40: 0 kg $ha^{-1}$ or 2:1:0 ratio of N:$P_2O_5$: $K_2O$)+ biofertilizers and 75 per cent RDF + biofertilizers + biocompost recorded higher level of growth in terms of plant height and stem girth in comparison with 50 per cent RDF with biofertilizers and control.

### 2.1.2 Effect of nutrient ratios on yield attributes and yield

Response to K applications in both rice and wheat increased with N application, indicating that higher K rates are required at higher N rates (Mondal, 1982). In a long-term experiment conducted, it was observed that grain yields of sorghum was 4.0 t $ha^{-1}$ with an application of 120 kg N $ha^{-1}$, 4.6 t $ha^{-1}$ with 120 kg N $ha^{-1}$ + 30 kg K $ha^{-1}$ (N:K ratio 4:1), and 5.0 t $ha^{-1}$ when 120 kg $ha^{-1}$ each of N and K (N:K ratio 1:1) were applied. In this experiment, application of K increased the grain yield by almost 1 t $ha^{-1}$ in the presence of N in the 3$^{rd}$ year (ICRISAT, 1983). Gopalakrishnan (2005) reported that in upland rice, panicle length, number of spikelets per panicle, number of filled grains per panicle, thousand grain weight, grain yield and straw yield were the highest with NK ratio 100:50 (N:$K_2O$ in kg $ha^{-1}$) compared to 80:40, 80:60, 100:75, 120:60 or 120:90 NK ratios. Barik *et al.* (2017) reported that the highest biomass was obtained in sweet sorghum with the application of N and K in 100:80 kg $ha^{-1}$ compared to 100:60, 50:60 or 50:80 ratios.

In an irrigated trial on rabi season sorghum at Pune, the yield increase with P application was 180 kg $ha^{-1}$ in the presence of 50 kg $ha^{-1}$ N and 450 kg $ha^{-1}$ with 150 kg $ha^{-1}$ N (Pawar *et al*., 1980). As reported by Ashiono *et al*. (2005), increase in grain yield, green stover yield and seed weight were obtained with the application of 40 kg N and 20 kg P ha$^{-1}$ (2:1 ratio of N and P) in comparison with the higher levels of nitrogen and phosphorous in dry land sorghum. In an experiment on grain sorghum in Ghana, Buah *et al*. (2012) observed that though application of K did not influence the yield attributes and yield, P increased the yield by 14 per cent while N affected the yield in a quadratic manner. In this trial the two N:P ratios i.e., 40:0 and 40:17.2 kg ha$^{-1}$ were economically superior. Sumeriya and Singh (2014) reported that 100 per cent RDF in N:P ratio 2:1 (80: 40 kg of N and $P_2O_5$) enhanced the grain and forage yield in sorghum. Schlegel and Havlin (2020) concluded that fifty-five year of irrigated sorghum response to N and P fertilization demonstrated a strong positive interaction between N and P on grain yield, apparent N and P recovery, and profitability.

Akram *et al*. (2007) reported that in sorghum, the highest grain yield (2.26 t ha$^{-1}$) and biological yield (31.7 t ha$^{-1}$) were obtained with the combined application of P and K in 2:1 ratio (80:40 kg ha$^{-1}$) in comparison with application of nutrients solely. In a trial conducted in maize, combination of P and K in 90:60 kg ha$^{-1}$ was found to produce higher grain yield compared to lower levels (Hussain *et al*., 2007). Rao *et al*. (2014) reported a marked increase in number of filled grain per panicle in kharif rice due to 25 per cent increase in P and K doses and 50 per cent increase in P dose. As reported by Sundaresh (2016), application of P and K doses as 75:62.5 kg ha$^{-1}$ produced a grain yield of 52.03 q ha$^{-1}$ and straw yield of 87.57 q ha$^{-1}$ in finger millet, compared to the application of P and K in 1:1 ratio (50:50 kg ha$^{-1}$).

Azam *et al*. (2010) demonstrated the effect of NPK fertilizers in different ratios in sorghum and observed that higher green fodder yield (81 t ha$^{-1}$) along with higher dry matter yield (16.67 t ha$^{-1}$) were obtained with the application of NPK at the rate of 80:50:25 kg ha$^{-1}$. Garma *et al*. (2013) reported that NPK ratio as 80:30:30 kg ha$^{-1}$ was sufficient to improve the yield in sweet corn when compared to its use in combination with bio sludge. Kaur and Satpal (2019) investigated the effect of different rates of application of NPK in forage sorghum in Punjab and Haryana and reported significantly higher green fodder and dry matter yield with the application of 150 per cent RDF in Punjab (100 per cent RDF - 100: 20: 25 kg ha$^{-1}$ of N: $P_2O_5$:

$K_2O$) and Haryana (100 per cent RDF - 75: 15: 0 kg $ha^{-1}$ of N: $P_2O_5$: $K_2O$ ) compared to 75 per cent RDF and control. Thesiya *et al.* (2019) concluded that the application of NPK in a ratio of 40:20:0 kg N: $P_2O_5$: $K_2O$ $ha^{-1}$ was sufficient to produce a grain yield of 2.05 t $ha^{-1}$ and stover yield 5.85 t $ha^{-1}$ in little millet.

**2.1.3 Effect of nutrient ratios on pest and disease incidence**

In a field trial on rice, Subramanian and Balasubramanian (1976) observed a considerable reduction in thrips population with increasing levels of potassium. Kulagod *et al*. (2011) found that in rice, significantly higher population of ear head bug and grain damage was observed in treatments receiving only N followed by treatments receiving NPK in 2:1:1 proportion. Treatments receiving only K recorded significantly lower population but the treatments with P alone and P in combination with N supported moderate bug population. Tanzubil (2014) conducted an experiment on pest infestation and N fertilizer application in sorghum and recommended to limit the N application to 50 kg $ha^{-1}$ to minimise the effect of insect pests and to improve the grain quality

A progressive increase in the leaf spot diseases in sorghum with increasing dose of N was reported by Naik *et al*. (1976). A positive effect of N and K interaction was reported by Singh (1978) on rust of wheat. Rowaished (1980) reported that increasing the N dose increased the disease severity in winter wheat. Adding phosphorus fertilizer along with nitrogen rendered the crop more susceptible to this disease, while adding potassium fertilizer moderated the effect. Sime *et al*. (2017) observed that the fertilizer ratio of N:P:K (20:10:10) at the dose 200 kg $ha^{-1}$ render the plant less susceptible to the blast at all its growth phases and suggested the use of fertilizers at the proper doses for fighting against rice blast.

**2.1.4 Effect of nutrient ratios on plant nutrient content and uptake**

In an experiment conducted to assess different NK ratios in upland rice, Gopalakrishnan (2005) reported highest grain crude protein content, total chlorophyll content and NPK content recorded with NK ratio 100:50 (N:$K_2O$ in kg $ha^{-1}$) compared to 80:40, 80:60, 100:75, 120:60 or 120:90 NK ratios. The pearl millet grain protein content increased from 9.85 to 11.29 per cent at 90 kg N $ha^{-1}$, and from 10.01

to 11.51 per cent at 120 kg N $ha^{-1}$ with the increase in K level from 0 to 60 kg $K_2O$ $ha^{-1}$ (Yadav *et al.*, 2007). According to Almodares *et al*. (2008), the highest carbohydrate content in sweet sorghum was recorded with the application of N and K (through 180 kg urea and 50 kg potassium sulphate). Mekdad and El-Sherif (2016) reported the highest sugar content in sweet sorghum with the combined application of 120 kg N and 75 kg K. As reported by Barik *et al*. (2017), the ratio of nitrogen and potassium had a significant effect on sweet sorghum when the other parameters remain constant. In their trial, application N and K (100:80 kg $ha^{-1}$) resulted in the highest sugar concentration at 100 DAS.

Higher level of crude protein in sorghum was found with the application of N and P at the rate of 20 and 30 kg $ha^{-1}$ respectively in comparison with the higher amount of nitrogen application in dry land region (Ashiono *et al*., 2005). Shaheen *et al*. (2010) investigated the effect of different fertilizer ratios in sorghum and concluded that full N + P and half N + P along with compost resulted in higher NPK uptake in grain and stover when compared to the control treatment. Sumeriya and Singh (2014) observed that NPK uptake and protein content were enhanced with the treatment of 100 per cent RDF (80: 40 kg of N and $P_2O_5$) over 50 per cent RDF and control in an experiment with varied recommended dose of fertilizers in sorghum. Mussarat *et al.* (2021) reported that N and P nutrition had significant effect on chlorophyll content in wheat and application of 160 kg N and 90 kg P resulted in highest SPAD (chlorophyll meter) value.

Choudhary *et al.* (1981) reported that the available N content in the soil was enhanced by the application of P and K on long term basis. In an experiment conducted in sorghum, Akram *et al*. (2007) reported that the nitrogen uptake was improved with P and K application but the difference between the two was non significant; and their combined use surpassed their alone application. Phosphorus and potassium uptake were also the highest with P+K application followed by the K alone and P alone treatments. Sundaresh (2016) reported that in finger millet, the highest NPK uptake (179.20 kg N, 29.56 kg $P_2O_5$ and 70.89 kg $K_2O$ $ha^{-1}$) with P:K ratio of 75:62.5 kg $ha^{-1}$ which was 150 per cent RDP and 125 per cent RDK with respect to P and K.

Elevated levels of crude protein have been recorded with the application of 80:50:25 NPK kg ha$^{-1}$ in an experiment conducted by Azam *et al*. (2010) for three consecutive years in sorghum with different NPK fertilizer ratios. Paramasivan *et al*. (2011) reported that, the highest total N uptake by maize crop was noticed in Pilamedu and Pilaviduthi series of soil with 250:60:25 and 250:76:88 kg NPK ha$^{-1}$. Jat *et al*. (2013) investigated the nutrient management consequences on sorghum crop and revealed that high fertilizer dose up to the mark of recommendation based on soil test result gave the high chlorophyll content along with high NPK uptake in contrast to the low recommended fertilizer doses.

### 2.1.5 Effect of nutrient ratios on soil properties

In an experiment conducted in upland rice, the available N, P, K and S in the soil after the experiment was the highest with NK ratio 120:90 kg ha$^{-1}$ compared to NK ratios 80:40, 80:60, 100:50, 100:75 and 120:60 (Gopalakrishnan, 2005). In an experiment on P:K ratios in finger millet, Sundaresh (2016) observed significantly higher electrical conductivity and available N content in soil in the post experimental period with the application of P and K in 1:1 ratio (75 :75 kg ha$^{-1}$). However, the available P content of the soil was the highest with P and K ratio 75: 62.5 kg ha$^{-1}$ while the available K content was the maximum with P and K ratio 62.5 :75 kg ha$^{-1}$. Mussarat *et al*. (2021) reported that in wheat crop cultivated in highly calcareous soil, the available P content was the highest (3.30 kg ha$^{-1}$) with the application of 160 kg N ha$^{-1}$ and 60 kg $P_2O_5$ per hectare. The increase was 202 per cent over the treatment receiving 80 kg ha$^{-1}$ N and 60 kg ha$^{-1}$ P.

Ngala *et al.* (2013) reported that combination of sub-optimal rates of FYM and NPK fertilizers enhanced the peal millet yields with positive N and P balances in the soils. Application of NPK (90:19.6:62.2 kg ha$^{-1}$) and its double dose to rice decreased the soil bulk density in soil during the post experimental period (Bi *et al*., 2014). Pallavi *et al.* (2016) conducted a field experiment on nutrient management on finger millet and revealed the treatment that containing higher recommended doses of fertilizers resulted in high available NPK content in soil which was followed by 75 per cent RDF + 25 per cent N through poultry manure. According to Singh *et al.* (2020), application of NPK at the ratio of 20:40:40 kg ha$^{-1}$ along with biochar in finger millet resulted in the lowest bulk density (1.08 Mg $m^{-3}$), highest organic carbon content (0.82 per cent), highest available N (328.75 kg $ha^{-1}$), P (36.10 kg $ha^{-1)}$ and K ( 186.10 kg $ha^{-1}$) content in soil after the experimentation.

### 2.1.6 Effect of nutrient ratios on economics of cultivation

In an experiment on the effect of varied levels of phosphorous and potassium in sorghum, Akram *et al*. (2007) reported that the application of phosphorous and potassium enhanced the net returns and net income. Buah *et al*. (2012) concluded that 40:0 kg $ha^{-1}$ and 40:17.2 kg $ha^{-1}$ N and P were the economically superior nutrient doses in the investigation with varied ratios of NPK in sorghum. Sumeriya and Singh (2014) reported that economic efficiency and net returns in sorghum were enhanced by 10.61 per cent with the treatment of 100 per cent RDF (80: 40 kg of N and $P_2O_5$ $ha^{-1}$) in contrast with 50 per cent RDF and the control

Mishra *et al*. (2015) conducted an experiment to determine the economics of grain sorghum with varied nutrient ratios and concluded that 150 per cent of recommended dose of fertilizers (120:60:60 kg $ha^{-1}$ of N: $P_2O_5$: $K_2O$) gave the greater net returns and high benefit cost ratio (1.79) which was followed by normal RDF treatment in contrast to the control. Meena *et al*. (2017) reported that among various nutrient ratios, the highest returns and cost-benefit ratio were obtained with the application of 100: 50: 50 kg $ha^{-1}$ of N: $P_2O_5$: $K_2O$ in comparison with 80: 40: 40 and 60: 30: 30 kg $ha^{-1}$ of N: $P_2O_5$: $K_2O$ in sorghum. Patil *et al.* (2018) demonstrated a field experiment with different nutrient management practices in rabi sorghum and reported that crop nutrition through inorganic fertilizers recorded the highest benefit-cost ratio (2.64). Kaur and Satpal (2019) observed that maximum net returns and benefit- cost ratio was possible in forage sorghum with 125 per cent RDF in Punjab (100 per cent RDF is 100: 20: 25 kg $ha^{-1}$ of N: $P_2O_5$: $K_2O$) and Haryana (100 per cent RDF is 75: 15: 0 kg $ha^{-1}$ of N: $P_2O_5$: $K_2O$) region in contrast to 100 per cent and 75 per cent RDF and control.

## 2.2 EFFECT OF TIME OF APPLICATION OF NUTRIENTS

Split application of nutrients at critical stages of sorghum crop results in the best growth, yield and economic output with optimum cost-benefit ratio. Application of fertilizers at basal, knee high stage resulted in elevated growth and yield compared to the nutrient application at basal or single stage (Aragaw *et al*., 2020).

### 2.2.1 Effect of time of application of nutrients on growth and growth attributes

#### *2.2.1.1 Time of application of nitrogen*

Higher number of tillers was obtained with the application of N, one-third at sowing, one-third after first cutting and the final third dose after second cutting in comparison to the application of entire quantity of N at sowing in sorghum (Iptas and Brohi, 2002). In an experiment conducted to study the effect of nitrogen application rate at varied stages of growth, Almodares and Darany (2006) recorded the highest growth of sorghum with the application of nitrogen at 5 or 8 leaf stage over the application at booting and soft dough stage. In another trial, split application of N at basal, growing stage and after first cut with the proportions of 40, 30, 30 per cent respectively had a better effect on growth in terms of plant height and leaf width compared to the application of 50 per cent N at basal and remaining 50 per cent after first cut in sorghum (Jung *et al*., 2016). Mishra (2018) reported significantly higher plant height and leaf area index with application of 25 per cent N at sowing + 45 per cent N at 30 DAS (days after sowing) + 5 per cent at 45 DAS (foliar spray) + 15 per cent N at 55 DAS + 10 per cent at flowering (70 DAS) in sorghum. Mekdad and Emam (2019) conducted an investigation with varied timings of nitrogen application in sorghum to determine the effect on growth and development. The results indicated that plant growth in terms of plant height, stalk diameter and stem weight was higher for the treatment of nitrogen application at 3 different stages over 2 equal splits. Abera *et al.* (2020) investigated the outcome of assorted application of nitrogen during the crop duration in sorghum. The results of the study indicated higher growth of crop when N was given in split doses and the leaf area index was the highest (2.86) with equal nitrogen application at three stages viz., sowing, mid vegetative and at booting stage in contrast to application at sowing, mid vegetative stage and mid vegetative, booting stage.

Anjum *et al*. (2018) recorded the highest plant height in hybrid maize when N was applied in three splits (60 kg $ha^{-1}$ before sowing + 60 kg $ha^{-1}$ at knee height stage

+ 60 kg ha$^{-1}$ before tasselling stage) in comparison with two splits (90 kg ha$^{-1}$ at sowing + 90 kg ha$^{-1}$ at knee height stage) and single application of 180 kg N ha$^{-1}$ before sowing. According to Baladaniya *et al.* (2018), schedule of application of nitrogen wherein 30 per cent was given as basal at sowing + 70 per cent as top dressing in two equal splits at 30 and 45 DAS, significantly enhanced the plant height, number of total tillers and effective tillers per plant at 30 and 45 DAS and at harvest in pearl millet. This was in comparison with the N application in 2 splits as 50 per cent as basal + 50 per cent as top dressing and 40 per cent as basal + 60 per cent as top dressing. Chavan *et al*. (2018) reported that application of 100 kg nitrogen per ha along with three equal splits of nitrogen (at transplanting, 30 and 60 days after transplanting) resulted in the highest dry matter production in finger millet.

##### *2.2.1.2 Time of application of potassium*

Asif and Anwar (2007) showed that the phenological development of maize increased with the application of 90 kg ha$^{-1}$ K, and had a positive relationship to the number of split K applications. Saleem *et al*. (2011) conducted an experiment on time of application of K in maize and sorghum and reported that the application of K in three split doses (at planting, after one month and after two months of planting) produced significantly taller plants compared with those of single application in maize, which indicated that the plants absorbed potassium with the passage of time during their growth period. However the split application of potassium could not significantly influence the plant height in sorghum.

### 2.2.2 Effect of time of application of nutrients on yield attributes and yield

#### *2.2.2.1 Time of application of nitrogen*

Iptas and Brohi (2002) demonstrated an experiment on sorghum with different timings of nitrogen application to determine the effects on biomass production and concluded that one-third N at sowing, one-third after first cutting and the final third dose after second cutting yielded greater in comparison with the control. Almodares and Darany (2006) obtained higher fresh stalk yield of sorghum with the application of nitrogen at 5 or 8 leaf stage over the application at booting and soft dough stage. Aleminew *et al.* (2015) investigated the effect of application timings of urea during the sorghum growth period on its yield. Results of this trial indicated that the highest grain yield was recorded with the urea application ½ at thinning and half at knee high stage compared to the application of full dose at planting and split application of 1/3 at thinning and remaining at knee high and stem elongation stage. Melaku *et al.* (2018) reported that split application of 41 kg $ha^{-1}$, 64 kg $ha^{-1}$ and 87 kg $ha^{-1}$ of nitrogen fertilizer, half at planting and half at knee height stage, gave 19 per cent, 15 per cent and 18 per cent increase in sorghum grain yield over a single dose application, respectively. Applying 87 kg $ha^{-1}$ nitrogen fertilizer with split application half at planting and half at knee height stage, along with 46 kg $ha^{-1}$ of $P_2O_5$, gave the highest grain yield and income. Mishra (2018) reported significantly higher harvest index in sorghum with application of 25 per cent N at sowing + 45 per cent N at 30 DAS (days after sowing) + 5 per cent at 45 DAS (foliar spray) + 15 per cent N at 55 DAS + 10 per cent at flowering (70 DAS). This treatment also gained an yield advantage of 0.27 t $ha^{-1}$ over the control (application of 50 per cent N at sowing and 50 per cent at 30 DAS).

Hegde and Gowda (1986) reported that application of N on sandy loam soils at the rate of 50 kg $ha^{-1}$ in two split doses (half at planting and remaining dose at 25-30 days after planting) enhanced the grain yield in finger millet to 2650 kg $ha^{-1}$ when compared to its application only at planting (2430 kg $ha^{-1}$). Chavan *et al*. (2018) reported that application of 100 kg nitrogen per ha along with three equal splits of nitrogen (at transplanting, 30 and 60 days after transplanting resulted in the highest grain and straw yield in finger millet.

#### *2.2.2.2 Time of application of potassium*

Lavanya (2009) reported that application of potassium in two split doses increased the vegetative growth and yield in finger millet compared to single application. Saleem *et al*. (2011) conducted an experiment with varied levels of potash in split doses in sorghum and results revealed that the potash application at 3 varied timings (40 kg K each at sowing, one month after planting and two months after planting) recorded the highest grain yield besides higher stalk yield in comparison with control treatment. In a recent assessment, Singh *et al*. (2021) reported that the application of 75 kg $K_2O$ $ha^{-1}$ to each crop in two-splits, basal and panicle emergence in rice and basal and pre-silking in maize, significantly improved the grain yield as compared to a single full dose basal application.

### 2.2.3 Effect of time of application of nutrients on pest and disease incidence

Raypuriya *et al*. (2017) conducted an experiment in sorghum with assorted timing of fertilizer application to assess the pest incidence rate. Results revealed that the application of 25 per cent N at sowing + 45 per cent at 30 days after sowing+ 5 per cent foliar spray at 45 days after sowing+ 15 per cent at boot leaf stage+ 10 per cent at grain filling stage greatly reduced the shoot fly infestation in contrast to the application at other stages with 50 per cent N each at sowing + 30 days after sowing, 25 per cent N each at sowing + boot leaf stage and 50 per cent N at 30 DAS. Abuley *et al.* (2019) reported that timing of N-fertilizer application had a significant effect on the susceptibility of potatoes to early blight. Potatoes that received the entire quantity of N-fertilizer at emergence or as split applications had higher N contents and were less susceptible to early blight than those that received the entire quantity of N-fertilizer before planting.

### 2.2.4 Effect of time of application of nutrients on plant nutrient content and uptake

Mosali *et al.* (2010) conducted an experiment on timing of nitrogen application at pre-planting and 10 leaf stage of sweet sorghum. Result of investigation revealed that split application enhanced the crude protein content in comparison with the control treatment. Abbasi *et al*. (2013) investigated the effect of break application of N fertilizer in maize at specified growth stages on nitrogen concentration and concluded that break application of N fertilizers at planting and v6 leaf stage (6 leaf stage with visible collar) enhanced the nitrogen concentration and chlorophyll content over the fertilizer application at basal. Xue *et al.* (2016) reported that N application during the late growth stages of wheat (booting, heading or anthesis) increased the protein concentration in the grain. Chavan *et al*. (2019) conducted a study on the yield and quality of finger millet with split doses of nitrogen. The results of the experiment indicated that protein content, protein yield, and nutrient content in finger millet were significantly higher with three splits of nitrogen application (at transplanting, 30 and

60 days after transplanting, while significantly the lowest value was recorded due to basal dose of nitrogen application.

Pan *et al*. (2012) inferred that when 30 per cent N was applied as basal + 20 per cent 10 DAT and 50 per cent 36 DAT, the roots of rice had stronger abilities to absorb the nutrients from water and soil. Davies *et al*. (2020) concluded that enhanced nitrogen uptake was possible in maize with the split application of nitrogen at three growth stages compared with the single dose application at planting. Sharma and Singh (2020) observed that the split K application improved its availability throughout the growth period and resulted in better uptake of K in wheat. Singh *et al*. (2021) reported that the application of 75 kg $K_2O$ $ha^{-1}$ to each crop in rice and maize in two-splits, at basal and panicle emergence in rice and basal and pre-silking in maize, significantly improved K uptake and grain yield as compared to a single full dose basal application.

### 2.2.5 Effect of time of application of nutrients on soil properties

Mariga *et al*. (2000) investigated an experiment to determine the application timing of fertilizers in maize on soil properties. The result of the research revealed that application of fertilizers at planting, 3 and 4 weeks after emergence of crop and at initiation tasselling enhanced the soil fertility level. Olagbende (2019) observed that in maize crop, split application of urea (30 kg $ha^{-1}$ basal application + 20 kg $ha^{-1}$ applied at 15 days after planting + 10 kg $ha^{-1}$ applied at 30 days after planting) significantly increased the N content of the soil. No variation was however observed in case of other nutrients. Split urea fertilizer application retained a considerable amount of nitrogen in soil even after the harvest of maize. In another trial on maize, Ogunboye *et al*. (2020) reported that the three split application of N (60 kg at planting + 30 kg at 30 DAS + 30 kg at silking) improved the available nutrient status (organic carbon, N, P, K, Ca and Mg) in the soil after the experiment in maize compared to its single application at planting or two split applications.

### 2.2.6 Effect of time of application of nutrients on economics of cultivation

Pan *et al*. (2012) recommended that application of 30 per cent N as basal + 20 per cent 10 DAT and 50 per cent 36 DAT with 240 kg N $ha^{-1}$ would be the most profitable N application schedule in Central China. Abebe and Feyisa (2017) proved that split application of 1/3 N at 10-15 DAP + 1/3 N at 35-40 DAP + 1/3 N at 55- 60 DAP could enhance the marginal rate of return and benefit -cost ratio in maize in comparison with the split application of 1/3 N at 35- 40 DAP + 1/3 N 55- 60 DAP+ 1/3 N at 80-85 DAP , ½ N at 10-15 DAP + ½ N at 35- 40 DAP and control. Melaku *et al.* (2018) reported that nitrogen application at varied growth stages of crop resulted in higher economic efficiency with high marginal rate of return over single dose of nitrogen fertilizer application in sorghum crop in Ethiopia. While evaluating the performance of sorghum hybrids to split application of N, Mishra (2018) reported that the highest net returns and benefit: cost ratio (2.08) were obtained with application of 25 per cent N at sowing + 50 per cent N at 30 DAS + 15 per cent N at boot leaf stage (55 DAS) + 10 per cent at flowering (70 DAS). In another study, Abera *et al*. (2020) observed that nitrogen application at 3 stages (sowing, mid vegetative and booting) of growth enhanced the net benefits from sorghum crop than 2 split applications at sowing, mid vegetative and mid vegetative, booting stage. Highest monetary gain, net returns and benefit-cost ratio (3.67) was recorded in maize when N was applied as three split doses (60 kg at planting + 30 kg at 30 DAS + 30 kg at silking) compared to its two split doses and single application in maize (Ogunboye *et al*., 2020).

In contrary to the above findings, Mariga *et al*. (2000) opined that ammonium nitrate application as break doses to the maize crop was economically a non-viable option on account of labour cost in Zimbabwe.

# 3. MATERIALS AND METHODS

The experiment entitled "Nutrient scheduling in rainfed sorghum (*Sorghum bicolor* L. Moench)" was conducted at College of Agriculture, Vellayani, Thiruvananthapuram during January to May 2021 in order to investigate the nutrient scheduling and its effects on growth, yield, quality and economics of cultivation of rainfed sorghum. The details of materials used and methods followed are presented in this chapter.

## 3.1 EXPERIMENTAL SITE

The experiment was conducted in block D of the Instructional farm, College of Agriculture, Vellayani, Thiruvananthapuram. The site was located at a latitude of N 08°25'45.69" and longitude of E 076°59'23.67" and at an altitude of 29 m above mean sea level.

### 3.1.1 Soil

Composite soil sample was taken from the field before the experiment and analysed for its mechanical composition and chemical properties. The soil was sandy clay loam lateritic belonging to the order Oxisol with strong acidity, safe electrical conductivity and medium organic carbon content. The soil was low in available nitrogen and high in available phosphorus and potassium. The mechanical composition and chemical properties of soil are given in Table 1 and Table 2 respectively.

Table 1. Mechanical composition of the soil of the experimental site

| Sl. No. | Fractions | Content (per cent) | Method used |
|---|---|---|---|
| 1 | Sand | 47.44 | Bouyoucos hydrometer method (Bouyoucos, 1962) |
| 2 | Silt | 23.85 | |
| 3 | Clay | 27.81 | |

Table 2. Chemical properties of soil of the experimental site

| Parameter | Content | Rating | Method used |
|---|---|---|---|
| Soil reaction (pH) | 5.20 | Strongly acidic | 1:2.5 soil solution ratio using pH meter with glass electrode (Jackson, 1973) |
| Electrical conductivity ($dSm^{-1}$) | 0.20 | Safe | Digital conductivity meter (Jackson, 1973) |
| Organic carbon (per cent) | 0.81 | Medium | Walkley and Black rapid titration method (Jackson, 1973) |
| Available N (kg $ha^{-1}$) | 250.00 | Low | Alkaline permanganate method (Subbiah and Asija, 1956) |
| Available P (kg $ha^{-1}$) | 103.20 | High | Bray colorimetric method (Jackson, 1973) |
| Available K (kg $ha^{-1}$) | 298.00 | High | Ammonium acetate method (Jackson, 1973) |

**3.1.2. Climate and Season**

The experiment was conducted during summer season, 2021. The data on mean maximum and minimum temperatures, relative humidity and rainfall were collected from the Class B Agromet observatory of Department of Agricultural Meteorology, College of Agriculture, Vellayani and are presented in Appendix I as standard week averages. The observations are graphically represented in Fig. 1

The mean maximum temperature ranged between $34.2^0$ C to $32.0^0$ C and mean minimum temperature ranged between $26.4^0$ C to $20.4^0$ C, mean maximum relative humidity ranged between 94.70 per cent to 87.30 per cent, and mean minimum relative humidity ranged between 87.90 per cent to 64.70 per cent. A total rainfall of 221.30 mm was received during the cropping season.

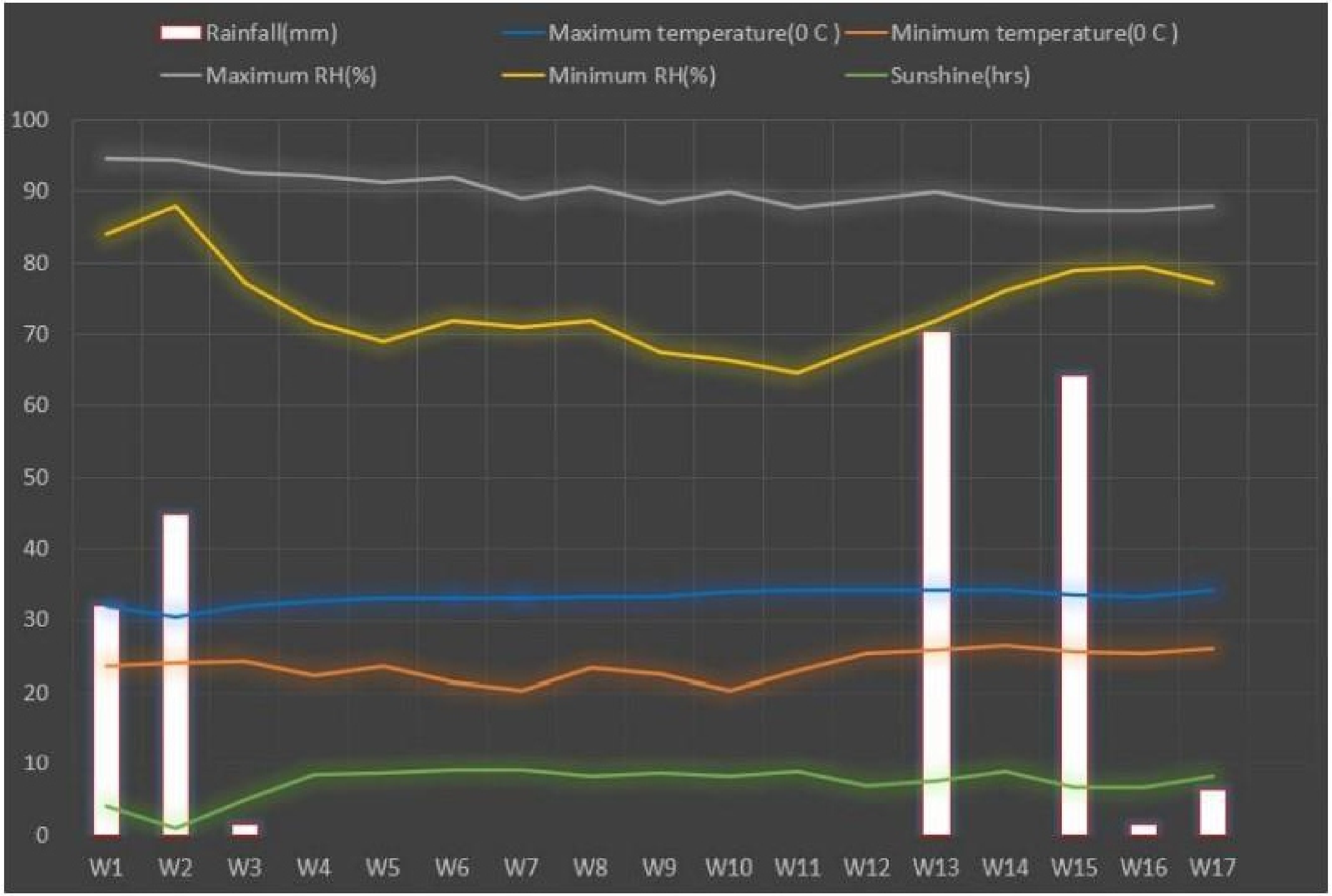


**Fig. 1 Weather parameters during the period of field experiment**

### 3.1.3 Cropping History of Experimental Plot

The experiment plot was cultivated with red gram in the previous year and was left uncultivated in the previous season.

## 3.2 MATERIALS

### 3.2.1 Crop and Variety

High yielding grain sorghum variety Co-30 released from Tamil Nadu Agricultural University was used for the study. Co-30 is a derivative of APK 1 x TNS 291, having 95-105 days duration with tan green leaf sheath, cylindrical shaped ear heads and white grain, suitable for rainfed and irrigated cultivation (TNAU, 2021).

### 3.2.2 Manures and Fertilizers

Well decomposed farm yard manure containing 0.65 per cent nitrogen, 0.52 per cent $P_2O_5$ and 0.85 per cent $K_2O$ was used as a source of organic manure in the main field. Urea (46 per cent nitrogen), rajphos (20 per cent $P_2O_5$) and muriate of potash (60 per cent $K_2O$) were used as chemical sources of nitrogen, phosphorus and potassium respectively.

## 3.3 METHODS

### 3.3.1 Design and Layout

Design : Factorial RBD

Treatments : 3 x 4

Replications : 3

Spacing : 45 cm x 15 cm

Plot size : 4.5 m x 4.5 m

Variety : Co-30

Season : Summer 2021

Location : College of Agriculture, Vellayani

#### *3.3.1.1 Treatments*

**N:K ratios (R)**

$r_1$ - 1:0.5

$r_2$ - 1:1

$r_3$ - 1:1.5

**Time of application (T)**

$t_1$- ½ N as basal + ½ N at 30 DAS + full K as basal

$t_2$- $^1/3$ N as basal + $^1/3$ N at 30 DAS+ $^1/3$ N at 60 DAS + full K as basal

$t_3$- ½ N and ½ K as basal + ½ N and ½ K at 30 DAS

$t_4$- $^1/3$ N and $^1/3$ K as basal+ $^1/3$ N and $^1/3$ K at 30 DAS +$^1/3$ N and $^1/3$ K at 60 DAS

**Treatment Combinations**

| | | | |
|---|---|---|---|
| $r_1t_1$ | $r_1t_2$ | $r_1t_3$ | $r_1t_4$ |
| $r_2t_1$ | $r_2t_2$ | $r_2t_3$ | $r_2t_4$ |
| $r_3t_1$ | $r_3t_2$ | $r_3t_3$ | $r_3t_4$ |

### 3.3.2 Crop Management

#### *3.3.2.1 Land Preparation*

The experimental area was ploughed with a power tiller and the clods were crushed and brought to fine tilth using a cultivator. Bunds were taken to separate the experimental area into individual plots. Plots of 4.5 m × 4.5 m were prepared with 30 cm wide bunds on all four sides. Ridges and furrows were formed at a spacing of 45 cm between two ridges within the plots. Irrigation and drainage channels were also provided.

#### *3.3.2.2 Seeds and Sowing*

Seeds at the rate of 12 kg ha$^{-1}$were dibbled on the ridges maintaining a plant to plant spacing of 15cm.

#### *3.3.2.3 Application of Manures and Fertilizers*

Farm yard manure was applied at the rate of 5 t ha$^{-1}$ at the time of land preparation. Nitrogen was applied at the rate of 50 kg ha$^{-1}$ as urea, to all the treatments as per the time of application of treatments. Potassium was applied as per the treatment ratios and application schedule. The entire quantity of phosphorus at the rate of 25 kg ha$^{-1}$ was applied as basal dose on soil test basis.

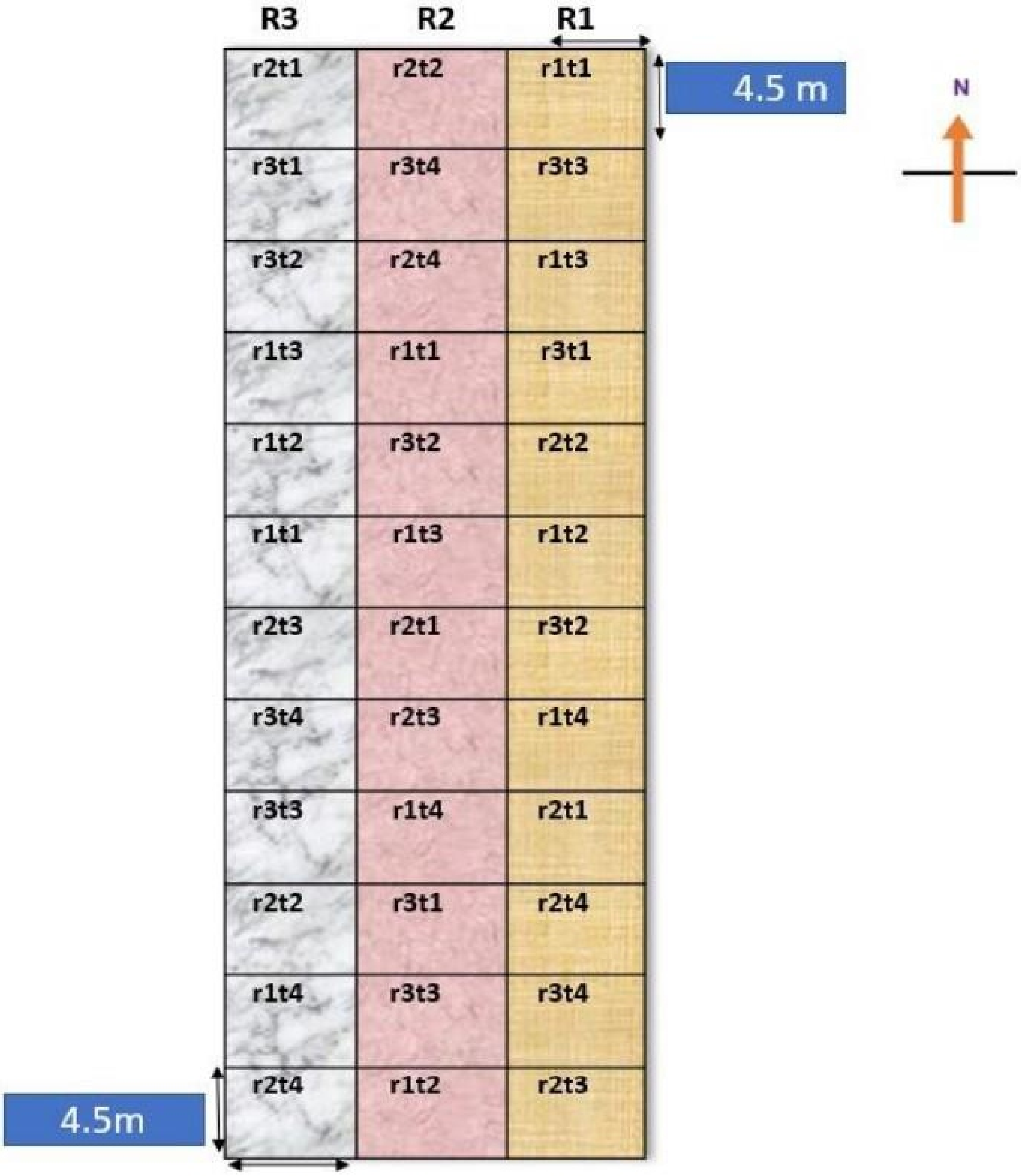


**Fig. 2 Layout of the experiment**

***3.3.2.4 Thinning and Gap Filling***

Thinning and gap filling were done at 20DAS.

***3.3.2.5 Water Management***

Crop was raised as a rainfed crop. However since there was no rainfall at the time of sowing during the 4$^{th}$ standard week (Fig.1), supplemental irrigation was given upto the crop establishment.

***3.3.2.6 Weed Management***

Two hand weeding were done at 20 and 40 DAS.

***3.3.2.7 Plant Protection***

To control shoot fly attack at 30 DAS, Quinalphos 25 EC was sprayed at the rate of 2 mL per litre twice at one week interval.

***3.3.2.8 Harvest***

Border plants were harvested separately from each plot and the crop was harvested from net plot area. Threshing was done manually and the produce was cleaned, sundried and weighed.

3.4 OBSERVATIONS

**3.4.1 Growth and Growth attributes**

Five observational plants were selected and tagged in each plot and observations were taken from these plants and average was worked out.

***3.4.1.1 Plant Height***

The plant height was measured from ground level to the growing tip of the main stem and expressed in cm at 30, 60, 90 DAS and at harvest.

***3.4.1.2 Number of Leaves per Plant***

Number of fully expanded and functional leaves was counted at 30, 60, 90 DAS and at Harvest.

***3.4.1.3 Leaf Area Index***

The length and width of fully opened leaf lamina was taken and the leaf area was calculated at 30 and 60 DAS as per the formula suggested by Elsahookie and Cheyed (2014) for sorghum .

Leaf Area = $LW_4$ x 6.18

Where L= Length of $4^{th}$ leaf from top

W= Width of $4^{th}$ leaf from top

(6.18 is the constant obtained by multiplying 0.75 with leaf number 4 constant i.e. 8.242)

LAI was worked out using the formula put forth by Watson (1947).

$$\text{LAI} = \frac{\text{Leaf area per plant (cm}^2)}{\text{Land area occupied by the plant (cm}^2)}$$

***3.4.1.4 Days to 50 percent Flowering***

Number of days was counted when 50 per cent of plants reached flowering stage from the date of sowing.

***3.4.1.5 Dry Matter Production at Harvest***

The sample plants were cut after the final harvest. It was shade dried and then oven dried at 60 $\pm$ $5^0$C till a constant weight was achieved and total dry matter production was expressed in kg $ha^{-1}$

***3.4.1.6 Rooting Depth***

At the harvest stage, the sample plants were uprooted properly with an auger and the rooting depth was measured. The mean value was calculated and expressed in cm.

***3.4.1.7 Root Volume***

Root volume was found out by displacement method (Misra and Ahmed, 1987) and expressed in $cm^3$ per plant.

**Plate 1: Preparation of plots**


**Plate 2: General view of the experiment**

**Plate 3: Sorghum crop at 40 DAE**

**Plate 4: Sorghum crop at 80 DAE**

**Plate 5: Sorghum crop at maturity**

**Plate 6: Harvesting of the crop**

### 3.4.2 Yield Attributes and Yield

Observations were taken from the five selected plants and average was worked out.

#### *3.4.2.1 Length of Panicle*

After the harvest, panicle length was measured from base of the panicle to its tip and expressed in cm.

#### *3.4.2.2 Number of Grains per Panicle*

From the sample plants in each plot, the grains from each panicles were removed and counted and the mean value was worked out.

#### *3.4.2.3 Grain Weight per Panicle*

The grains removed from sample panicles were weighed using an electronic balance. The mean value was worked out and was expressed as g per panicle.

#### *3.4.2.4 Test Weight*

Thousand fully filled, bold grains were taken and weighed from each plot separately. The mean value was worked out and expressed in grams.

#### *3.4.2.5 Grain Yield*

The panicles harvested from each plot were threshed separately and grains were separated, sundried, cleaned and weighed for calculating the grain yield. The values were recorded and expressed in kg $ha^{-1}$.

#### *3.4.2.6 Green Stover Yield:*

After completion of the harvesting, the green stover was cut at the ground level from each plot and the weight of stover was expressed in kg $ha^{-1}$

#### *3.4.2.7 Harvest Index*

Harvest index (HI) was calculated by using the formula suggested by Donald and Hamblin (1976).

$$HI = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

**3.4.3 Pest and Disease Incidence**

The plants were observed for noting the pest and disease incidences if any.

3.5 PLANT ANALYSIS

**3.5.1 Chlorophyll Content**

The chlorophyll content of fresh leaf sample was estimated using the method suggested by Yoshida *et al*. (1976) at 30 and 60 DAS and expressed in mg $g^{-1}$ of leaf tissue.

**3.5.2 Crude Protein (grain and stover):**

The nitrogen contents of both cob and stover were estimated and then multiplied by a factor of 6.25 to obtain the crude protein content (Simpson *et al*, 1965) and expressed in percentage, on dry weight basis.

**3.5.3 Uptake of N, P and K (at harvest)**

***3.5.3.1 Uptake of N***

The N content was analysed by using the modified microkjeldahl method suggested by Jackson (1973). The N content was then multiplied with total dry matter production to obtain the uptake and expressed in kg $ha^{-1}$.

***3.5.3.2 Uptake of P***

The P content was analysed by Vanadomolybdate phosphoric yellow colour method (Piper, 1966) and the uptake was determined by multiplying it with total dry matter production.

***3.5.3.3 Uptake of K***

The K content was analysed by using flame photometer method and the uptake was determined by multiplying it with total dry matter production (Piper, 1966).

3.6 SOIL ANALYSIS

Representative soil samples were collected from the plot before and after the experiment and the samples were analysed.

### 3.6.1 pH

The pH of the soil sample was found out by diluting with water in the ratio 1:2.5 and then analysing with pH meter (Jackson, 1973)

### 3.6.2 Electrical Conductivity

Electrical conductivity of soil sample was found out using conductivity meter (Jackson, 1973)

### 3.6.3 Organic Carbon

Organic carbon content was estimated using Walkley and Black rapid titration method (Jackson, 1973) and expressed in percentage.

### 3.6.4 Available N

Available N content of soil sample was analysed by using Alkaline Permanganate method suggested by Subbiah and Asija (1956) and expressed inkg $ha^{-1}$.

### 3.6.5 Available P

Available P content of soil sample was analysed by using Bray colorimetric method (Jackson, 1973) and expressed in kg $ha^{-1}$.

### 3.6.6 Available K

Available K content was analysed by extracting the soil sample with neutral normal ammonium acetate and estimated using flame photometer (Jackson, 1973) and expressed in kg $ha^{-1}$

## 3.7 ECONOMIC ANALYSIS

### 3.7.1 Net Income

Cost of cultivation was deducted from gross returns to obtain the net income

Net income (₹ $ha^{-1}$) = gross returns (₹$ha^{-1}$) - cost of cultivation (₹ $ha^{-1}$)

### 3.7.2 Benefit- Cost ratio

The benefit-cost ratio was worked out by using the following formula

$$\text{B:C Ratio} = \frac{\text{Gross returns (₹ ha}^{-1}\text{)}}{\text{Cost of cultivation (₹ ha}^{-1}\text{)}}$$

3.8 STATISTICAL ANALYSIS

Data generated were statistically analysed by using Analysis of Variance technique (ANOVA) suggested by Panse and Sukhatme (1985) as applied to Randomised Block Design. The significance was tested using F test (Snedecor and Cochran, 1967). Critical difference was worked out at 5 per cent level of probability, wherever the treatment differences were found significant.

# 4. RESULTS

The study entitled "Nutrient scheduling in rainfed sorghum (*Sorghum bicolor* L. Moench)" was carried out during 2019-21 at College of Agriculture, Vellayani, Thiruvananthapuram. The main objective of the study was to standardise the nutrient schedule for rainfed sorghum and to workout the economics. The results of the study are presented in this chapter**.**

## 4.1 GROWTH AND GROWTH ATTRIBUTES

### 4.1.1 Plant height

Result of the effect of N:K ratios, time application and their interaction on plant height of sorghum is presented in Table 3.

Main effects of N:K ratios significantly influenced the plant height only at 60 DAS, 90 DAS and at harvest.

The 1:1.5 ratio ($r_3$) recorded significantly higher plant height at all the three stages of observation (122.33, 237.99 and 248.27 cm at 60 DAS, 90 DAS and harvest respectively) followed by $r_1$ (1:0.5 N and K ratio) and $r_2$ (1:1 N and K ratio) recording 116.91 and 113.27 cm plant height respectively at 60 DAS. At 90 DAS, $r_3$ treatment was followed by $r_2$ and $r_1$, which recorded a plant height of 227.18 cm and 225.83 cm respectively. At harvest stage, again $r_3$ was superior (248.27 cm) and was followed by $r_2$ and $r_1$, which recorded a plant height of and 237.78 cm and 232.65 cm respectively. However the $r_1$ and $r_2$ were on par at all the growth stages with respect to the influence on plant height.

Data on main effect of time of nutrient application indicated that at 30 and 60 DAS, $t_4$ (application of N and K in 3 equal splits with 1/3 of each applied as basal, at 30 DAS and 60 DAS) resulted in the highest plant height (27.71 cm at 30 DAS and 122.97 cm at 60 DAS respectively) compared to other treatments $t_3$ (N and K applied in 2 equal splits with ½ of each at basal and at 30 DAS), $t_2$ (N in 3 equal split doses at basal, 30 DAS and 60 DAS with full K as basal) and $t_1$ (N in 2 equal split doses at basal and 30 DAS with full K as basal). The $t_3$, $t_2$ and $t_1$ recorded the plant height 23.44 cm, 23.39 cm and 22.56 cm at 30 DAS and 116.03 cm, 117.77 cm and 113.23 cm at 60 DAS respectively which were on par each other. At 90 DAS, $t_3$ registered the highest plant height of 236.38 cm which was statistically superior to $t_2$, $t_4$ and $t_1$ recording a plant height of 229.97 cm, 227.88 cm and 227.11 cm respectively which did not significantly vary each other. At harvest plant height was not significantly influenced by the time of application of nutrients.

The R x T interaction significantly influenced the plant height at all the stages of observation. At 30 DAS, $r_3t_4$ resulted in the highest plant height (33.90 cm), but it was on par with all other treatments except $r_1t_3$ which recorded the lowest plant height of 20.23 cm. At 60 DAS a slightly different trend was observed wherein the highest plant was recorded with $r_1t_4$ (129.77 cm) which was on par with $r_3t_4$ (128.07 cm), $r_3t_1$ (127.43 cm), $r_2t_3$ (126.33 cm) and $r_3t_2$ (122.40 cm) but significantly superior to $r_1t_2$ resulting in a plant height of 119.47 cm.

The $r_1t_2$ was however statistically superior to $r_2t_2$ (111.43 cm), $r_3t_3$ (111.40 cm), $r_2t_4$ (111.07 cm), $r_1t_3$ 110.37 cm), $r_1t_1$(108.03 cm) and $r_2t_1$ (104.23 cm) which were on par each other with respect plant height. At 90 DAS the plants were the tallest (247.07 cm) with the treatment combination $r_3t_1$ which was statistically on par with $r_3t_3$ (242.63 cm), $r_2t_3$ (240.40 cm), and $r_1t_2$ (239.47 cm) and significantly superior to $r_3t_4$ recording a plant height of 231.73 cm which in turn was on par with $r_3t_2$, $r_1t_4$, $r_2t_1$, $r_1t_3$ and $r_2t_4$.

Similar trend was noticed at harvest stage also wherein $r_3t_1$ which recorded a plant height of 258.67 cm was significantly superior to all other treatments except $r_3t_3$ and $r_2t_3$, which resulted in a plant height of 253.43 cm and 249.53 cm respectively which were on par with $r_3t_1$. At both the stages (90 DAS and at harvest) $r_1t_1$ produced shorter plants (207.90 cm and 212.47 cm plant height respectively).

Table 3. Effect of N:K ratios, time of application and their interactions on plant height, cm.

| Treatments | Plant height | | | |
|---|---|---|---|---|
| | 30 DAS | 60 DAS | 90 DAS | At harvest |
| **N:K ratios(R)** | | | | |
| $r_1$ (1:0.5) | 22.48 | 116.91 | 225.83 | 232.65 |
| $r_2$ (1:1) | 24.53 | 113.27 | 227.18 | 237.78 |
| $r_3$ (1:1.5) | 25.82 | 122.33 | 237.99 | 248.27 |
| SEm (±) | 0.89 | 1.31 | 1.81 | 2.18 |
| CD (0.05) | NS | 3.939 | 5.442 | 6.534 |
| **Time of application (T)** | | | | |
| $t_1$ (½ N as basal + ½ N at 30 DAS + full K as basal) | 22.56 | 113.23 | 227.11 | 235.19 |
| $t_2$ ($^1/3$ N as basal + $^1/3$ N at 30 DAS+ $^1/3$ N at 60 DAS + full K as basal) | 23.39 | 117.77 | 229.97 | 239.34 |
| $t_3$ (½ N and ½ K as basal + ½ N and K at 30 DAS) | 23.44 | 116.03 | 236.38 | 244.47 |
| $t_4$ ($^1/3$ N and $^1/3$ K as basal +$^1/3$ N and $^1/3$ K at 30 DAS + $^1/3$ N and $^1/3$ K at 60 DAS | 27.71 | 122.97 | 227.88 | 239.27 |
| SEm (±) | 1.03 | 1.52 | 2.09 | 2.52 |
| CD (0.05) | 3.088 | 4.549 | 6.284 | NS |
| **R x T interaction** | | | | |
| $r_1t_1$ | 23.00 | 108.03 | 207.90 | 212.47 |
| $r_1t_2$ | 23.33 | 119.47 | 239.47 | 243.50 |
| $r_1t_3$ | 20.23 | 110.37 | 226.10 | 230.43 |
| $r_1t_4$ | 23.33 | 129.77 | 229.87 | 244.20 |
| $r_2t_1$ | 22.17 | 104.23 | 226.37 | 234.43 |
| $r_2t_2$ | 23.37 | 111.43 | 219.90 | 233.80 |
| $r_2t_3$ | 26.70 | 126.33 | 240.40 | 249.53 |
| $r_2t_4$ | 25.90 | 111.07 | 222.03 | 233.37 |
| $r_3t_1$ | 22.50 | 127.43 | 247.07 | 258.67 |
| $r_3t_2$ | 23.47 | 122.40 | 230.53 | 240.73 |
| $r_3t_3$ | 23.40 | 111.40 | 242.63 | 253.43 |
| $r_3t_4$ | 33.90 | 128.07 | 231.73 | 240.23 |
| SEm (±) | 1.78 | 2.63 | 3.63 | 4.36 |
| CD (0.05) | 5.348 | 7.879 | 10.885 | 13.067 |

### 4.1.2. Leaves per plant

Result of the effect of N:K ratios, time application and their interaction on leaves per plant of sorghum is presented in Table 4.

The main effect of N:K ratios significantly influenced the number of leaves per plant at all stages of observation except 30 DAS. At 60 DAS, the highest number of leaves were produced (9.54) by $r_3$ (1:1.5 ratio of N and K) which was significantly higher than the value obtained with $r_2$ (1:1 ratio of N and K- 8.50 leaves) which in turn was statistically superior to $r_1$ (1:0.5 ratio of N and K-7.88 leaves). At 90 DAS significantly higher number of leaves were produced (10.75) with $r_3$ compared to $r_1$ (9.67 leaves) and $r_2$ (9.58 leaves) which were on par each other. At harvest stage, no difference in the number of leaves per plant from 90 DAS observation was observed which indicated that no new leaves were produced after 90 DAS.

Schedule of application of nutrients significantly influenced the number of leaves per plant at all the stages of observation. At 30 DAS, the highest number of leaves was produced (4.50) with $t_4$ (application of N and K in 3 equal splits with 1/3 of each applied as basal, at 30 DAS and 60 DAS) which was on par with $t_3$ (N and K applied in 2 equal splits with ½ of each at basal and at 30 DAS) and $t_2$ (N in 3 equal split doses with 1/3 at basal, 30 DAS and 60 DAS with full K as basal) producing 4.44 and 4.00 leaves per plant respectively. The above treatments were however significantly superior to $t_1$ (N in 2 equal split doses with ½ at basal and ½ at 30 DAS with full K as basal) which produced the lowest number of leaves (3.61). At 60 DAS, $t_3$ recorded the highest number of leaves (9.17) which was on par with $t_4$ (9.06). Both $t_3$ and $t_4$ were statistically superior to the on par treatments $t_1$ and $t_2$ producing 8.44 and 7.89 leaves per plant respectively. Similar trend was noticed during 90 DAS and at harvest also wherein $t_3$ recorded the highest number of leaves (10.50) which did not differ statistically from $t_4$ (10.28 leaves) and $t_1$ (10.00 leaves). The $t_3$, $t_4$ and $t_1$ were however significantly superior to $t_2$ which produced the lowest number of leaves (9.22).

The R x T interaction could significantly affect the leaf production at all the stages of observation except 30 DAS. At 60 DAS $r_3t_4$ recorded significantly higher number of leaves (11.00) compared to all other treatments and was followed by $r_2t_3$, $t_3t_3$

and $r_3t_1$ producing 9.83, 9.50 and 9.17 leaves per plant respectively which were on par each other. Similar trend was noticed at 90 DAS also wherein $r_3t_4$ produced significantly higher number of leaves (12.50) than all other treatments and was followed by $r_3t_3$ (11.00 leaves), $r_2t_3$ (10.83 leaves), $r_1t_1$ (10.50 leaves) and $r_3t_1$ (10.33 leaves) which were comparable in their effect. Number of leaves produced at the harvest stage was the same as that recorded at 90 DAS.

### 4.1.3. Leaf area index (LAI)

Result of the effect of N:K ratios, time application and their interaction on LAI of sorghum is presented in Table 5 .

The N: K ratios did significantly influence the LAI only at 40 DAS. The highest value of LAI was recorded (2.65) with $r_3$ (1:1.5 ratio of N and K) which was significantly superior to $r_2$ (LAI-2.35) and $r_1$ (LAI-2.25). The $r_2$ (1:1 ratio of N and K) and $r_1$ (1:0.5 ratio of N and K) were however on par each other.

The time of application of nutrients could influence the LAI only at 40 DAS. The LAI was the highest (2.62) with $t_4$ (application of N and K in 3 equal splits with 1/3 of each applied as basal, at 30 DAS and 60 DAS) which was significantly superior to $t_3$ (2.45), $t_1$ (2.37) and $t_2$ (2.23). The $t_3$ (N and K applied in 2 equal splits with ½ of each at basal and at 30 DAS) and $t_1$ (N in 2 equal split doses as ½ at basal and ½ at 30 DAS with full K as basal) were on par each other although significantly superior to $t_2$ (N in 3 equal split doses with 1/3 at basal, 30 DAS and 60 DAS with full K as basal).

The R x T interaction could significantly influence the LAI only at 60 DAS. The LAI was the highest with $r_3t_4$ treatment (5.90) which was on par with $r_2t_4$, $r_3t_1$, $r_1t_3$, $r_1t_2$, $r_2t_2$ and $r_3t_3$ recording the LAI 5.86, 5.77, 5.74, 5.73, 5.71 and 5.62 respectively. These treatments were however significantly superior to $r_2t_1$ (5.48) which was on par with $r_2t_3$ (5.35), $r_1t_1$ (5.30), $r_3t_2$ (5.30) and $r_1t_4$ (5.28).

Table 4. Effect of N:K ratios, time of application and their interactions on leaves per plant

| Treatments | Number of Leaves per plant | | | |
|---|---|---|---|---|
| | 30 DAS | 60 DAS | 90 DAS | At harvest |
| **N:K ratios(R)** | | | | |
| $r_1$ (1:0.5) | 3.83 | 7.88 | 9.67 | 9.67 |
| $r_2$ (1:1) | 4.21 | 8.50 | 9.58 | 9.58 |
| $r_3$ (1:1.5) | 4.38 | 9.54 | 10.75 | 10.75 |
| SEm (±) | 0.16 | 0.16 | 0.18 | 0.18 |
| CD (0.05) | NS | 0.486 | 0.543 | 0.543 |
| **Time of application (T)** | | | | |
| $t_1$ (½ N as basal + ½ N at 30DAS + full K as basal) | 3.61 | 8.44 | 10.00 | 10.00 |
| $t_2$ ($^1/3$ N as basal + $^1/3$ N at 30DAS+ $^1/3$ N at 60 DAS + full K as basal) | 4.00 | 7.89 | 9.22 | 9.22 |
| $t_3$ (½ N and ½ K as basal + ½ N and ½ K at 30 DAS) | 4.44 | 9.17 | 10.50 | 10.50 |
| $t_4$ ($^1/3$ N and $^1/3$ K as basal +$^1/3$ N and $^1/3$ K at 30 DAS + $^1/3$ N and $^1/3$ K at 60 DAS | 4.50 | 9.06 | 10.28 | 10.28 |
| SEm (±) | 0.18 | 0.19 | 0.21 | 0.21 |
| CD (0.05) | 0.551 | 0.561 | 0.627 | 0.627 |
| **R x T interaction** | | | | |
| $r_1t_1$ | 3.50 | 8.17 | 10.50 | 10.50 |
| $r_1t_2$ | 3.83 | 7.17 | 9.17 | 9.17 |
| $r_1t_3$ | 4.00 | 8.17 | 9.67 | 9.67 |
| $r_1t_4$ | 4.00 | 8.00 | 9.33 | 9.33 |
| $r_2t_1$ | 3.67 | 8.00 | 9.17 | 9.17 |
| $r_2t_2$ | 4.33 | 8.00 | 9.33 | 9.33 |
| $r_2t_3$ | 4.67 | 9.83 | 10.83 | 10.83 |
| $r_2t_4$ | 4.17 | 8.17 | 9.00 | 9.00 |
| $r_3t_1$ | 3.67 | 9.17 | 10.33 | 10.33 |
| $r_3t_2$ | 3.83 | 8.50 | 9.17 | 9.17 |
| $r_3t_3$ | 4.67 | 9.50 | 11.00 | 11.00 |
| $r_3t_4$ | 5.33 | 11.00 | 12.5 | 12.5 |
| SEm (±) | 0.32 | 0.32 | 0.36 | 0.36 |
| CD (0.05) | NS | 0.971 | 1.086 | 1.086 |

Table 5. Effect of N:K ratios, time of application and their interactions on LAI

| Treatments | LAI | |
|---|---|---|
| | 40 DAS | 60 DAS |
| **N:K ratios(R)** | | |
| $r_1$ (1:0.5) | 2.25 | 5.51 |
| $r_2$ (1:1) | 2.35 | 5.60 |
| $r_3$ (1:1.5) | 2.65 | 5.64 |
| SEm (±) | 0.04 | 0.05 |
| CD (0.05) | 0.111 | NS |
| **Time of application (T)** | | |
| $t_1$ (½ N as basal + ½ N at 30 DAS + full K as basal) | 2.37 | 5.50 |
| $t_2$ ($^1/_3$ N as basal + $^1/_3$ N at 30DAS+ $^1/_3$ N at 60 DAS + full K as basal) | 2.23 | 5.58 |
| $t_3$ (½ N and ½ K as basal + ½ N and ½ K at 30 DAS) | 2.45 | 5.57 |
| $t_4$ ($^1/_3$ N and $^1/_3$ K as basal +$^1/_3$ N and $^1/_3$ K at 30 DAS + $^1/_3$ N and $^1/_3$ K at 60 DAS | 2.62 | 5.68 |
| SEm (±) | 0.04 | 0.06 |
| CD (0.05) | 0.128 | NS |
| **R x T interaction** | | |
| $r_1t_1$ | 2.12 | 5.30 |
| $r_1t_2$ | 2.09 | 5.73 |
| $r_1t_3$ | 2.31 | 5.74 |
| $r_1t_4$ | 2.49 | 5.28 |
| $r_2t_1$ | 2.24 | 5.48 |
| $r_2t_2$ | 2.15 | 5.71 |
| $r_2t_3$ | 2.48 | 5.35 |
| $r_2t_4$ | 2.53 | 5.86 |
| $r_3t_1$ | 2.75 | 5.77 |
| $r_3t_2$ | 2.44 | 5.30 |
| $r_3t_3$ | 2.57 | 5.62 |
| $r_3t_4$ | 2.83 | 5.90 |
| SEm (±) | 0.07 | 0.10 |
| CD (0.05) | NS | 0.306 |

### 4.1.4 Days to 50 per cent flowering

Result of the effect of N:K ratios, time application and their interaction on days to 50 per cent flowering of sorghum is presented in Table 6.

The N:K nutrition influenced the days to 50 per cent flowering and less number of days was required for flowering (57.00) with $r_3$ (1:1.5 ratio of N and K) which was significantly lower than the other two ratios, i.e., 58.58 and 59.42 days with $r_2$ and $r_1$ respectively which were also statistically on par. The days required for flowering was found to increase with increasing levels of K in N:K ratio.

Time of application of nutrients significantly influenced the days to 50 per cent flowering and less number of days was required for flowering with $t_4$ (54.89) followed by $t_3$ (56.89) which were significantly lower than the days required with $t_2$ (60.44) and $t_1$ (61.11) which in turn were on par each other.

The R x T interaction significantly influenced the days to 50 per cent flowering and was the lowest (50.67) with $r_3t_4$ which was significantly lower than all other treatments. The $r_3t_4$ was followed by $r_3t_3$ (55.33), $r_2t_4$ (56.00) and $r_2t_3$ (57.00) wherein an increasing trend was noticed with respect to time required for flowering which were on par in their effect. The treatments $r_1t_4$ (58.00), $r_1t_3$ (58.33), $r_2t_2$ (60.00) and $r_1t_2$ (60.00) required more number of days for 50 per cent flowering and were on par each other.

### 4.1.5. Dry matter production at harvest

Result of the effect of N:K ratios, time application and their interaction on dry matter production at harvest in sorghum is presented in Table 7.

The nutrient ratios could not influence the dry matter production at harvest significantly. However, there was significant influence on dry matter production due to schedule of application of nutrients. The highest dry matter production was recorded (6843.00 kg $ha^{-1}$) with $t_3$ (N and K applied in 2 equal splits with ½ of each at basal and at 30 DAS) which was statistically superior to $t_1$- N in 2 equal split doses as ½ at basal and ½ at 30 DAS with full K as basal (5971.11 kg $ha^{-1}$) and $t_2$- N in 3 equal split doses with 1/3 at basal, 30 DAS and 60 DAS with full K as basal

Table 6. Effect of N:K ratios, time of application and their interactions on days to 50 per cent flowering

| Treatments | Days to 50 per cent flowering |
|---|---|
| **N:K ratios(R)** | |
| $r_1$ (1:0.5) | 59.42 |
| $r_2$ (1:1) | 58.58 |
| $r_3$ (1:1.5) | 57.00 |
| SEm (±) | 0.42 |
| CD (0.05) | 1.270 |
| **Time of application (T)** | |
| $t_1$ (½ N as basal + ½ N at 30 DAS + full K as basal) | 61.11 |
| $t_2$ ($^1/_3$ N as basal + $^1/_3$ N at 30 DAS+ $^1/_3$ N at 60 DAS + full K as basal) | 60.44 |
| $t_3$ (½ N and ½ K as basal + ½ N and ½ K at 30 DAS) | 56.89 |
| $t_4$ ($^1/_3$ N and $^1/_3$ K as basal +$^1/_3$ N and $^1/_3$ K at 30 DAS + $^1/_3$ N and $^1/_3$ K at 60 DAS | 54.89 |
| SEm (±) | 0.49 |
| CD (0.05) | 1.467 |
| **R x T interaction** | |
| $r_1t_1$ | 61.33 |
| $r_1t_2$ | 60.00 |
| $r_1t_3$ | 58.33 |
| $r_1t_4$ | 58.00 |
| $r_2t_1$ | 61.33 |
| $r_2t_2$ | 60.00 |
| $r_2t_3$ | 57.00 |
| $r_2t_4$ | 56.00 |
| $r_3t_1$ | 60.67 |
| $r_3t_2$ | 61.33 |
| $r_3t_3$ | 55.33 |
| $r_3t_4$ | 50.67 |
| SEm (±) | 0.85 |
| CD (0.05) | 2.540 |

Table 7. Effect of N:K ratios, time of application and their interactions on dry matter production at harvest, kg $ha^{-1}$

| Treatments | Dry matter production at harvest |
|---|---|
| **N:K ratios(R)** | |
| $r_1$ (1:0.5) | 5994.67 |
| $r_2$ (1:1) | 6484.00 |
| $r_3$ (1:1.5) | 6403.42 |
| SEm (±) | 154.03 |
| CD (0.05) | NS |
| **Time of application (T)** | |
| $t_1$ (½ N as basal + ½ N at 30 DAS + full K as basal) | 5971.11 |
| $t_2$ ($^1/_3$ N as basal + $^1/_3$ N at 30 DAS+ $^1/_3$ N at 60 DAS + full K as basal) | 5905.67 |
| $t_3$ (½ N and ½ K as basal + ½ N and ½ K at 30 DAS) | 6843.00 |
| $t_4$ ($^1/_3$ N and $^1/_3$ K as basal +$^1/_3$ N and $^1/_3$ K at 30 DAS + $^1/_3$ N and $^1/_3$ K at 60 DAS | 6456.33 |
| SEm (±) | 177.86 |
| CD (0.05) | 531.789 |
| **R x T interaction** | |
| $r_1t_1$ | 5343.33 |
| $r_1t_2$ | 5196.67 |
| $r_1t_3$ | 6666.33 |
| $r_1t_4$ | 6772.33 |
| $r_2t_1$ | 6023.33 |
| $r_2t_2$ | 6558.33 |
| $r_2t_3$ | 6908.00 |
| $r_2t_4$ | 6446.33 |
| $r_3t_1$ | 6546.67 |
| $r_3t_2$ | 5962.00 |
| $r_3t_3$ | 6954.67 |
| $r_3t_4$ | 6150.33 |
| SEm (±) | 308.06 |
| CD (0.05) | NS |

(5905.67 kg ha$^{-1}$) and on par with $t_4$ (6456.33 kg ha$^{-1}$). The $t_4$ ((application of N and K in 3 equal splits with 1/3 of each applied as basal, at 30 DAS and 60 DAS) was however on par with $t_1$ which in turn did not vary from $t_2$ (5905.67 kg ha$^{-1}$).

The R x T interaction could not record significant influence on the dry matter production at harvest.

**4.1.6. Rooting depth**

Result of the effect of N:K ratios, time application and their interaction on rooting depth of sorghum at harvest is presented in Table 8.

The highest rooting depth was recorded with $r_3$ (26.64 cm) which was significantly superior to $r_2$ and $r_1$ resulting in a rooting depth of 22.32 cm and 22.25 cm which in turn were on par each other.

Time of application of nutrients could significantly affect the rooting depth and the highest value (25.58 cm) was recorded by $t_4$ which was on par with $t_2$ (24.65 cm). The $t_2$ was followed by $t_3$ (23.81 cm) and $t_1$ (20.90 cm) while $t_3$ also had an on par relation with $t_2$. Rooting depth was the lowest with $t_1$ and all other treatments produced significantly higher rooting depth than $t_1$.

The data on RxT interaction indicated that the rooting depth was the highest (31.18 cm) with $r_3t_2$ which was followed by $r_3t_4$ (27.95 cm) and $r_2t_4$ (24.93 cm). The $r_2t_4$ was followed by $r_3t_3$ (24.17 cm), $r_1t_4$ (23.85 cm), $r_1t_3$ (23.80 cm), $r_1t_2$ (23.52 cm), $r_2t_3$ (23.47 cm) and $r_3t_1$ (23.27 cm) which were on par each other. The lowest rooting depth was recorded with $r_1t_1$ (17.82 cm) which did not vary from $r_2t_2$ (19.25 cm).

**4.1.7 Root volume**

Result of the effect of N:K ratios, time application and their interaction on root volume of sorghum at harvest is presented in Table 8.

The main effect of N:K ratios significantly influenced the root volume. The treatment $r_3$ (N and K ratio 1:1.5) resulted in the highest root volume (137.63 cm$^3$) which did not differ from $r_2$ (N and K ratio 1:1) producing a root volume of 135.47 cm$^3$. Both $r_3$ and $r_2$ were significantly superior to $r_1$ (N and K ratio 1:0.5) which produced a root volume of 122.60 cm$^3$.

Time of nutrient application had significant influence on root volume. Highest root volume was recorded (142.21 $cm^3$) with $t_4$ (application of N and K in 3 equal splits with 1/3 of each applied as basal, at 30 DAS and 60 DAS) which was followed by $t_2$ (N in 3 equal split doses with 1/3 at basal, 30 DAS and 60 DAS with full K as basal), $t_1$ (N in 2 equal split doses as ½ at basal and ½ at 30 DAS with full K as basal) and $t_3$ (N and K applied in 2 equal splits with ½ of each at basal and at 30 DAS) wherein root volume recorded were 129.55, 128.97, and 126.87 $cm^3$ respectively which were on par each other.

The RxT interaction was significant in case of root volume and the highest root volume of 155.41 $cm^3$ was recorded with $r_3t_4$ which was significantly superior to all other treatments except $r_2t_4$. The $r_2t_4$ registered a root volume of 147.26 $cm^3$ and was on par with $r_3t_4$. The $r_2t_4$ was followed by $r_2t_1$, $r_3t_3$ and $r_2t_2$ producing root volume 139.94, 139.03 and 138.48 $cm^3$ which were on par with $r_2t_4$. Root volume was the lowest (112.54 $cm^3$) with $r_1t_1$ which statistically did not differ from $r_3t_2$ (121.63 $cm^3$) and $r_2t_3$ (116.21 $cm^3$)

## 4.2 YIELD ATTRIBUTES AND YIELD

### 4.2.1 length of panicle

Result of the effect of N:K ratios, time application and their interaction on length of panicle, number of grains per panicle is given in Table 9.

Nutrient ratio $r_3$ produced the longest panicle (24.80 cm) which was followed by $r_2$ (22.53 cm) and $r_1$(19.40 cm). Treatment $r_3$ (1: 1.5 N and K ratio) was significantly superior to $r_2$ (1:1 N and K ratio) which in turn was superior to $r_1$ (1:0.5 N and K ratio).

The main effect of time of application of nutrients could significantly affect the length of panicle which recorded the highest value (20.22 cm) in $t_3$ (N and K applied in 2 equal splits with ½ of each at basal and at 30 DAS), followed by $t_2$ (18.81 cm), $t_4$ (18.80 cm) and $t_1$ (18.73 cm) which were on par each other.

The R x T interaction could significantly influence the length of the panicle. Panicle was the longest with $r_2t_3$ (20.92 cm) followed by $r_3t_3$ (20.91 cm), $r_2t_1$ (20.61 cm), $r_2t_2$ (20.30 cm), $r_3t_2$ (19.55 cm) and $r_2t_4$ (19.16 cm) which were on par each other. The $r_2t_4$ treatment was followed by $r_3t_1$, $r_1t_3$, $r_1t_4$ and $r_3t_4$ which statistically did not differ

Table 8. Effect of N:K ratios, time of application and their interactions on rooting depth and root volume.

| Treatments | Rooting depth (cm) | Root volume ($cm^3$ per plant) |
|---|---|---|
| **N:K ratios(R)** | | |
| $r_1$ (1:0.5) | 22.25 | 122.60 |
| $r_2$ (1:1) | 22.32 | 135.47 |
| $r_3$ (1:1.5) | 26.64 | 137.63 |
| SEm (±) | 0.31 | 1.85 |
| CD (0.05) | 0.919 | 5.560 |
| **Time of application (T)** | | |
| $t_1$ (½ N as basal + ½ N at 30 DAS + full K as basal) | 20.90 | 128.97 |
| $t_2$ ($^1/_3$ N as basal + $^1/_3$ N at 30 DAS+ $^1/_3$ N at 60 DAS + full K as basal) | 24.65 | 129.55 |
| $t_3$ (½ N and ½ K as basal + ½ N and ½ K at 30DAS) | 23.81 | 126.87 |
| $t_4$ ($^1/_3$ N and $^1/_3$ K as basal +$^1/_3$ N and $^1/_3$ K at 30DAS + $^1/_3$ N and $^1/_3$ K at 60 DAS | 25.58 | 142.21 |
| SEm (±) | 0.35 | 2.14 |
| CD (0.05) | 1.061 | 6.42 |
| **R x T interaction** | | |
| $r_1t_1$ | 17.82 | 112.54 |
| $r_1t_2$ | 23.52 | 128.53 |
| $r_1t_3$ | 23.80 | 125.37 |
| $r_1t_4$ | 23.85 | 123.96 |
| $r_2t_1$ | 21.62 | 139.94 |
| $r_2t_2$ | 19.25 | 138.48 |
| $r_2t_3$ | 23.47 | 116.21 |
| $r_2t_4$ | 24.93 | 147.26 |
| $r_3t_1$ | 23.27 | 134.43 |
| $r_3t_2$ | 31.18 | 121.63 |
| $r_3t_3$ | 24.17 | 139.03 |
| $r_3t_4$ | 27.95 | 155.41 |
| SEm (±) | 0.61 | 3.71 |
| CD (0.05) | 1.838 | 11.12 |

with each other. The length of panicle was the lowest (16.57 cm) with $r_1t_2$ which was on par with $r_1t_1$ (16.70 cm).

### 4.2.2 Number of grains per panicle

Result of the effect of N:K ratios, time application and their interaction on number of grains per panicle of sorghum is given in Table 9.

The main effects or the interaction effect of the treatments could not significantly influence the grain number per panicle.

### 4.2.3 Grain weight per panicle

Result of the effect of N:K ratios, time application and their interaction on grain weight per panicle of sorghum is given in Table 9.

The grain weight per panicle was significantly influenced by the main effect of N:K ratios. The highest grain weight per panicle was recorded (46.47 g) with $r_2$ 1:1 N and K ratio) and was followed by $r_3$ (1:1.5 N and K ratio) and $r_1$ (1:0.5 ratio of N and K) which produced a grain weight of 42.77 g and 42.26 g respectively, which were on par in effect.

The main effect of time of nutrient application or its interaction with N and K ratios could not significantly influence the grain weight per panicle.

### 4.2.4. Test weight

Result of the effect of N:K ratios, time application and their interaction on test weight of sorghum grain is indicated in Table 9.

The main effects or the interaction effects of the treatments could not significantly influence the test weight of grain.

Table 9. Effect of N:K ratios, time of application and their interactions on length of panicle, number of grains per panicle, grain weight per panicle and test weight of grain.

| Treatments | Length of panicle (cm) | Number of grains per panicle | Grain weight per panicle (g) | Test weight (g) |
|---|---|---|---|---|
| **N:K ratios(R)** | | | | |
| $r_1$ (1:0.5) | 19.40 | 2077.67 | 42.26 | 24.32 |
| $r_2$ (1:1) | 22.53 | 2116.92 | 46.47 | 24.16 |
| $r_3$ (1:1.5) | 24.80 | 2217.08 | 42.77 | 24.50 |
| SEm (±) | 0.31 | 41.89 | 0.98 | 0.23 |
| CD (0.05) | 0.928 | NS | 2.934 | NS |
| **Time of application (T)** | | | | |
| $t_1$ (½ N as basal + ½ N at 30 DAS + full K as basal) | 18.73 | 2060.44 | 42.19 | 24.19 |
| $t_2$ ($^1/3$ N as basal + $^1/3$ N at 30 DAS+ $^1/3$ N at 60 DAS +full K as basal) | 18.81 | 2190.11 | 42.38 | 24.36 |
| $t_3$ (½ N and ½ K as basal + ½ N and ½ K at 30 DAS) | 20.22 | 2109.78 | 46.26 | 24.10 |
| $t_4$ ($^1/3$ N and $^1/3$ K as basal +$^1/3$ N and $^1/3$ K at 30 DAS + $^1/3$ N and $^1/3$ K at 60 DAS) | 18.80 | 2188.56 | 44.51 | 24.66 |
| SEm (±) | 0.34 | 48.37 | 1.13 | 0.26 |
| CD (0.05) | 1.072 | NS | NS | NS |
| **R x T interaction** | | | | |
| $r_1t_1$ | 16.70 | 2005.67 | 36.79 | 24.00 |
| $r_1t_2$ | 16.57 | 2158.00 | 40.00 | 24.67 |
| $r_1t_3$ | 18.82 | 1998.67 | 45.39 | 24.03 |
| $r_1t_4$ | 18.66 | 2148.33 | 46.87 | 24.57 |
| $r_2t_1$ | 20.61 | 2062.67 | 47.61 | 23.90 |
| $r_2t_2$ | 20.30 | 2047.33 | 44.91 | 23.93 |
| $r_2t_3$ | 20.92 | 2057.00 | 47.20 | 24.37 |
| $r_2t_4$ | 19.16 | 2300.67 | 46.17 | 24.43 |
| $r_3t_1$ | 18.87 | 2113.00 | 42.17 | 24.67 |
| $r_3t_2$ | 19.55 | 2365.00 | 42.23 | 24.47 |
| $r_3t_3$ | 20.91 | 2273.67 | 46.20 | 23.90 |
| $r_3t_4$ | 18.59 | 2116.67 | 40.49 | 24.97 |
| SEm (±) | 0.62 | 83.78 | 1.96 | 0.45 |
| CD (0.05) | 1.856 | NS | NS | NS |

### 4.2.5 Grain yield

Result of the effect of N:K ratios, time application and their interaction on grain yield of sorghum is given in Table 10.

The $r_2$ ratio (N and K in 1:1) produced the highest grain yield of 3449.33 kg $ha^{-1}$ which was statistically superior to the treatment $r_1$ (1:0.5 N and K ratio-2811.67 kg $ha^{-1}$). The treatment $r_2$ however was on par with $r_3$ (N and K in 1: 1.5 ratio) which produced a grain yield of 3298.67 kg $ha^{-1}$.

The main effect of time of application of N and K was found to be significant and $t_3$ (½ N and ½ K as basal + ½ N and ½ K at 30 DAS) resulted in the highest grain yield of 3532.22 kg $ha^{-1}$ followed by $t_4$ (3350.11 kg $ha^{-1}$) which were on par each other. Both $t_3$ and $t_4$ were significantly superior to $t_2$ (2943.22 kg $ha^{-1}$) and $t_1$ (2920.67 kg $ha^{-1}$) which in turn did not vary each other.

The RxT interaction could significantly influence the grain yield of sorghum and $r_3t_3$ treatment (N and K in 1: 1.5 ratio and its application in two split doses ie., ½ N and ½ K as basal + ½ N and ½ K at 30 DAS) produced the highest grain yield (3635.67 kg $ha^{-1}$) which was on par with all other treatments except $r_1t_1$ (2205.33 kg $ha^{-1)}$ and $r_1t_2$ (2052.67 kg $ha^{-1}$) which in turn did not differ each other. $r_1t_3$-3522.67 kg $ha^{-1}$, $r_1t_4$-3466.00 kg $ha^{-1}$, $r_2t_3$-3438.33 kg $ha^{-1}$, $r_3t_1$-3349.67 kg $ha^{-1}$, $r_3t_2$-3232.00 kg $ha^{-1}$, $r_2t_1$-3207.00 kg $ha^{-1}$ and $r_3t_4$ -2977.33 kg $ha^{-1}$) to $r_1t_1$ and $r_1t_2$.

### 4.2.6 Green stover yield

Result of the effect of N:K ratios, time application and their interaction on green stover yield of sorghum is given in Table 10.

The main effects or the interaction effects of the treatments could not significantly influence the green stover yield.

Table 10. Effect of N:K ratios, time of application and their interactions on grain yield, green stover yield, and harvest index of sorghum

| Treatments | Grain yield (kg ha$^{-1}$) | Green stover yield (kg ha$^{-1}$) | Harvest index |
|---|---|---|---|
| **N:K ratios(R)** | | | |
| $r_1$ (1:0.5) | 2811.67 | 10926 | 0.39 |
| $r_2$ (1:1) | 3449.33 | 10767 | 0.45 |
| $r_3$ (1:1.5) | 3298.67 | 10788 | 0.45 |
| SEm (±) | 113.46 | 286.49 | 0.01 |
| CD (0.05) | 339.241 | NS | 0.037 |
| **Time of application (T)** | | | |
| $t_1$ (½ N as basal + ½ N at 30 DAS + full K as basal) | 2920.67 | 10746 | 0.41 |
| $t_2$ ($^1/_3$ N as basal + $^1/_3$ N at 30 DAS+ $^1/_3$ N at 60 DAS + full K as basal) | 2943.22 | 10319 | 0.42 |
| $t_3$ (½ N and ½ K as basal + ½ N and ½ K at 30 DAS) | 3532.22 | 11641 | 0.44 |
| $t_4$ ($^1/_3$ N and $^1/_3$ K as basal +$^1/_3$ N and $^1/_3$ K at 30 DAS + $^1/_3$ N and $^1/_3$ K at 60 DAS | 3350.11 | 10602 | 0.46 |
| SEm (±) | 131.01 | 330.81 | 0.01 |
| CD (0.05) | 391.722 | NS | NS |
| | | | |
| $r_1t_1$ | 2205.33 | 10513 | 0.35 |
| $r_1t_2$ | 2052.67 | 10463 | 0.33 |
| $r_1t_3$ | 3522.67 | 11130 | 0.45 |
| $r_1t_4$ | 3466.00 | 11596 | 0.43 |
| $r_2t_1$ | 3207.00 | 9997 | 0.45 |
| $r_2t_2$ | 3545.00 | 10746 | 0.46 |
| $r_2t_3$ | 3438.33 | 12079 | 0.42 |
| $r_2t_4$ | 3607.00 | 10247 | 0.47 |
| $r_3t_1$ | 3349.67 | 11729 | 0.44 |
| $r_3t_2$ | 3232.00 | 9746 | 0.46 |
| $r_3t_3$ | 3635.67 | 11712 | 0.45 |
| $r_3t_4$ | 2977.33 | 9964 | 0.46 |
| SEm (±) | 226.91 | 572.99 | 0.02 |
| CD (0.05) | 678.482 | NS | NS |

### 4.2.7 Harvest index

Result of the effect of N:K ratios, time application and their interaction on harvest index of sorghum is given in Table 10.

Harvest index was significantly superior in $r_2$ (N and K in 1:1) and $r_3$ (N and K in 1: 1.5) both producing a value of 0.45 compared to $r_1$ (0.39)

The time of application however could not significantly influence the harvest index. The interaction effects also did not produce any significant effect on harvest index.

## 4.3 PEST AND DISEASE INCIDENCE

Mild incidence of shoot fly was noticed at 1 month after planting and was controlled by spraying Quinalphos 25 EC at the rate of 2 ml per litre twice at one week interval.

## 4.4 PLANT ANALYSIS

### 4.4.1 Chlorophyll content

Result of the effect of N:K ratios, time application and their interaction on chlorophyll content is given in Table 11.

The chlorophyll content of plant tissue was influenced by the main effect of N:K ratio both at 30 and 60 DAS. At 30 DAS, the $r_3$ (1:1.5 ratio of N and K) which recorded the highest chlorophyll content (0.61 mg $g^{-1}$) was on par with $r_2$ (1:1 N and K ratio) which produced a chlorophyll content of 0.58 mg $g^{-1}$. Chlorophyll content was the lowest (0.55 mg $g^{-1}$) with $r_1$ (1:0.5 N and K ratio) which in turn was on par with $r_2$. At 60 DAS, the highest chlorophyll content (1.10 mg $g^{-1}$) was recorded by $r_3$ which was followed by $r_2$ (1.00 mg $g^{-1}$) and then by $r_1$ (0.94 mg $g^{-1}$). The $r_3$ was significantly superior to $r_2$ and $r_1$, while $r_2$ was superior to $r_1$ alone.

The time of application could significantly affect the chlorophyll content at both 30 and 60 DAS. At 30 DAS, the chlorophyll content was the highest (0.66 mg $g^{-1}$) with $t_3$ which did not differ from $t_4$ (0.65 mg $g^{-1}$) and was followed by $t_2$ (0.56 mg $g^{-1}$) and $t_1$ (0.46 mg $g^{-1}$). The $t_3$ and $t_4$ were however on par each other. Similar trend was repeated at 60 DAS also wherein, the highest chlorophyll content was recorded with $t_3$ (1.11 mg

$g^{-1}$) which was on par with $t_4$ (1.10 mg $g^{-1}$). The $t_3$ and $t_4$ were significantly superior to $t_2$ (0.95 mg $g^{-1}$) followed by $t_1$ (0.89 mg $g^{-1}$).

The R x T interaction could significantly influence the chlorophyll content only at 30 DAS and the highest chlorophyll content was recorded by $r_2t_4$ (0.71 mg $g^{-1}$), which was on par with $r_3t_3$ (0.69 mg $g^{-1}$), $r_2t_3$, $r_1t_3$ and $r_3t_4$ (0.65 mg $g^{-1}$) and significantly superior to all other treatments.

**4.4.2 Crude protein content (grain)**

Result of the effect of N:K ratios, time application and their interaction on crude protein content of sorghum grain is given in Table 12.

Main effect of nutrient ratios, time of application of nutrients and their interactions could not significantly affect the crude protein content of grain.

**4.4.3 Crude protein content (stover)**

Result of the effect of N:K ratios, time application and their interaction on crude protein content of sorghum stover is given in Table 12.

Main effect of nutrient ratios, time of application of nutrients and their interactions could not significantly affect the crude protein content of stover.

**4.4.4. Uptake of N, P and K**

***4.4.4.1 Uptake of N***

Result of the effect of N:K ratios, time application and their interaction on N uptake by the crop is given in Table 13.

The main effect of N:K ratios significantly affected the N uptake and it was the highest (68.90 kg $ha^{-1}$) with $r_2$ (1:1), which was on par with $r_3$ (1:1.5) recording an uptake of 66.48 kg $ha^{-1}$. Both $r_2$ and $r_3$ were significantly superior to $r_1$ (1:0.5) with an N uptake of 59.32 kg $ha^{-1}$.

Table 11. Effect of N:K ratios, time of application and their interactions on chlorophyll content, mg $g^{-1}$

| Treatments | Chlorophyll content | |
|---|---|---|
| | 30 DAS | 60 DAS |
| **N:K ratios(R)** | | |
| $r_1$ (1:0.5) | 0.55 | 0.94 |
| $r_2$ (1:1) | 0.58 | 1.00 |
| $r_3$ (1:1.5) | 0.61 | 1.10 |
| SEm (±) | 0.01 | 0.02 |
| CD (0.05) | 0.039 | 0.045 |
| **Time of application (T)** | | |
| $t_1$ (½ N as basal + ½ N at 30 DAS + full K as basal) | 0.46 | 0.89 |
| $t_2$ ($^1/_3$ N as basal + $^1/_3$ N at 30 DAS+ $^1/_3$ N at 60 DAS + full K as basal) | 0.56 | 0.95 |
| $t_3$ (½ N and ½ K as basal + ½ N and ½ K at 30 DAS) | 0.66 | 1.11 |
| $t_4$ ($^1/_3$ N and $^1/_3$ K as basal +$^1/_3$ N and $^1/_3$ K at30 DAS + $^1/_3$ N and $^1/_3$ K at 60 DAS | 0.65 | 1.10 |
| SEm (±) | 0.02 | 0.02 |
| CD (0.05) | 0.045 | 0.052 |
| **R x T interaction** | | |
| $r_1t_1$ | 0.43 | 0.84 |
| $r_1t_2$ | 0.55 | 0.92 |
| $r_1t_3$ | 0.65 | 0.99 |
| $r_1t_4$ | 0.58 | 1.01 |
| $r_2t_1$ | 0.41 | 0.86 |
| $r_2t_2$ | 0.56 | 0.91 |
| $r_2t_3$ | 0.65 | 1.10 |
| $r_2t_4$ | 0.71 | 1.13 |
| $r_3t_1$ | 0.52 | 0.99 |
| $r_3t_2$ | 0.57 | 1.03 |
| $r_3t_3$ | 0.69 | 1.23 |
| $r_3t_4$ | 0.65 | 1.15 |
| SEm (±) | 0.03 | 0.03 |
| CD (0.05) | 0.077 | NS |

Table 12. Effect of N:K ratios, time of application and their interactions on crude protein content of grain and stover, per cent

| Treatments | Crude protein content | |
|---|---|---|
| | Grain | Stover |
| **N:K ratios(R)** | | |
| $r_1$ (1:0.5) | 9.62 | 6.40 |
| $r_2$ (1:1) | 9.37 | 6.61 |
| $r_3$ (1:1.5) | 9.73 | 6.49 |
| SEm (±) | 0.29 | 0.06 |
| CD (0.05) | NS | NS |
| **Time of application (T)** | | |
| $t_1$ (½ N as basal + ½ N at 30 DAS + full K as basal) | 9.457 | 6.49 |
| $t_2$ ($^1/3$ N as basal + $^1/3$ N at 30 DAS+ $^1/3$ N at 60 DAS + full K as basal) | 9.022 | 6.52 |
| $t_3$ (½ N and ½ K as basal + ½ N and ½ K at 30 DAS) | 10.06 | 6.45 |
| $t_4$ ($^1/3$ N and $^1/3$ K as basal +$^1/3$ N and $^1/3$ K at 30 DAS + $^1/3$ N and $^1/3$ K at 60 DAS | 9.76 | 6.53 |
| SEm (±) | 0.33 | 0.07 |
| CD (0.05) | NS | NS |
| **R x T interaction** | | |
| $r_1t_1$ | 10.51 | 6.13 |
| $r_1t_2$ | 8.60 | 6.50 |
| $r_1t_3$ | 10.10 | 6.39 |
| $r_1t_4$ | 9.24 | 6.52 |
| $r_2t_1$ | 9.23 | 6.71 |
| $r_2t_2$ | 9.64 | 6.66 |
| $r_2t_3$ | 9.45 | 6.58 |
| $r_2t_4$ | 9.17 | 6.49 |
| $r_3t_1$ | 8.64 | 6.63 |
| $r_3t_2$ | 8.82 | 6.40 |
| $r_3t_3$ | 10.62 | 6.37 |
| $r_3t_4$ | 10.87 | 6.57 |
| SEm (±) | 0.58 | 0.12 |
| CD (0.05) | NS | NS |

The main effect of time of nutrient application also had significant effect on N uptake. The highest N uptake of 74.28 kg ha$^{-1}$ was observed with $t_3$ (½ N and ½ K as basal + ½ N and ½ K at 30 DAS), which was on par with $t_4$ ($^1/3$ N and $^1/3$ K as basal +$^1/3$ N and $^1/3$ K at 30 DAS + $^1/3$ N and $^1/3$ K at 60 DAS) recording an uptake value of 73.93 kg ha$^{-1}$. Both $t_3$ and $t_4$ were significantly superior to $t_1$ (½ N as basal + ½ N at 30 DAS + full K as basal) and $t_2$ ($^1/3$ N as basal + $^1/3$ N at 30 DAS+ $^1/3$ N at 60 DAS + full K as basal) with low uptake values 58.15 and 53.24 kg ha$^{-1}$ respectively which in turn were on par.

The R x T interaction results indicated that $r_2t_3$ recorded the highest N uptake value of 88.91 kg ha$^{-1}$and was on par with $r_3t_4$ and $r_3t_3$ with uptake values 84.80 and 78.42 kg N ha$^{-1}$ respectively and superior to all other treatments. The $r_3t_4$ was followed by $r_1t_4$ recording an N uptake of 68.65 kg ha$^{-1}$ which did not vary from $r_2t_4$, $r_2t_1$, $r_1t_1$, $r_1t_3$, $r_3t_2$ and $r_2t_2$ which registered uptake values of 68.33, 64.37, 62.69, 55.50, 55.29 and 53.97 kg ha$^{-1}$ respectively. N uptake was the lowest with $r_3t_1$ (47.40 kg ha$^{-1}$) which was on par with $r_1t_2$ (50.46 kg ha$^{-1}$).

#### *4.4.4.2 Uptake of P*

Result of the effect of N:K ratios, time application and their interaction on P uptake by the crop is given in Table 13.

The N:K ratio $r_3$ (1:1.5) recorded significantly higher P uptake (49.88 kg ha$^{-1}$) than $r_1$ (1:0.5 ratio of N and K). The $r_3$ was however on par with $r_2$ (49.41 kg ha$^{-1}$) which recorded a P uptake of 49.41 kg ha$^{-1.}$

The time of application of nutrients significantly influenced the P uptake and $t_3$ recorded the highest uptake (52.95 kg ha$^{-1}$) which was on par with $t_4$ (49.39 kg ha$^{-1}$). Both $t_3$ and $t_4$ were significantly superior to $t_2$ (45.20 kg ha$^{-1)}$ and $t_1$ (44.55 kg ha$^{-1}$) which were on par each other.

The R x T interaction significantly influenced the P uptake and $r_3t_3$ recorded the highest P uptake (54.92 kg ha$^{-1}$) which did not vary from $r_2t_3$, $r_1t_4$, $r_1t_3$, $r_3t_1$, $r_2t_4$, $r_2t_2$ and $r_3t_2$ which recorded the P uptake values 54.02, 51.66. 49.89, 49.56, 49.40, 49.33 and 47.90 kg ha$^{-1}$ respectively. The $r_3t_3$ was however significantly superior to $r_3t_4$ (47.12 kg ha$^{-1}$) and $r_2t_1$ (44.98 kg ha$^{-1}$) which were on par each other. The P uptake was the lowest with $r_1t_2$ which was statistically similar to $r_1t_1$ (39.11kg ha$^{-1}$).

#### *4.4.4.3 Uptake of K*

Result of the effect of N:K ratios, time application and their interaction on K uptake by the crop is given in Table 13.

Data on the K uptake indicated that the highest uptake was recorded in $r_2$ (278.56 kg ha$^{-1}$) which did not differ from $r_3$ (K uptake-268.61 kg ha$^{-1}$) but superior to $r_1$ (196.15 kg ha$^{-1}$).

The main effect of time of application could significantly influence the K uptake and $t_3$ recorded the highest uptake of K (272.82 kg ha$^{-1}$) which was on par with $t_2$ (271.06 kg ha$^{-1}$), but superior to $t_4$ (237.44 kg ha$^{-1}$) and $t_1$ (209.77 kg ha$^{-1}$).

RxT interaction had significant influence on K uptake and $r_2t_3$ recorded the highest K uptake of 295.05 kg ha$^{-1}$ which was on par with $r_3t_2$ (292.60 kg ha$^{-1}$), but significantly superior to all other treatments. The $r_3t_2$ was followed by $r_1t_3$ (276.38 kg ha$^{-1}$) which did not vary from $r_3t_4$, $r_3t_1$, $r_2t_4$, $r_3t_3$ and $r_2t_1$ which registered K uptake values, 271.59, 263.21, 250.54, 247.04 and 246.04 kg ha$^{-1}$ respectively. The K uptake was drastically reduced to 170.06 kg ha$^{-1}$ in $r_1t_1$.

## 4.5 SOIL ANALYSIS

### 4.5.1 pH

Result of the effect of N:K ratios, time application and their interaction on pH of the soil after the experiment is given in Table 14.

The pH of the soil was significantly higher (5.70) with $r_2$ (1:1 ratio of N and K) in comparison with $r_1$(1:0.5 ratio of N and K) which recorded a pH of 5.52. The $r_2$ was however on par with $r_3$ (1:1.5 ratio of N and K) which registered a pH of 5.67.

Table 13. Effect of N:K ratios, time of application and their interactions on uptake of N, P and K, kg ha$^{-1}$

| Treatments | Uptake of N | Uptake of P | Uptake of K |
|---|---|---|---|
| **N:K ratios(R)** | | | |
| $r_1$ (1:0.5) | 59.32 | 44.79 | 196.15 |
| $r_2$ (1:1) | 68.90 | 49.41 | 278.56 |
| $r_3$ (1:1.5) | 66.48 | 49.88 | 268.61 |
| SEm (±) | 2.49 | 1.18 | 5.14 |
| CD (0.05) | 7.469 | 3.552 | 15.416 |
| **Time of application (T)** | | | |
| $t_1$ (½ N as basal + ½ N at 30 DAS + full K as basal) | 58.15 | 44.55 | 209.77 |
| $t_2$ ($^1/_3$ N as basal + $^1/_3$ N at 30 DAS+ $^1/_3$ N at 60 DAS + full K as basal) | 53.24 | 45.20 | 271.06 |
| $t_3$ (½ N and ½ K as basal + ½ N and ½ K at 30 DAS) | 74.28 | 52.95 | 272.82 |
| $t_4$ ($^1/_3$ N and $^1/_3$ K as basal +$^1/_3$ N and $^1/_3$ K at 30 DAS + $^1/_3$ N and $^1/_3$ K at 60 DAS | 73.93 | 49.39 | 237.44 |
| SEm (±) | 2.88 | 1.37 | 5.93 |
| CD (0.05) | 8.625 | 4.102 | 17.801 |
| **R x T interaction** | | | |
| $r_1t_1$ | 62.69 | 39.11 | 170.06 |
| $r_1t_2$ | 50.46 | 38.48 | 197.98 |
| $r_1t_3$ | 55.50 | 49.89 | 276.38 |
| $r_1t_4$ | 68.65 | 51.66 | 190.19 |
| $r_2t_1$ | 64.37 | 44.98 | 246.04 |
| $r_2t_2$ | 53.97 | 49.22 | 222.60 |
| $r_2t_3$ | 88.91 | 54.02 | 295.05 |
| $r_2t_4$ | 68.33 | 49.40 | 250.54 |
| $r_3t_1$ | 47.40 | 49.56 | 263.21 |
| $r_3t_2$ | 55.29 | 47.90 | 292.60 |
| $r_3t_3$ | 78.42 | 54.92 | 247.04 |
| $r_3t_4$ | 84.80 | 47.12 | 271.59 |
| SEm (±) | 4.98 | 2.37 | 10.28 |
| CD (0.05) | 14.939 | 7.104 | 30.833 |

The time of application of nutrients also significantly influenced the pH of the soil during the post experimental period. The pH was enhanced to 5.70 in both $t_3$ and $t_1$ which were significantly superior to $t_2$ (5.53) and on par with $t_4$ (5.58).

The RxT interaction did not influence the pH of the soil after the experiment.

**4.5.2 Electrical Conductivity (EC)**

Result of the effect of N:K ratios, time application and their interaction on EC of the soil after the experiment is given in Table 14.

The main effects of the treatments or their interaction could not significantly influence the electrical conductivity of soil after the experiment.

**4.5.3 Organic carbon**

Result of the effect of N:K ratios, time application and their interaction on organic carbon content of the soil after the experiment is given in Table 14.

Ratios of N:K nutrition could significantly affect the organic carbon content of the soil after the experiment. The highest organic carbon content (0.83 per cent) was observed with $r_3$ (1:1.5 ratio of N and K) which was on par with $r_2$ (1:1 ratio of N and K) recording an organic carbon content of 0.78 per cent. Both $r_1$ and $r_2$ were significantly superior to $r_1$ (1:0.5 N and K ratio) which produced an organic carbon content of 0.66 per cent.

Time of nutrient application also had significant effect on organic carbon content of soil after the experiment. The content was the highest with $t_3$ (0.89 per cent) which was on par with $t_4$ (0.84 per cent) and both $t_3$ and $t_4$ were significantly superior to $t_2$ (0.69 per cent) followed by $t_1$ (0.61 per cent).

The RxT interaction significantly influenced the organic carbon content in soil and significantly higher content was obtained with $r_3t_3$ (1.06 per cent) which was on par with $r_2t_3$ (0.98 per cent) and superior to all other treatments.

Table 14. Effect of N:K ratios, time of application and their interactions on pH, EC and organic carbon status of soil after the experiment.

| Treatments | pH | EC (dS $m^{-1}$) | Organic carbon (per cent) |
|---|---|---|---|
| **N:K ratios (R)** | | | |
| $r_1$ (1:0.5) | 5.52 | 0.26 | 0.66 |
| $r_2$ (1:1) | 5.70 | 0.24 | 0.78 |
| $r_3$ (1:1.5) | 5.67 | 0.24 | 0.83 |
| SEm (±) | 0.04 | 0.01 | 0.02 |
| CD (0.05) | 0.107 | NS | 0.063 |
| **Time of application (T)** | | | |
| $t_1$ (½ N as basal + ½ N at 30 DAS + full K as basal) | 5.70 | 0.25 | 0.61 |
| $t_2$ (1/3 N as basal + 1/3 N at 30 DAS + 1/3 N at 60 DAS + full K as basal) | 5.53 | 0.23 | 0.69 |
| $t_3$ (½ N and ½ K as basal + ½ N and ½ K at 30 DAS) | 5.70 | 0.23 | 0.89 |
| $t_4$ (1/3 N and 1/3 K as basal +1/3 N and 1/3 K at 30 DAS + 1/3 N and 1/3 K at 60 DAS | 5.58 | 0.27 | 0.84 |
| SEm (±) | 0.04 | 0.04 | 0.02 |
| CD (0.05) | 0.124 | NS | 0.073 |
| **R x T interaction** | | | |
| $r_1t_1$ | 5.55 | 0.30 | 0.65 |
| $r_1t_2$ | 5.53 | 0.23 | 0.64 |
| $r_1t_3$ | 5.53 | 0.24 | 0.65 |
| $r_1t_4$ | 5.45 | 0.25 | 0.73 |
| $r_2t_1$ | 5.74 | 0.21 | 0.60 |
| $r_2t_2$ | 5.53 | 0.25 | 0.66 |
| $r_2t_3$ | 5.81 | 0.19 | 0.98 |
| $r_2t_4$ | 5.73 | 0.30 | 0.88 |
| $r_3t_1$ | 5.81 | 0.23 | 0.59 |
| $r_3t_2$ | 5.53 | 0.22 | 0.79 |
| $r_3t_3$ | 5.76 | 0.24 | 1.06 |
| $r_3t_4$ | 5.55 | 0.28 | 0.90 |
| SEm (±) | 0.07 | 0.03 | 0.38 |
| CD (0.05) | NS | NS | 0.126 |

The $r_3t_3$ was followed by $r_3t_4$, $r_2t_4$ and $r_3t_2$ with respect to soil organic carbon content (0.90, 0.88 and 0.79 per cent respectively) which were statistically similar. The $r_3t_3$ was however significantly superior to $r_1t_4$ (0.73 per cent), $r_2t_2$ (0.66 per cent), $r_1t_1$ (0.65 per cent), $r_1t_3$ (0.65 per cent) and $r_1t_2$ (0.64 per cent). The organic carbon content was greatly reduced (0.59 per cent) in $r_3t_1$ which was on par with $r_2t_1$ (0.60 per cent).

### 4.5.4 Available nutrient status of soil after the experiment

#### *4.5.4.1 Available N*

Result of the effect of N:K ratios, time application and their interaction on available N content of the soil after the experiment is given in Table 15.

The nutrient ratios had significant influence on available N content of soil. The highest available soil N content was recorded (296.88 kg $ha^{-1}$) with $r_3$ (1:1.5 N and K ratio) which was significantly higher than $r_2$ (259.24 kg $ha^{-1}$) and $r_1$ (244.61 kg $ha^{-1}$) which were on par each other.

The time of application of nutrients also had significant influence on available N status of soil after the experiment and the highest content was recorded by $t_4$ (294.09 kg $ha^{-1}$) which was significantly superior to $t_2$ (266.21 kg $ha^{-1}$) followed by $t_1$ (218.82 kg $ha^{-1}$). The $t_3$ which recorded an available N content of 288.51 kg $ha^{-1}$ was however on par with $t_4$.

The RxT interaction significantly affected the available N status of soil after the experiment. The available N was the highest (363.78 kg $ha^{-1}$) with $r_3t_3$ which was on par with $r_2t_4$ (326.14 kg $ha^{-1}$) and significantly superior to all other treatments. It was followed by $r_1t_2$ (305.24 kg $ha^{-1}$) which was statistically equal to $r_2t_3$, $r_3t_4$, $r_3t_2$, $r_1t_4$ and $r_3t_1$ recording a value of 296.88, 288.51, 271.79, 267.61 and 263.42 kg $ha^{-1}$ respectively. The N uptake was the lowest with $r_2t_1$ (192.34 kg $ha^{-1}$) which did not vary from $r_2t_2$, $r_1t_3$, and $r_1t_1$.

#### *4.5.4.2 Available P*

Result of the effect of N:K ratios, time application and their interaction on available P content of the soil after the experiment is given in Table 15.

Available P content of the soil was the highest (90.37 kg $ha^{-1}$) in $r_2$ (1:1 ratio of N and K) which was significantly superior to $r_3$ (1:1.5 ratio of N and K) resulting in an available soil P content of 58.58 kg $ha^{-1}$, which was significantly higher than the available P content recorded with $r_1$ (1: 0.5 kg N and K- 56.70 kg $ha^{-1}$).

The schedule of nutrient application could significantly influence the available P content of the soil after the experiment. Significantly higher available soil P content was recorded (82.05 kg $ha^{-1}$) by $t_3$ (½ N and ½ K as basal + ½ N and ½ K at 30 DAS) compared to all other treatments and was followed by $t_4$ (application of N and K in 3 equal splits with 1/3 of each applied as basal, at 30 DAS and 60 DAS) recording a value of 73.38 kg $ha^{-1}$. The $t_4$ was found to be significantly superior to $t_2$ producing an available soil P content of 60.40 kg $ha^{-1}$ which in turn was followed by $t_1$ (58.37 kg $ha^{-1}$).

Data on RxT interaction indicated that $r_2t_3$ recorded significantly higher available soil P content of 116.08 kg $ha^{-1}$compared to all other treatments and was followed by $r_2t_4$ (106.53 kg $ha^{-1}$), $r_1t_3$ (79.90 kg $ha^{-1}$), $r_3t_4$ (74.67 kg $ha^{-1}$) and $r_2t_2$ (70.22 kg $ha^{-1}$) and was on par with $r_1t_2$ (69.41 kg $ha^{-1}$). The $r_1t_2$ in turn was significantly superior to $r_2t_1$ (68.67 kg $ha^{-1}$) which in turn was on par with $r_3t_1$ (67.90 kg $ha^{-1}$). The $r_3t_1$ was however significantly superior to $r_3t_3$ (50.18 kg $ha^{-1}$) followed by $r_3t_2$ (41.56 kg $ha^{-1}$). The lowest available P content was recorded by $r_1t_1$ (38.54 kg $ha^{-1}$) which was on par with $r_1t_4$ (38.95 kg $ha^{-1}$)

#### *4.5.4.3 Available K*

Result of the effect of N:K ratios, time application and their interaction on available K content of the soil after the experiment is given in Table 15.

The main effects of the treatments or their interactions could not influence the available K content of soil after the experiment.

Table 15. Effect of N:K ratios, time of application and their interactions on available N, P and K status of soil after the experiment, kg $ha^{-1}$

| Treatments | Available N | Available P | Available K |
|---|---|---|---|
| **N:K ratios(R)** | | | |
| $r_1$ (1:0.5) | 244.61 | 56.70 | 124.65 |
| $r_2$ (1:1) | 259.24 | 90.37 | 120.65 |
| $r_3$ (1:1.5) | 296.88 | 58.58 | 125.66 |
| SEm (±) | 7.91 | 0.33 | 2.66 |
| CD (0.05) | 23.725 | 0.989 | NS |
| **Time of application (T)** | | | |
| $t_1$ (½ N as basal + ½ N at 30DAS + full K as basal) | 218.82 | 58.37 | 121.41 |
| $t_2$ ($^1/3$ N as basal + $^1/3$ N at 30 DAS+ $^1/3$ N at 60 DAS +full K as basal) | 266.21 | 60.40 | 118.52 |
| $t_3$ (½ N and ½ K as basal + ½ N and ½ K at 30 DAS) | 288.51 | 82.05 | 130.44 |
| $t_4$ ($^1/3$ N and $^1/3$ K as basal +$^1/3$ N and $^1/3$ K at 30 DAS + $^1/3$ N and $^1/3$ K at 60 DAS | 294.09 | 73.38 | 124.24 |
| SEm (±) | 9.13 | 0.38 | 3.07 |
| CD (0.05) | 27.396 | 1.142 | NS |
| **R x T interaction** | | | |
| $r_1t_1$ | 200.70 | 38.54 | 120.06 |
| $r_1t_2$ | 305.24 | 69.41 | 117.88 |
| $r_1t_3$ | 204.89 | 79.90 | 140.33 |
| $r_1t_4$ | 267.61 | 38.95 | 120.33 |
| $r_2t_1$ | 192.34 | 68.67 | 124.60 |
| $r_2t_2$ | 221.61 | 70.22 | 115.67 |
| $r_2t_3$ | 296.88 | 116.08 | 125.67 |
| $r_2t_4$ | 326.14 | 106.52 | 116.66 |
| $r_3t_1$ | 263.42 | 67.90 | 119.58 |
| $r_3t_2$ | 271.79 | 41.56 | 122.00 |
| $r_3t_3$ | 363.78 | 50.18 | 125.33 |
| $r_3t_4$ | 288.51 | 74.67 | 135.73 |
| SEm (±) | 15.82 | 0.66 | 5.31 |
| CD (0.05) | 47.451 | 1.979 | NS |

## 4.6 ECONOMIC ANALYSIS

### 4.6.1 Total cost of cultivation

Result of the effect of N:K ratios, time application and their interaction on total cost of cultivation of crop (₹ $ha^{-1}$) is given in Table 16.

Total cost of cultivation was the lowest (₹ 34983) with $r_1t_1$ (application of N and K in 1:0.5 ratio with ½ N given at basal + 30 DAS and full K as basal) and was followed by $r_2t_1$(₹ 35883), $r_1t_2$ (₹ 36483), $r_2t_4$ (₹ 36633), $r_2t_3$ or $r_2t_2$ (₹ 37383), $r_3t_1$ (₹ 37533), $r_1t_4$ or $r_1t_3$ (₹ 37983), $r_3t_2$ or $r_3t_3$ (₹ 38283) and $r_3t_4$ (₹ 39783)

### 4.6.2 Net income

Result of the effect of N:K ratios, time application and their interaction on net income generated (₹ $ha^{-1}$) is given in Table 16.

The net income was the highest (₹ 39737) with $r_3t_3$ wherein N and K in 1:1.5 ratio were applied with 2 equal splits with ½ of each at basal and at 30 DAS which was followed by $r_2t_3$ (₹ 38377), $r_2t_4$ (₹ 38017), $r_2t_2$ (₹ 37367), $r_1t_4$ (₹ 37267), $r_1t_3$ (₹ 37077), $r_3t_1$(₹ 35727), $r_2t_1$(₹ 32267), $r_3t_2$ (₹ 29667), $r_3t_4$ (₹ 24837), $r_1t_1$(₹ 19187). The net income was the lowest (₹ 15187) in $r_1t_2$.

### 4.6.3 Benefit-cost ratio (BCR)

Result of the effect of N:K ratios, time application and their interaction on BCR is given in Table 16.

The treatment combination $r_2t_4$ wherein N and K in 1:1 ratio were applied in such a way that both N and K were given in 3 equal splits with 1/3 of each applied as basal, at 30 DAS and 60 DAS and, $r_3t_3$ wherein N and K in 1:1.5 ratio were applied with 2 equal splits with ½ of each at basal and at 30 DAS resulted in the highest BCR of 2.04.These treatments were followed by $r_2t_3$ (2.03), $r_2t_2$ (2.00), $r_1t_3$ (1.98), $r_1t_4$ (1.98), $r_3t_1$(1.95), $r_2t_1$ (1.90), $r_3t_2$ (1.77), $r_3t_4$ (1.62) and $r_1t_1$(1.55). BCR was the lowest with $r_1t_2$ (1.42)

Table 16. Effect of N:K ratios, time of application and their interactions on total cost of cultivation, net income and benefit-cost ratio

| Treatments | Total cost of cultivation (₹ $ha^{-1}$) | Net income (₹ $ha^{-1}$) | Benefit – cost ratio* |
|---|---|---|---|
| $r_1t_1$ | 34983 | 19187 | 1.55 |
| $r_1t_2$ | 36483 | 15187 | 1.42 |
| $r_1t_3$ | 37983 | 37077 | 1.98 |
| $r_1t_4$ | 37983 | 37267 | 1.98 |
| $r_2t_1$ | 35883 | 32267 | 1.90 |
| $r_2t_2$ | 37383 | 37367 | 2.00 |
| $r_2t_3$ | 37383 | 38377 | 2.03 |
| $r_2t_4$ | 36633 | 38017 | 2.04 |
| $r_3t_1$ | 37533 | 35727 | 1.95 |
| $r_3t_2$ | 38283 | 29667 | 1.77 |
| $r_3t_3$ | 38283 | 39737 | 2.04 |
| $r_3t_4$ | 39783 | 24837 | 1.62 |

***** Benefit cost ratio calculated based on variable cost

The results of the study indicated the influence of N:K ratios and the time of application of nitrogen and potassium on growth attributes, yield attributes and yield, nutrient uptake, soil properties and economics of cultivation of sorghum.

# 5. DISCUSSION

The project entitled "Nutrient scheduling in rainfed sorghum (*Sorghum bicolor* L. Moench)" was carried out during summer season of 2021 at College of Agriculture, Vellayani, Thiruvananthapuram. The main objective of the study was to standardise the nutrient schedule for rainfed sorghum and to workout the economics. The results of the study are discussed in this chapter.

## 5.1 GROWTH AND GROWTH ATTRIBUTES

Application of N and K in 1:1.5 ratio ($r_3$) was found to improve the growth and growth attributes of sorghum with respect to various parameters such as plant height (Fig.3) and number of leaves per plant at different stages of observations (Fig. 4), LAI at 40 DAS (Fig. 5) and root characteristics such as rooting depth and root volume (Fig. 8).

Nitrogen has a major role in plant metabolic system and optimum rate of N improves growth attributes, photosynthetic rate and net assimilation rate. However efficiency of N applied is only 50-60 per cent in cereals other than rice, and there exist a positive relationship between N and K for the uptake and utilization of N by plants (Brar *et al*., 2011). As reported by Ahanger *et al*. (2015), K induced the enhancement of nitrate reductase and aminotransferases activities indicating its positive role in N metabolism of oats. In their study, K supplementation enhanced the activities of antioxidant enzymes (superoxide dismutase, catalase and ascorbate peroxidase) and contents of total phenols and tannins, probably strengthening both the enzymatic as well as non enzymatic antioxidant system. Recent reports by Xu *et al*. (2020) also indicated strong evidence for the direct or indirect impact of K level on N absorption and utilization and they have concluded that appropriate K supply not only increases $NO_3$ absorption in roots, but also promotes the transport from roots to shoots. Higher levels of K in $r_3$ would have promoted the N absorption, transport, metabolism and assimilation through increased enzymatic and non enzymatic activities which in turn would have promoted the plant growth and root development in a nutrient demanding crop like sorghum.

Another school of thought is the direct favourable effects of K nutrition on plant growth. The K is also essential for cell growth and as per the growth-promoting mechanism of K explained by Oosterhuis *et al.* (2014), it stimulates and controls ATPase in the plasma membrane to generate acid stimulation, which then triggers cell wall loosening and hydrolase activation, promoting cell growth. Besides this, K as a nutrient also has a very positive effect on root growth (Sustr *et al*., 2019). These coupled with better N utilisation under higher levels of K (Brar *et al*., 2011) would have resulted in improved growth attributes in $r_3$. Higher levels of K enhancing plant growth was reported by Almodares *et al*. (2008) and Barik *et al*. (2017) in sweet sorghum and Ye *et al*. (2019) in rice.

The $r_3$ ratio also narrowed the days required for the crop to reach 50 per cent flowering (Fig. 6). Eshghi and Tafazoli (2006) reported that low K impedes the transport of soluble carbohydrates from source to apical meristem, and low carbohydrate accumulation in the apical meristem inhibits or delays flowering. In addition, K plays an important role in the maintenance of the expansion of the cell and under low K, the plant also inhibits the output of sugar to maintain its morphological characteristics and cell turgor, and the formation of the reproductive organs is further influenced (Romheld and Kirkby, 2010). These may be the reasons for early flowering in ratio with higher quantity of K and longer days taken for 50 per cent flowering under low K levels.

The schedule of nutrient application wherein N and K were applied in 3 equal splits with 1/3 of each applied as basal, at 30 DAS and 60 DAS ($t_4$ ) improved the growth attributes such as plant height and number of leaves per plant at early growth stage, and were also found to increase the leaf area, rooting depth and root volume.

Application of N and K in 3 split doses leads to greater availability of K and lower transformation of K into non-exchangeable pool, which would have regulated the continuous growth of cells and tissues, enhanced the N uptake and protein synthesis, improved many physiological growth processes and delayed plant leaf senescence, hence would have increased the growth parameters of the crop. Mathukia *et al*. (2014) reported similar effect of split application of N and K in wheat. This treatment also had shortened the time required for 50 per cent flowering in the crop. Better availability of

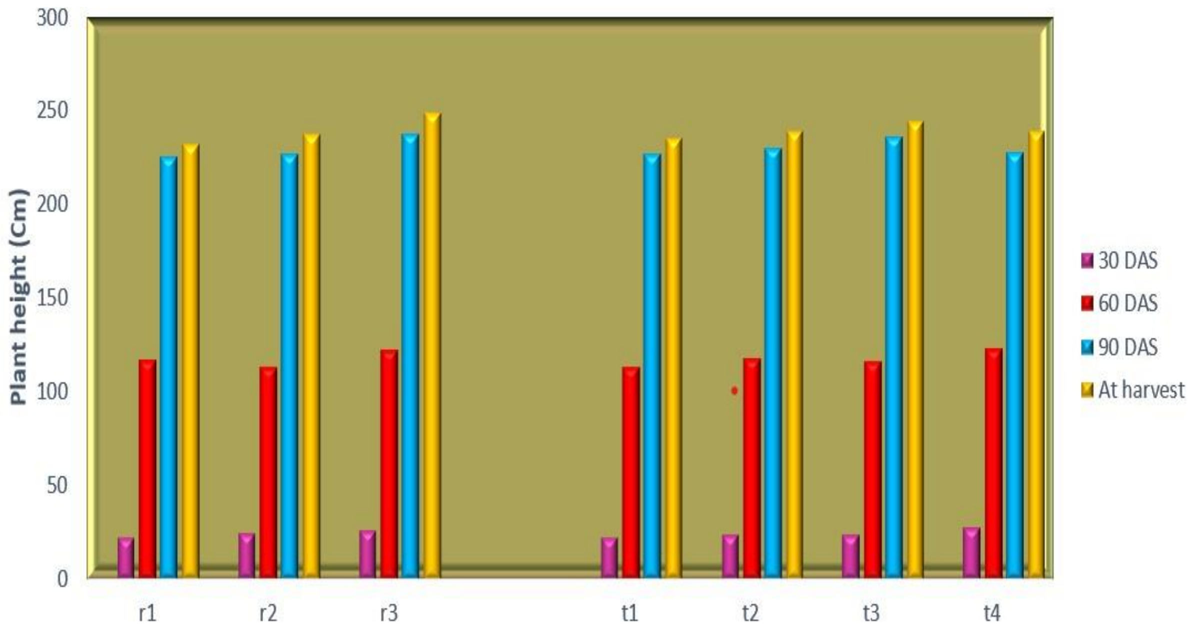


**Fig 3: Effect of N:K ratios, and time of application on plant height, cm.**

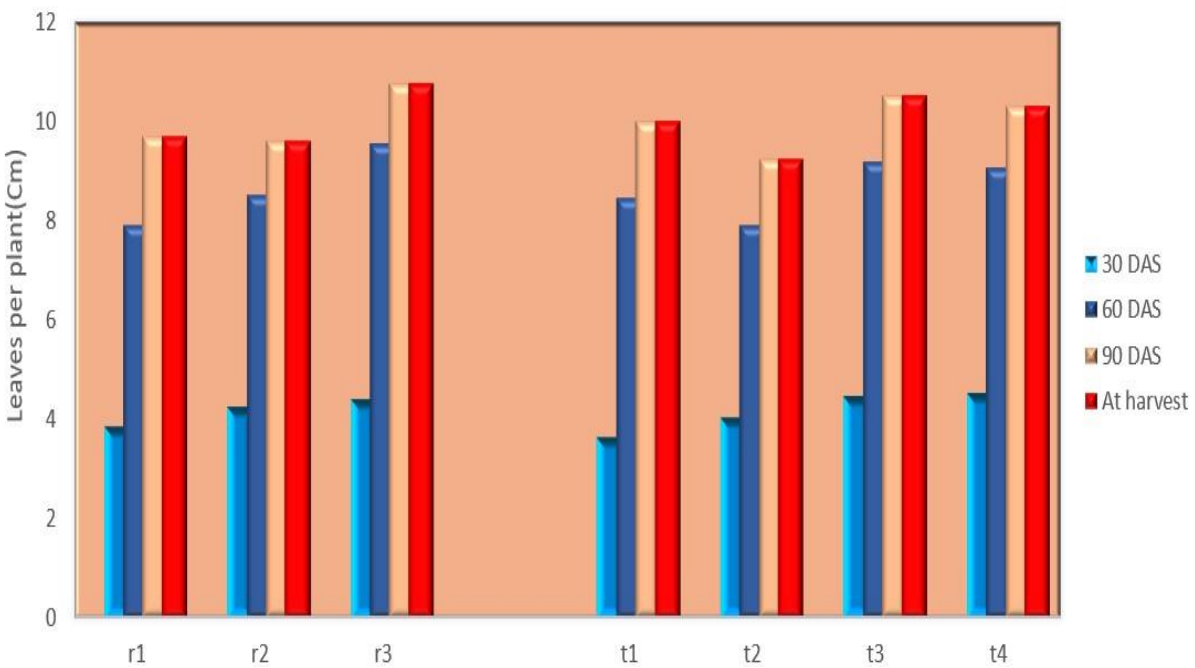


**Fig. 4: Effect of N:K ratios, and time application on leaves per plant**

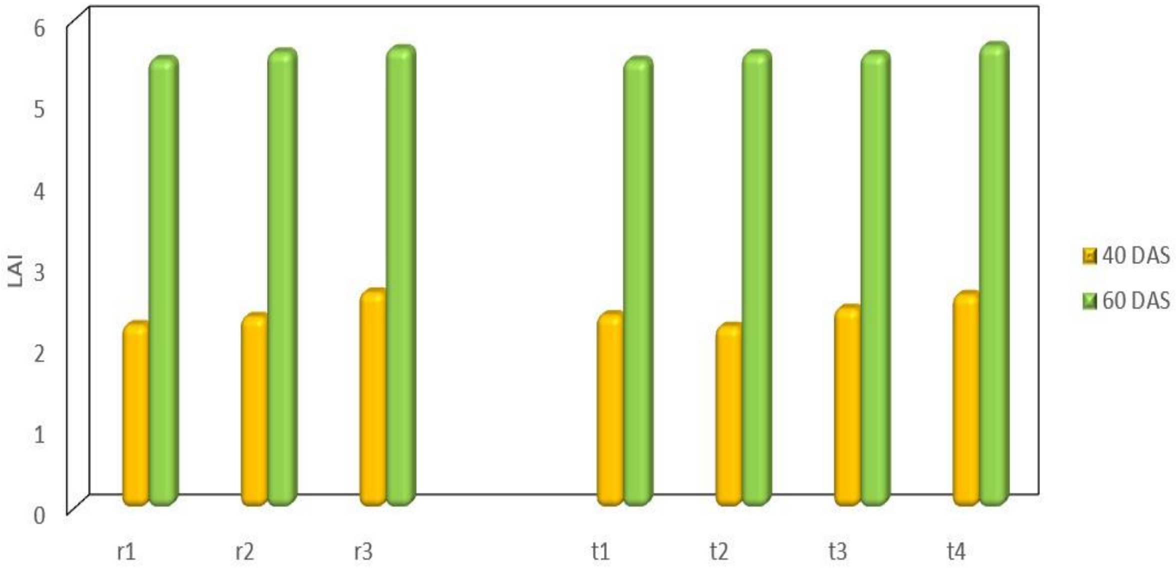


**Fig 5. Effect of N:K ratios and time of application on LAI**

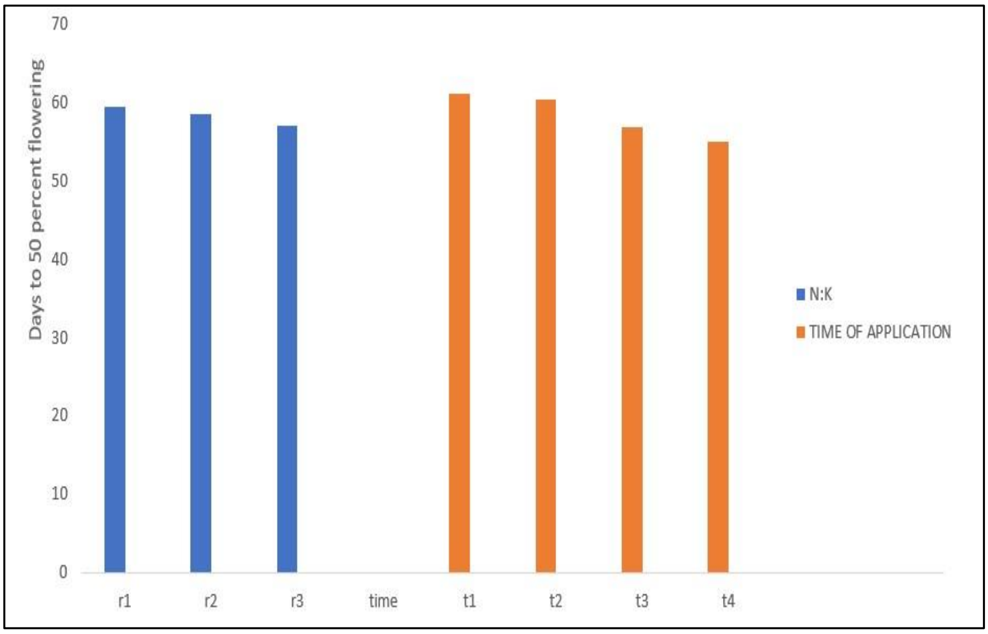


**Fig 6. Effect of N:K ratios, and time of application and on days to 50 per cent flowering**

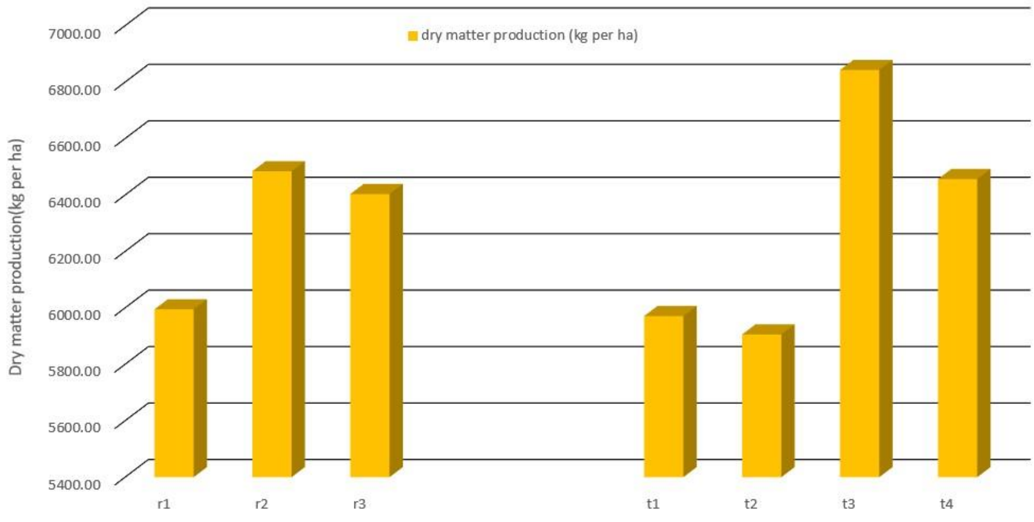


**Fig 7. Effect of N:K ratios, and time of application on dry matter production, kg ha$^{-1}$**

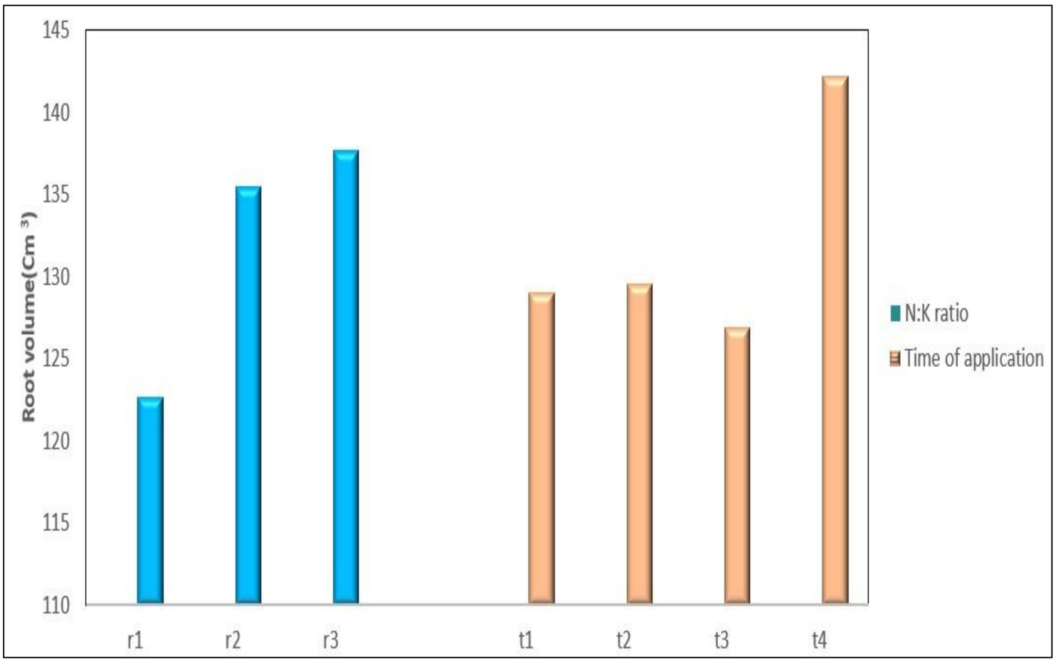


**Fig 8. Effect of N:K ratios, and time of application on root volume, cm$^3$**

K due to its reduced transformation into the non-exchangeable pool and leaching losses, consequent to the split application would have promoted the early flowering owing to the specific role of K in flowering as suggested by Eshghi and Tafazoli (2006). Similar results have been reported by Ye *et al*. (2019) in rice.

At later growth stages of crop, $t_3$ was found to promote the growth and growth attributes like plant height, number of leaves per plant and dry matter production. The treatment $t_3$ had only 2 split applications of N and K wherein the entire quantity was applied equally at basal and 30 DAS. In this schedule of application, the nutrient application was completed by 30 DAS and hence there was adequate time for assimilation of applied nutrients for its utilization during the active growth stage which would have reflected on its growth attributes at late growth stages, in contrast to $t_4$ wherein last split dose was applied at 60 DAS which would not have reflected on growth observations at later stage.

The interaction effect $r_3t_4$ was found to improve the plant height at first stage of observation while it promoted the leaf production at all stages of growth, produced higher LAI and promoted the root growth in terms of root volume and rooting depth. The crop also reached 50 per cent flowering earlier under $r_3t_4$ interaction. The manifestation of main effects of $r_3$ and $t_4$ could have promoted the growth and growth attributes of crop due to better N utilization on account of synergistic effect of K on N and also by virtue of higher availability of K.

## 5.2 YIELD ATTRIBUTES AND YIELD

Application of N and K in 1:1.5 ratio ($r_3$) was found to improve the yield attributes of sorghum and it increased the length of panicle (Fig. 9). The grain weight per panicle and grain yield (Fig. 10) were increased by applying equal or higher quantity of K in comparison with N in $r_2$ (1:1 N and K ratio) and $r_3$ (1:1.5 N and K ratio). These two treatments also resulted in the highest harvest index.

Potassium is important for ensuring optimal plant growth and is an activator of dozens of important enzymes having role in protein synthesis, sugar transport, N and C metabolism and photosynthesis and it plays a major role in the formation of crop yield (Marschner, 2012). Yield improvement in terms of grain weight per panicle, grain yield and harvest index could be therefore due to the favourable influence of K on plant metabolic functions.

Though a heritable trait, the panicle length was found to have increased under K nutrition. As pointed out by Zhou *et al*. (2017), optimized nutrient management can bring about physiological changes together with changes in organ formation and panicle structure, leading to changes in morphological mechanism of panicle development. Hence increase in the length of panicle could be attributed to the role of K in increasing photosynthesis as result of an increasingly effective photosynthetic action, expanding leaf size and number and progressively compelling translocation of photo-assimilates and amino N compounds into conceptive organs by the phloem (Cakmak, 2005). The K nutrition improving the panicle length was previously reported by Wulgo *et al*. (2019) in grain sorghum.

The treatments having split application of K was found to promote the yield attributes and yield. The length of panicle was increased when N and K were applied in 2 equal splits with ½ of each at basal and at 30 DAS in $t_3$. The two and three split applications of N and K in $t_3$ and $t_4$ respectively increased the grain yield in comparison with treatment with full basal application of K (Fig. 10).

Application higher dose of nutrients especially N and K as basal dose increase the chance of loss of these nutrients through leaching. According to Wani *et al*. (2014), higher response in split application of K may be attributed to higher buffering capacity of soil coupled with lower fixation of K. Hence split application of K along with split doses of N would have extended the availability of these nutrients to the later stage of crop growth which in turn could have favourably influenced the yield attributes and yield. Hegde and Gowda (1986) and Chavan *et al*. (2018) reported the beneficial influence of split application of N on yield of finger millet. Beneficial effect of split application of K on yield attributes and yield was reported by Lavanya (2009) in finger millet, Saleem *et al*. (2011) in sorghum, Akhter *et al*. (2017) in wheat and Singh *et al*. (2021) in maize. Improvement in the length of panicle could be considered as an expression of K nutrition modifying the morphological mechanism of panicle development as explained by Zhou *et al*. (2017).

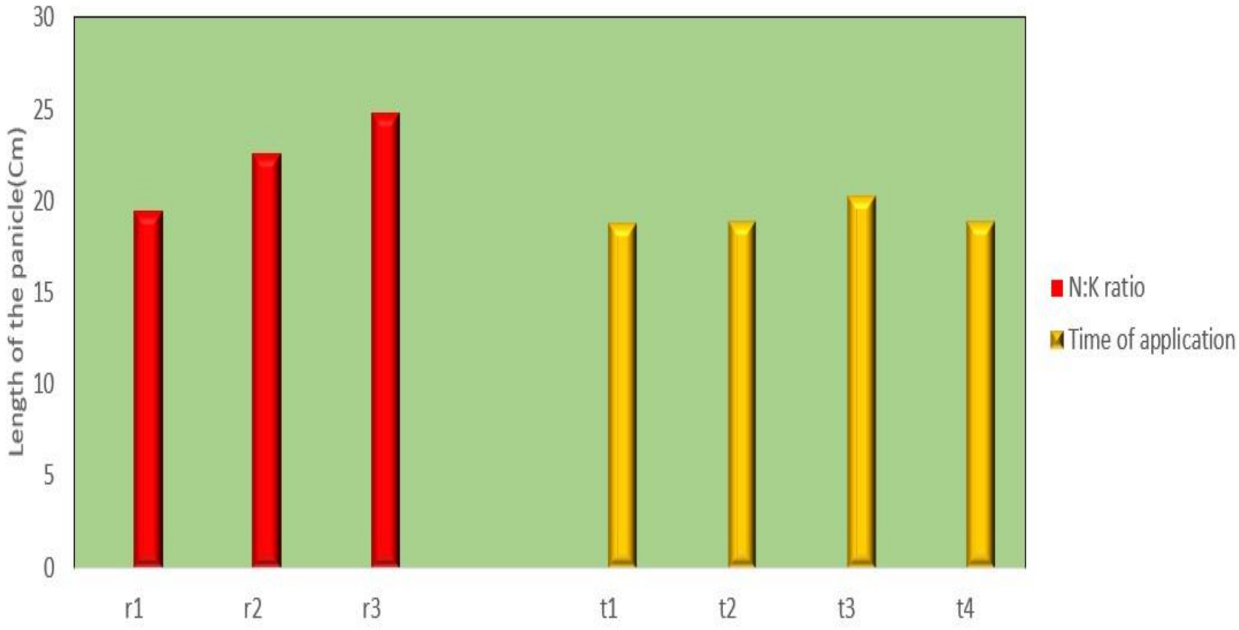


**Fig 9. Effect of N:K ratios and time of application on length of panicle, cm**

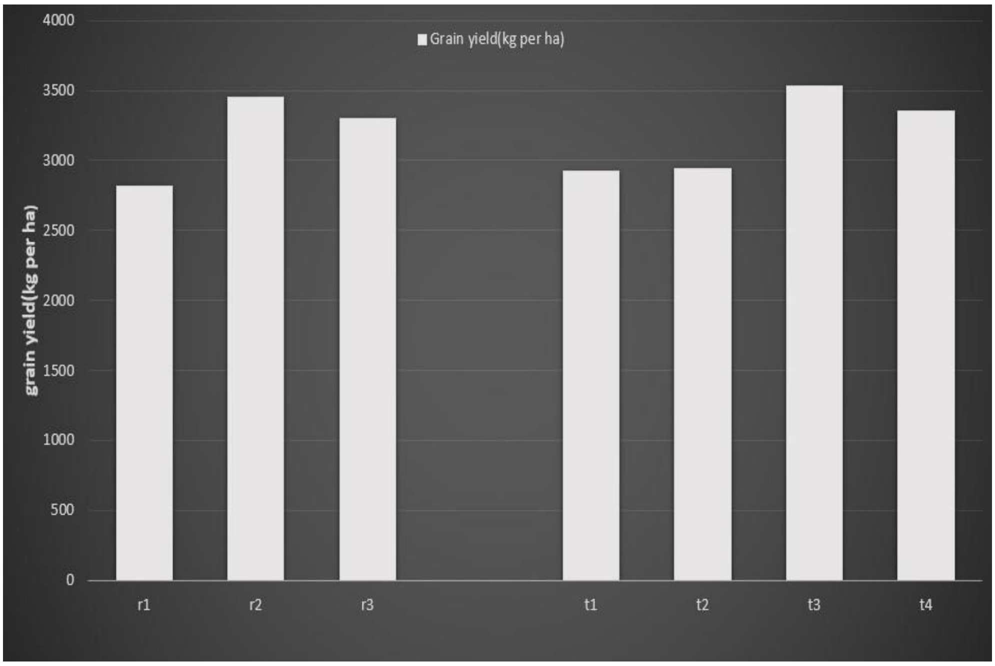


**Fig 10. Effect of N:K ratios and time of application on grain yield, kg $ha^{-1}$**

The $r_2t_3$ or $r_3t_3$ interactions wherein N and K were applied in 1:1 or 1.5:1 ratio in two split doses at basal and 30 DAS, favoured the yield attributes and yield, and increased the length of panicle and grain yield. The interaction effect also showed the same trend of the main effects which suggested the positive influence of the treatments on K availability, utilization and its manifestation on yield attributes and yield.

## 5.3 NUTRIENT CONTENT AND UPTAKE

Application of N and K in 1:1.5 ratio ($r_3$) or in equal proportion (1:1-$r_2$) enhanced the chlorophyll content (Fig. 11) and increased the uptake of nutrients in sorghum (Fig. 12, 13 and 14).

The increased chlorophyll content in $r_3$ or $r_2$ could be considered as a direct effect of K on photochemical activities in the plant. Zhao *et al*. (2001) opined that potassium deficiency is closely related to decreased chlorophyll content. The chlorophyll a and b in leaf tissue is formed by the action of chlorophyll oxygenase enzyme and CAO1 is the only gene in the chloroplast that regulates the relative content of chlorophyll a and b (Biswal *et al*., 2012). Being a co factor of several enzymes K affects the expression level of CAO1 gene by participating in multiple enzymatic reactions throughout the photosynthetic pigment synthesis process as pointed out by Hu *et al*. (2021). Higher quantity of K in $r_3$ and $r_2$ ratios (compared to $r_1$) would have promoted the chlorophyll content through its modification in the expression of genes regulating the synthesis of chlorophyll. Higher N and K levels increasing the chlorophyll content was previously reported by Gopalakrishnan (2005) in upland rice.

Application of N:K ratios 2:1 and 1:1 increased the uptake of all three nutrients *viz*., N, P and K which could be considered as a direct effect of K on nutrient uptake mechanism. There exists a close relationship between K+ and root-induced $NO_3^-$ uptake (Dong *et al*, 2004) and a moderate K supply will promote the influx of nitrate ions into roots which in turn would have reflected on N uptake favourably (Fig. 12). Application of K increasing the N uptake in sorghum was previously reported by Sharma and Ramna (1993).

The higher uptake of P (Fig. 13) could be considered as an indirect effect of K promoting the root growth. The data on rooting depth and root volume in $r_2$ and $r_3$

(Table 8) indicated that K nutrition promoted the root growth. In an early study, Newman and Andrews (1973) suggested that the P uptake had a good correlation with root growth irrespective of root density or plant age. Hence the higher root growth consequent to K application would have enhanced the P uptake.

Higher K uptake was observed in $r_2$ (N:K ratio 1:1) and $r_3$ (N:K ratio 1:1.5) as illustrated by Fig. 14 and the value was 4-5 times higher than that of N and P uptakes. The uptake pattern of the K in plants as explained by Ragel *et al*. (2019) emphasise that once $K^+$ is inside the root symplast (inner side of plasma membrane), it may be stored in vacuoles locally, or transported to the shoot via xylem and accumulated in aerial tissues. Plants accumulate large amounts of $K^+$ in their vacuoles, surpassing purely nutritional requirements. As vacuoles occupy most of the intracellular volume of plant cells and are the main cellular reservoir for $K^+$, changes in tissue $K^+$ concentration are largely a reflection of the dynamics of the vacuolar pool. In K - sufficient plants, K content can reach up to 10 per cent of plant dry weight (White and Karley, 2010). In the present experiment higher K concentration was recorded in plant (mean value 3.50 per cent) and grain (mean value 2.70 per cent). Kumar *et al*. (2018) reported, maximum K content of 2.89 per cent in stover and 3.30 per cent in grain of different sorghum cultivars. The soil had a higher available K status prior to the experimentation (298 kg $ha^{-1}$) which could have been attributed for the higher K uptake and accumulation noticed in plant, irrespective of treatments. More K was added to the soil with N:K ratios $r_2$ and $r_3$, contributing to the initially higher soil exchangeable pool of K, thereby enhancing the K uptake. Higher rates of K application producing higher K content and uptake in sorghum was previously reported by Ogunlela and Yusuf (1988).

The two and three split application of N and K (2 splits in $t_3$ and 3 splits in $t_4$) improved the chlorophyll content at early and late growth stages of crop compared to the treatments without split application of K. The N, P and K uptakes were also higher with the above treatments ($t_3$ and $t_4$). Split applications of N and K would have reduced the leaching losses nutrients ensuring their availability during the active growth stages. More K in the available pool could have contributed to the increased K uptake which in turn would have favourably influenced the chlorophyll content and uptake of N and P, through regulation of chlorophyll synthesis and promotion of root growth. Split

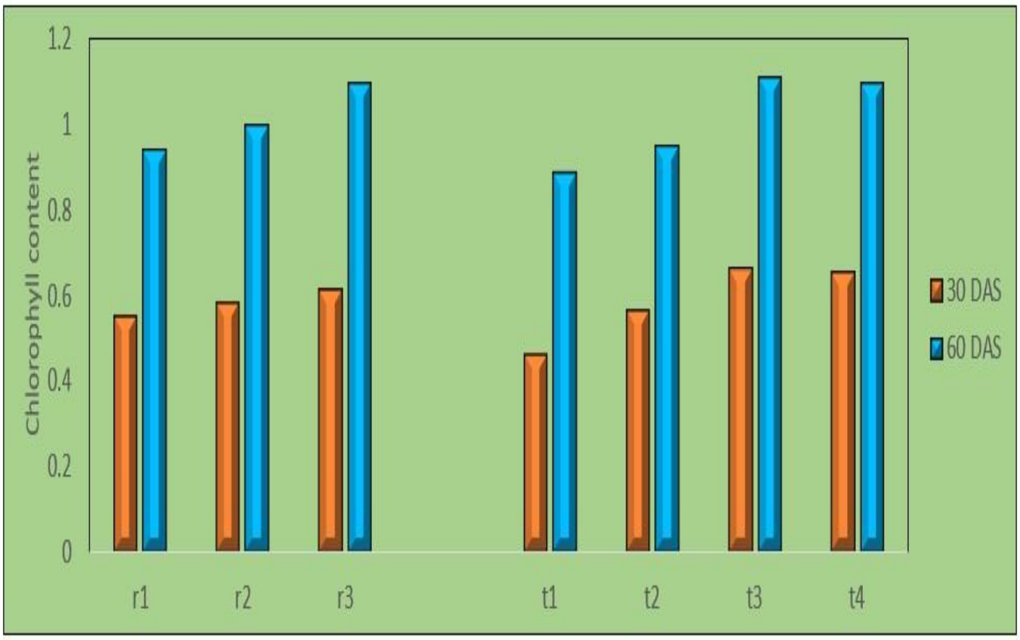


**Fig 11. Effect of N:K ratios and time of application on chlorophyll content, mg $g^{-1}$**

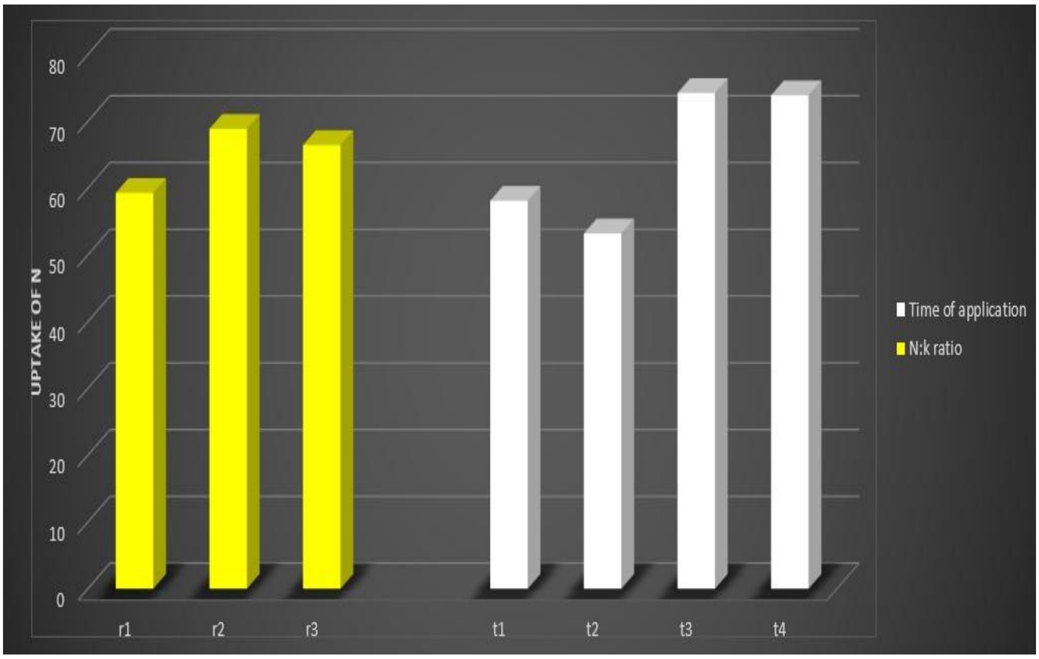


**Fig 12. Effect of N:K ratios and time of application on uptake of N, kg $ha^{-1}$**

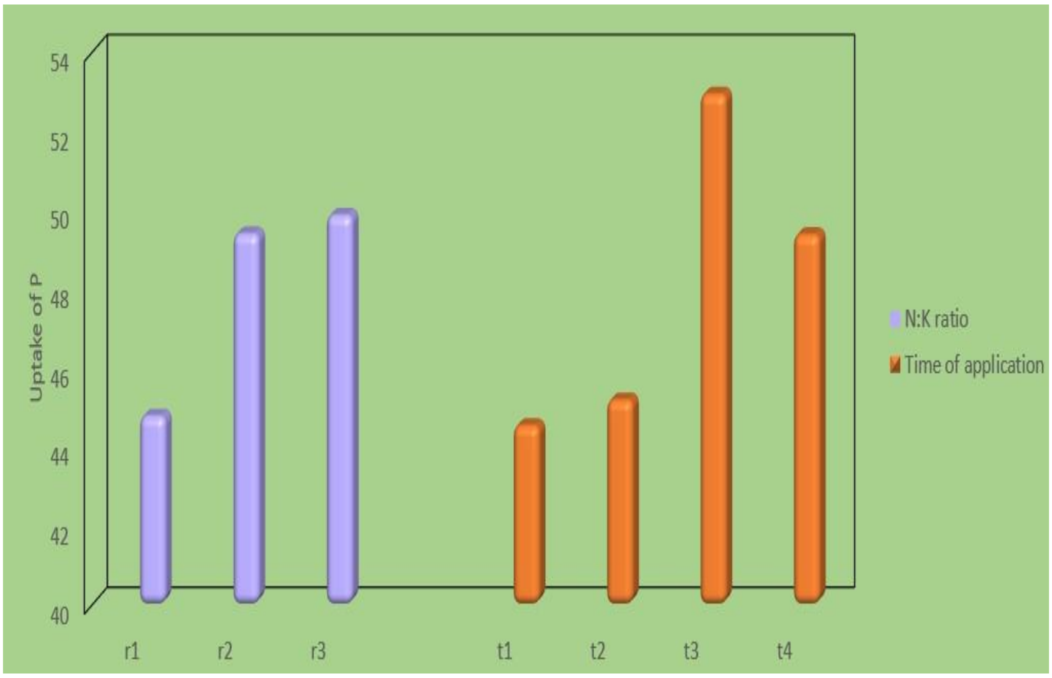


**Fig 13. Effect of N:K ratios, and time of application on uptake of P, kg ha$^{-1}$**

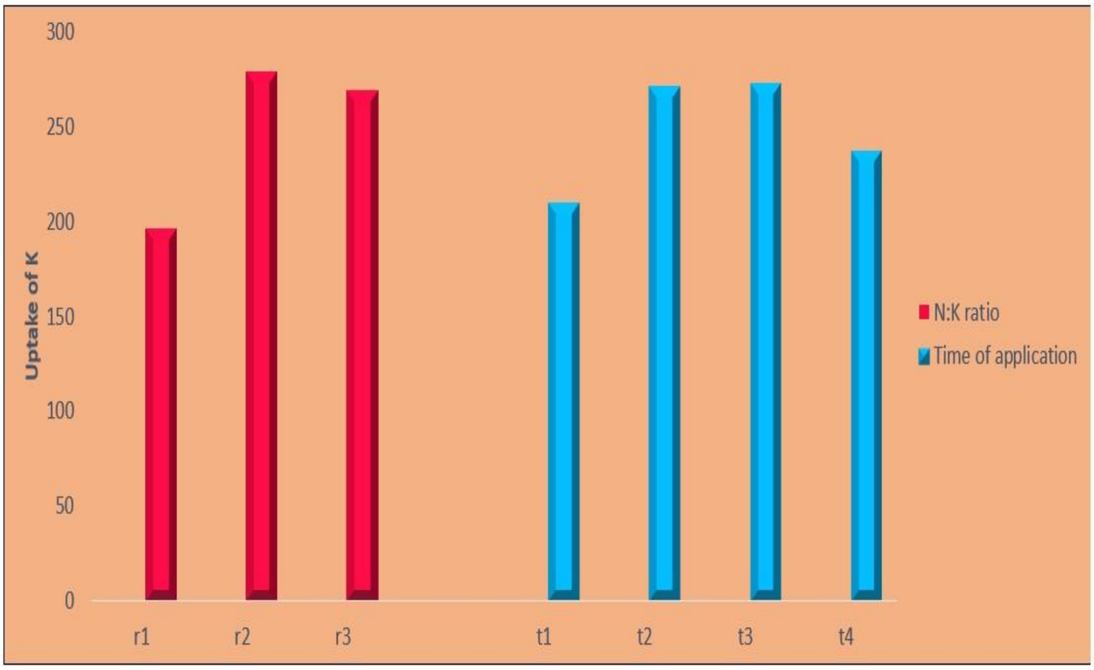


**Fig 14. Effect of N:K ratios, and time of application on uptake of K, kg ha$^{-1}$**

application of K increasing the K uptake was recently reported by Sharma and Singh (2020) in wheat and Singh *et al*. (2021) in maize.

The interaction effects $r_2t_4$ or $r_3t_3$ enhanced the chlorophyll content while $r_3t_3$ also increased the N and P uptake by the crop. The trends observed in the main effects were also manifested in their treatment combinations with respect to chlorophyll content and uptake of nutrients.

5.4 SOIL PROPERTIES

Application of N and K in equal proportion (1:1-$r_2$) or in 1:1.5 ratio ($r_3$) enhanced the soil pH (Fig. 15) and organic carbon content (Fig. 16) after the experiment compared to 1:0.5 N and K ratio ($r_1$). These treatments also improved the available N and P contents of soil.

The $K^+$ is a basic cation and its application in higher levels could have been added to the base saturation of soil. Base saturation of soil is closely related to the pH of soil as pH increases with increase in base saturation (Havlin, 2005) and hence the higher levels of K in $r_2$ and $r_3$ would have resulted in a moderation in the acidity.

Higher levels of K promoted the root development of sorghum (Table 8) and the root hairs of the sorghum exudates sorgoleone (Czarnota *et al*., 2003), an organic substance (secondary benzoquinone) to the rhizosphere (Wang *et al*., 2021), which might have improved the organic carbon status of the soil as indicated by Fig. 16.

Application of K in higher quantity in $r_2$ and $r_3$ enhanced the available N (Fig. 17) and P status (Fig. 18) of soil after the experimentation. There was a moderation in soil pH with higher rates of K application in the current study. Nitrification involves the microbial conversion of ammonium to nitrate and it generally increases with increasing soil pH in acidic soils. The available P status of soil also increases due to its reduced fixation with moderation of soil acidity (Tisdale *et al*., 1995) The moderation in pH consequent to the application of higher rate of application of K (Havlin, 2005) can be considered as the possible reason for improved availability of N and P in soil after the experiment. Similar results are reported by Gopalakrishnan (2005) in rice and Sundaresh (2016) in finger millet.

Application of N and K were in 2 equal splits with ½ of each at basal and at 30 DAS in $t_3$ increased the soil pH and organic carbon content of soil after the experiment. The split application of N and K would have reduced the leaching losses, there by contributing more K to the soil base saturation (Havlin, 2005) and this could have enhanced the soil pH. The improvement in the soil organic carbon status of soil after the experiment due to split application of N and K could be considered as an indirect effect of better root growth and release of root exudates of organic nature to the rhizosphere suggested by Wang *et al*. (2021).

The split application of N and K (2 splits in $t_3$ and 3 splits in $t_4$) improved the available N and P status of soil after the experiment as depicted in Fig. 17 and 18. Application of K in split doses would have increased the K use efficiency by supplying the plant available K to the exchangeable pool in the soil. Ability of $K^+$ to mobilise the $NO_3^-$ in soil has been previously reported by Dong *et al.* (2004) which would have improved the available N content in soil. This coupled with general synergetic interaction of N and P with K (Rietra *et al*., 2017) would have improved the available content of these nutrients in soil compared to the other treatments.

The $r_3t_3$ or $r_2t_3$ interactions wherein N and K were applied in1.5:1 or 1:1 ratio in two split doses at basal and 30 DAS, promoted the organic carbon content of soil which is a manifestation of their main effects. Higher quantity of K available to the plant through its split application has enhanced the root development which in turn would have improved the organic carbon content of soil, through root exudation of sorgoleone reported by Wang *et al*. (2021). Available N and P status of soil after the experiment was also increased under the above treatment combinations which could be considered as a manifestation of their main effects.

Though the treatment effects were not significant, the available K status of the soil after the experiment was medium in general, in spite of higher K uptake. Uptake of K+ is a driving process for accessing both the exchangeable pool and even a significant part of the nonexchangeable pool in the soil (White *et al*., 2013). Depletion of K in the rhizosphere consequent to the K uptake can release K from the nonexchangeable, interlayer pool in clay minerals to the soil solution as demonstrated

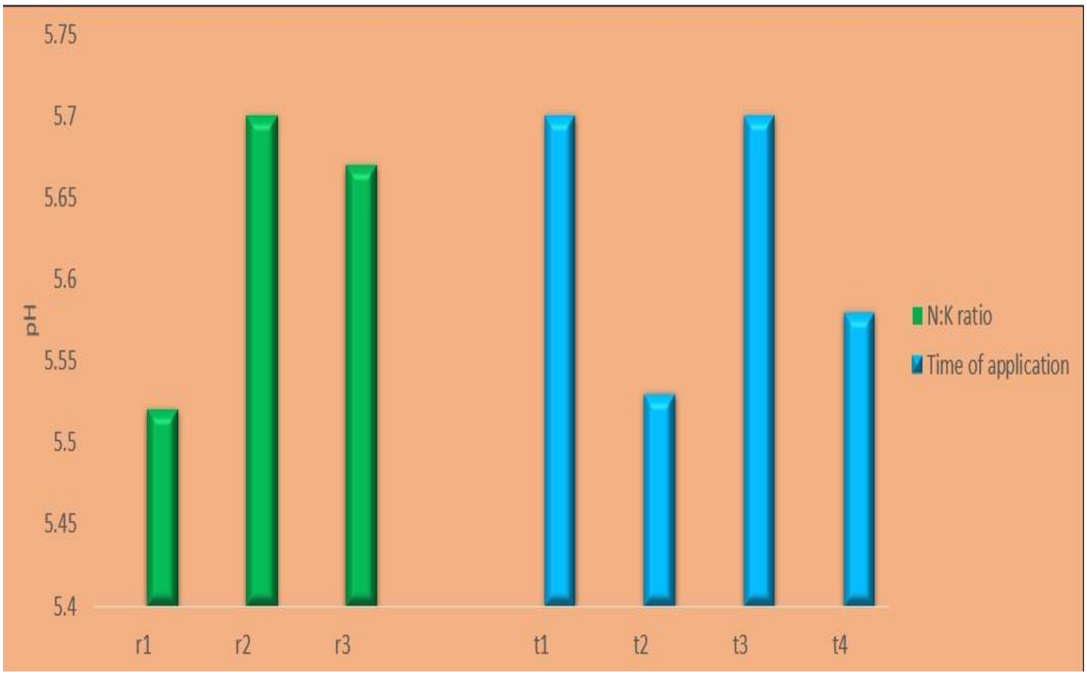


**Fig 15. Effect of N:K ratios and time of application on soil pH after the experiment**

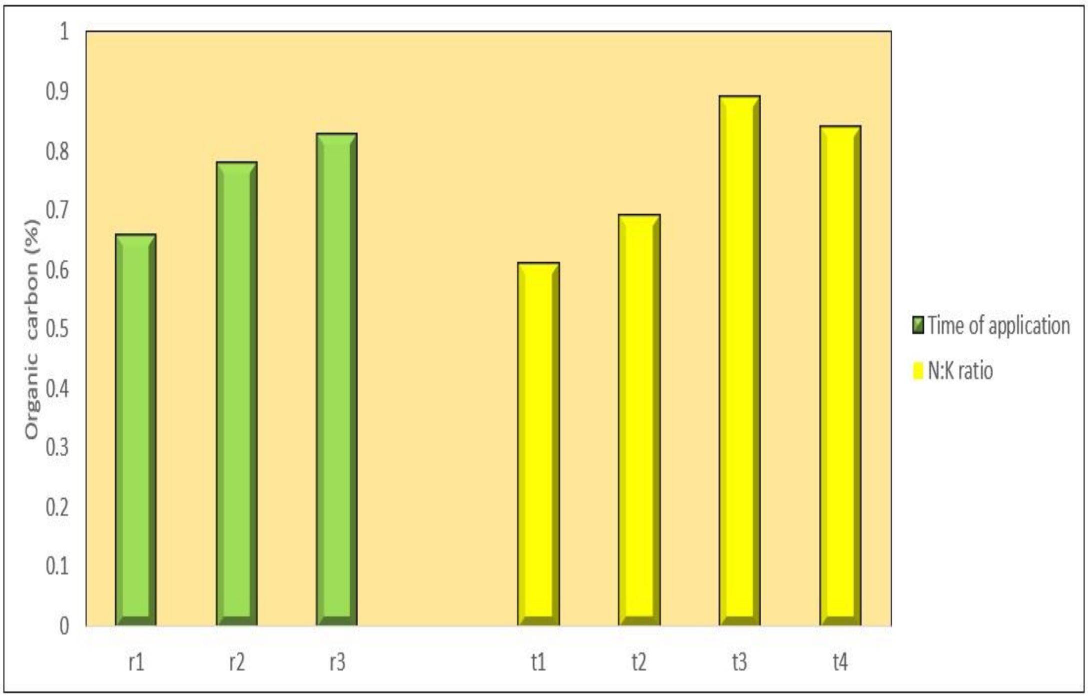


**Fig 16. Effect of N:K ratios, and time of application on soil organic carbon content after the experiment, per cent**

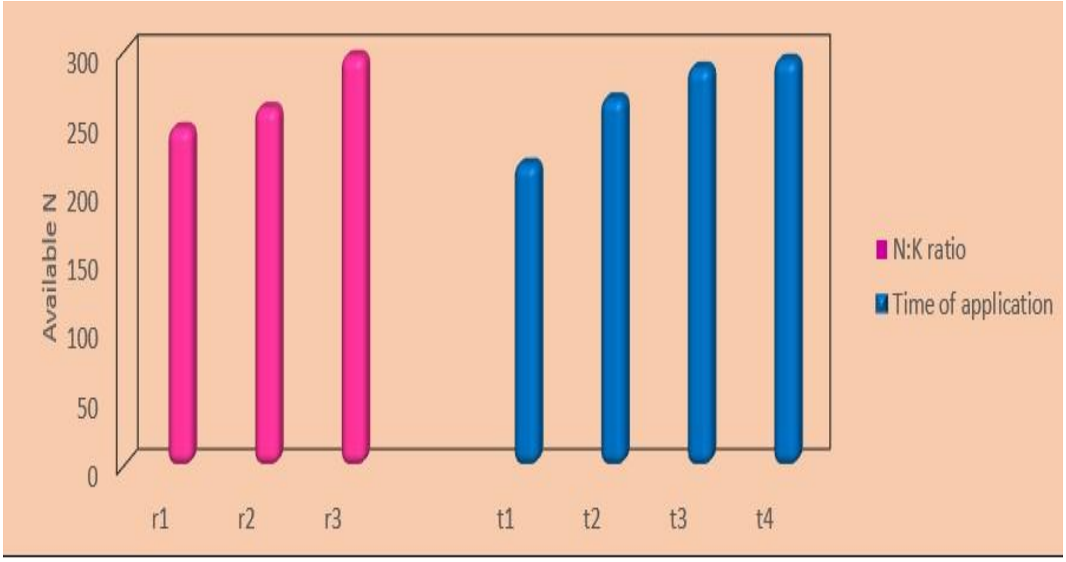


**Fig 17. Effect of N:K ratios and time of application on available N status of soil after the experiment, kg ha$^{-1}$**

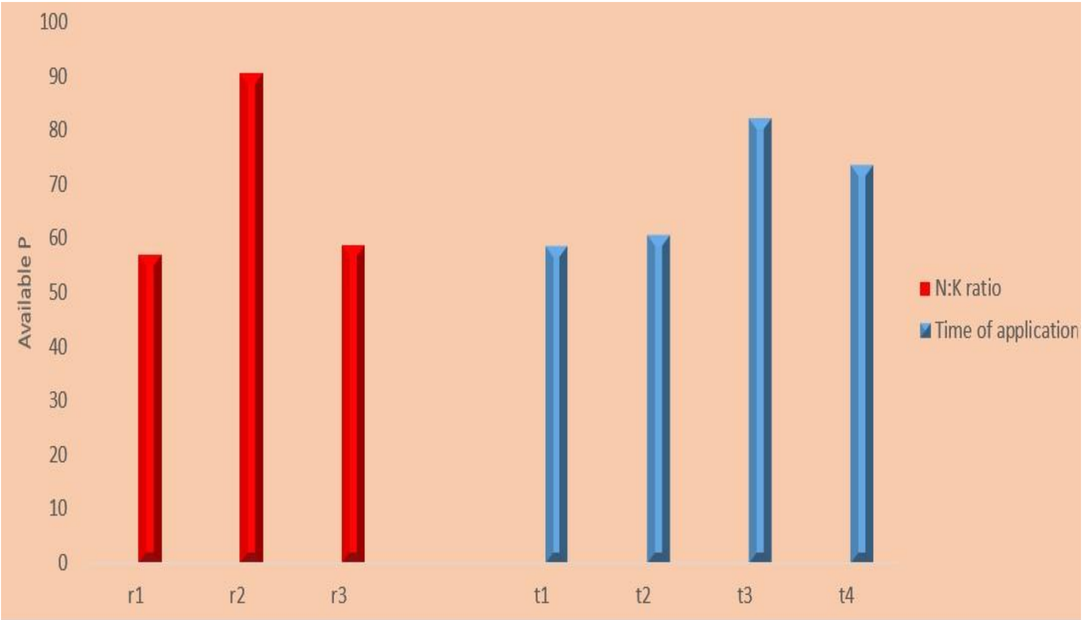


**Fig 18. Effect of N:K ratios, and time of application on available P status of soil after the experiment, kg ha$^{-1}$**

by Samal *et al*. (2010) in maize and wheat and this can be cited as the probable reason for moderate availability of soil K after the experiment.

5.5 ECONOMIC ANALYSIS

The highest net income (Fig. 19), and benefit-cost ratio (Fig. 20) were recorded by $r_3t_3$ wherein N and K in 1:1.5 ratio were applied in two split doses at basal and 30 DAS. The $r_2t_4$ with N and K application in 1:1 ratio with 3 splits also had higher benefit-cost ratio compared to treatments with application of entire quantity of low rate of K basal dose.

Higher grain yield and harvest index were recorded in the treatment with higher rate of application and split application of nutrients (Table 10) which led to the highest net income and benefit cost ratio. This is supported by the findings of Kaur and Satpal (2019).

Singh *et al.* (2021) opined that the substantial increase in the retail price of K fertilizers, consequent to the implementation of nutrient-based subsidy since 2010, necessitates judicious use of K fertilizers and calls for enhancement in its use efficiency which seldom exceeds 60 per cent K use efficiency. Though split application of N has been given more importance due to low N use efficiency of most soils, the present study emphases the need for optimum quantity of K in split doses to achieve higher K use efficiency and higher crop productivity.

The knowledge of K supplementation dynamics from soil non-exchangeable K pools to the exchangeable and solution phases is limited. This coupled with overreliance on native K supply to meet crop demand are the major reasons for deficit of K supply to crops. One-time application of K at the time of planting is often not suitable to supply adequate K to the crop during its peak demand phases. Conclusive research on rate and timing of K fertilizer application is therefore highly essential to arrive at optimum dosage and most appropriate nutrient scheduling in a nutrient demanding crop like sorghum.

Discussion of the results of this investigation indicated that the growth, growth attributes and yield of sorghum were significantly higher when N and K were applied in 1:1.5 ratio. Application of N and K in three equal splits with 1/3 of each applied as basal, 30 DAS and 60 DAS improved the growth and growth attributes of sorghum especially at early growth stages. Yield attributes and yield were significantly higher when N and K were applied in two equal split doses as ½ of each at basal and at 30 DAS. For getting higher grain yield, net income and BCR, application of N and K in the ratio 1:1.5, as two equal split doses, from two equal split dose of each at basal and at 30 DAS was found to be the most effective nutrient schedule.

The study suggested that the present POP recommendation of KAU for rainfed sorghum (45:25:25 kg NPK $ha^{-1}$) with full basal application of P and K and two split applications of N (half as basal and remaining half at 30 DAS) could be modified as 50:25:75 kg NPK $ha^{-1}$ with N and K in two equal split doses, half of each at basal and at 30 DAS and entire P as basal dose.

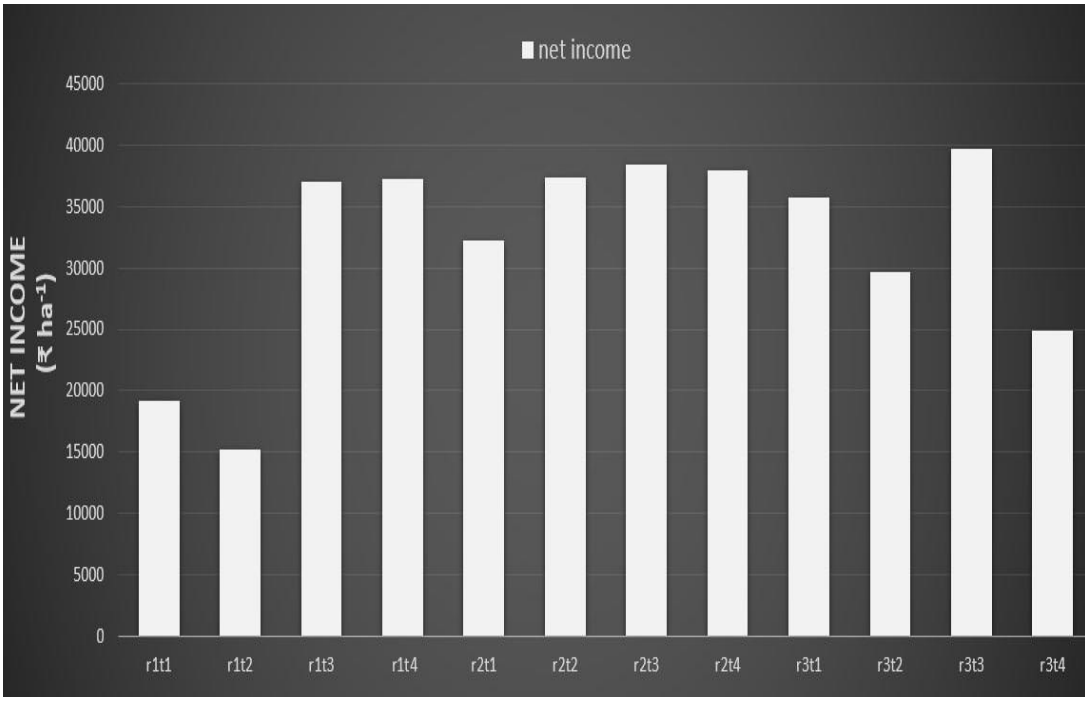


**Fig. 19: Effect of N:K ratios, and time of application on net income, ₹ ha$^{-1}$**

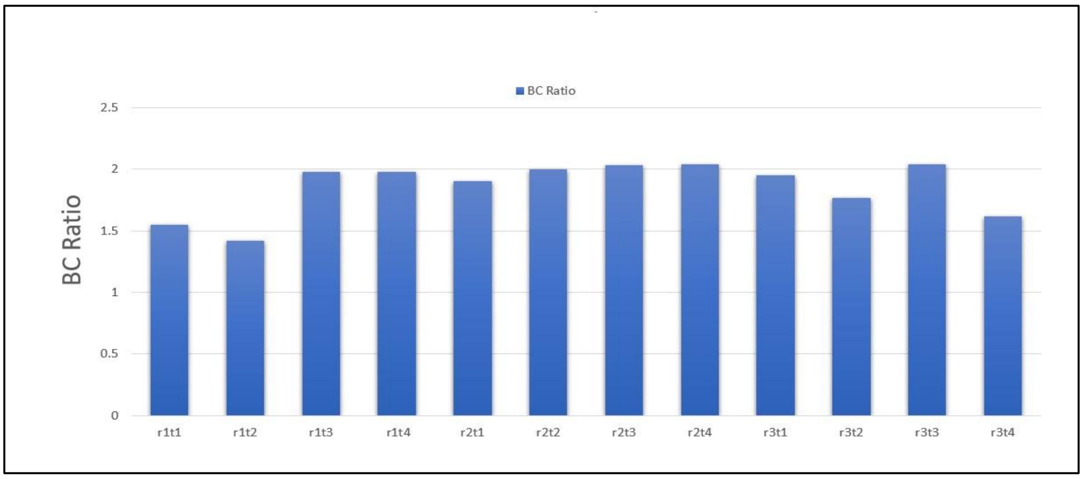


**Fig. 20: Effect of N:K ratios, and time of application on benefit-cost ratio**

# 6. SUMMARY

The study entitled "Nutrient scheduling in rainfed sorghum (*Sorghum bicolor* L. Moench)" was carried out during 2019-21 at College of Agriculture, Vellayani, Thiruvananthapuram to standardise the nutrient schedule for rainfed sorghum and to work out the economics.

The experiment was laid out in factorial randomised block design with 12 treatment combinations and three replications during summer 2021. The treatments comprised combinations of three N:K ratios ($r_1$ -1:0.5, $r_2$ -1:1 and $r_3$ -1:1.5) and four times of applications ($t_1$- ½ N as basal + ½ N at 30 DAS + full K as basal, $t_2$- $^1/3$ N as basal + $^1/3$ N at 30 DAS+ $^1/3$ N at 60 DAS + full K as basal, $t_3$- ½ N and ½ K as basal + ½ N and ½ K at 30 DAS, $t_4$- $^1/3$ N and $^1/3$ K as basal + $^1/3$ N and $^1/3$ K at 30 DAS + $^1/3$ N and $^1/3$ K at 60 DAS). The sorghum variety used for the study was Co-30. Farm yard manure at the rate of 5 t $ha^{-1}$ was applied uniformly at the time of land preparation. Nitrogen was applied at the rate of 50 kg $ha^{-1}$, uniformly to all the treatments as per the schedule of application. Potassium was applied in different treatment ratios as per the schedule of application of treatments. The entire quantity of phosphorus (25 kg $ha^{-1}$) was applied as basal dose on soil test basis. The salient findings of this study are summarized below.

The results indicated that the N:K ratios and the time of application of nutrients had significant influence on the growth and growth attributes of sorghum *viz*., plant height, number of leaves per plant, leaf area index (LAI), days to 50 per cent flowering and dry matter production.

Significantly taller plants were produced with N:K ratio $r_3$ (1:1.5) at 60 DAS (122.33cm), 90 DAS (237.99 cm) and at harvest (248.27cm). Plant height was significantly higher at 30 and 60 DAS (27.71 and 122.97 cm respectively) with $t_4$ (application of N and K in 3 equal splits with 1/3 of each applied as basal, at 30 DAS and 60 DAS) while $t_3$ (N and K applied in 2 equal splits with ½ of each at basal and at 30 DAS) produced significantly taller plants at 90 DAS and at harvest (236.38 and 244.47 cm respectively). The treatment combination $r_3t_4$ produced significantly higher plant height at 30 DAS (33.9 cm), while $r_1t_4$, resulted in higher plant height at 60 DAS

(129.77 cm). At 90 DAS and at harvest $r_3t_1$ produced the highest plant height (247.07 and 258.67 cm respectively).

The N:K ratio $r_3$ (1:1.5) resulted in significantly higher number of leaves per plant at 60 DAS (9.54), 90 DAS (10.75) and at harvest (10.75). Higher number of leaves per plant were recorded in $t_4$ at 30 DAS (4.50) followed by $t_3$. The $t_3$ recorded higher number of leaves per plant at 60 DAS (9.17), 90 DAS (10.50) and at harvest (10.50) followed by $t_4$. The treatment combination $r_3t_4$ recorded significantly higher number of leaves than other treatment combinations at 60 DAS (11.00) and 90 DAS (12.50). At harvest stage, the number of leaves produced was the same as that recorded at 90 DAS.

Leaf area index was significantly higher with $r_3$ (1:1.5) at 40 DAS (2.65) and was followed by $r_2$ (2.35) and $r_1$ (2.25) which were on par. The $t_4$ produced significantly greater LAI at 40 DAS (2.62). The LAI was significantly higher with $r_3t_4$ treatment combination (5.90) compared to $r_2t_1$, $r_2t_3$, $r_1t_1$, $r_3t_2$ and $r_1t_4$.

The crop took least number of days (57) to reach 50 per cent flowering in $r_3$ (1:1.5 N and K ratio). The $t_4$ resulted in lowest number of days for 50 per cent flowering (54.89) and was followed by $t_3$ (56.89). Significantly lower time was required for the crop to reach 50 per cent flowering in $r_3t_4$ (50.67 days).

Dry matter production at harvest was the highest (6843.00 kg $ha^{-1}$) in $t_3$ (N and K applied in 2 equal splits with ½ of each at basal and at 30 DAS) and was on par with $t_4$ (6456.33 kg $ha^{-1}$). Rooting depth was significantly higher (26.64 cm) in N:K ratio $r_3$ (1:1.5). The $t_4$ registered greater rooting depth (25.58 cm) and was on par with $t_2$ (24.65 cm). The interaction, $r_3t_2$ recorded the significantly higher rooting depth (31.18 cm). Root volume at harvest was the highest with $r_3$ (137.63 $cm^3$) which was on par with $r_2$ (135.47 $cm^3$). The schedule of application $t_4$ resulted in significantly higher root volume (142.21 $cm^3$). The treatment combination $r_3t_4$ recorded the highest root volume (155.41 $cm^3$) and was on par with $r_2t_4$ (147.26 $cm^3$).

The yield attributes and yield of the crop were significantly affected by ratios of N and K and the schedule of nutrient application. Length of panicle was significantly higher (24.80 cm) in $r_3$ (1:1.5 N and K ratio) and the schedule of application $t_3$ produced significantly longer panicles (20.22 cm). The treatment combination $r_2t_3$ resulted in significantly more length of panicle (20.92 cm). The grain weight per panicle was significantly higher (46.47 g) in $r_2$ (1:1 N and K ratio). Grain yield was significantly higher (3449.33 kg $ha^{-1}$) with $r_2$ (1:1) and was comparable with $r_3$ (3298.67 kg $ha^{-1}$). The highest grain yield (3532.22 kg $ha^{-1}$) was produced by $t_3$ (½ N and ½ K as basal + ½ N and ½ K at 30 DAS) followed by $t_4$ (3350.11 kg $ha^{-1}$) which were on par. The $r_3t_3$ treatment produced the highest grain yield (3635.67 kg $ha^{-1}$) and was comparable with all other treatments except $r_1t_1$ (2205.33 kg $ha^{-1}$) and $r_1t_2$ (2052.67 kg $ha^{-1}$). Harvest index was significantly superior in $r_2$ (N and K in 1:1) and $r_3$ (N and K in 1: 1.5) both producing a value of 0.45 compared to $r_1$ (0.39).

The N:K ratios, time of application of nutrients and their interactions could influence the chlorophyll content of plant. Chlorophyll content was significantly higher in $r_3$ at 30 DAS (0.61mg $g^{-1}$) and 60 DAS (1.10 mg $g^{-1}$). Chlorophyll content was also found to be significantly more in $t_3$ at 30 DAS (0.66 mg $g^{-1}$) and 60 DAS (1.11 mg $g^{-1}$) and was comparable with $t_4$ (0.65 and 1.10 mg $g^{-1}$ at 30 and 60 DAS respectively). Treatment combination $r_2t_4$ produced higher chlorophyll content (0.72 mg $g^{-1}$) at 30 DAS.

The treatments could significantly affect the uptake of nutrients by the crop. The N uptake was the highest in $r_2$ (68.90 kg $ha^{-1}$) which was on par with $r_3$ (66.48 kg $ha^{-1}$). The highest N uptake was recorded with $t_3$ (74.28 kg $ha^{-1}$) which was comparable with $t_4$ (72.93 kg $ha^{-1}$). The treatment combination $r_2t_3$ resulted in higher N uptake value of 88.91 kg $ha^{-1}$ which did not vary from $r_3t_4$, and $r_3t_3$. The highest P uptake was recorded with $r_3$ (49.88 kg $ha^{-1}$) which was comparable with $r_2$ (49.41 kg $ha^{-1}$). The nutrient schedule $t_3$ produced significantly higher P uptake (52.95 kg $ha^{-1}$) and was comparable with $t_4$. The interaction $r_3t_3$ registered the highest value of P uptake (54.92 kg $ha^{-1}$). K uptake was the highest in $r_2$ (278.56 kg $ha^{-1}$) which did not vary from $r_3$ (268.61 kg $ha^{-1}$). Treatment $t_3$ had the highest K uptake (272.82 kg $ha^{-1}$) and was comparable with $t_2$ (271.06 kg $ha^{-1}$). The treatment combination $r_2t_3$ recorded the highest K uptake (295.05 kg $ha^{-1}$) which was comparable with $r_3t_2$.

Results of the soil nutrient content after the experiment indicated that N:K ratios and time of application of nutrients resulted in significant changes in soil fertility status. The N:K ratio $r_2$ (1:1) recorded significantly higher pH (5.7) which was comparable with $r_3$ (5.67). Both $t_3$ and $t_1$ recorded higher soil pH of 5.70 after the experiment. The highest organic carbon content was recorded with $r_3$ (0.83 per cent) which was on par with $r_2$ (0.78 per cent). Organic carbon content was significantly higher in $t_3$ (0.89 per cent) which was comparable with $t_4$ (0.84 per cent). The interaction $r_3t_3$ produced significantly higher organic carbon content of 1.06 per cent which did not show any statistical variation from $r_2t_3$ (0.98 per cent). Significantly higher available N content (296.88 kg $ha^{-1}$) in soil was recorded with $r_3$ after the experiment. The $t_4$ produced the highest available N content (294.09 kg $ha^{-1}$) and was comparable with $t_3$ (288.51 kg $ha^{-1}$). The $r_3t_3$ recorded significantly higher available N content (363.78 kg $ha^{-1}$) and was comparable with $r_2t_4$. Available P content after the experiment was significantly higher with $r_2$ (90.37 kg $ha^{-1}$) and $t_3$ (82.05 kg $ha^{-1}$). Among interaction effects, $r_2t_3$ had the highest available P status (116.08 kg $ha^{-1}$) after the experiment.

Economic analysis of data revealed that the total cost of cultivation was the lowest (₹ 34983) with $r_1t_1$ (application of N and K in 1:0.5 ratio with ½ N given at basal + 30 DAS and full K as basal). The net income was the highest (₹ 39737) with $r_3t_3$ wherein N and K in 1:1.5 ratio were applied as 2 equal splits with ½ of each at basal and at 30 DAS, which was followed by $r_2t_3$ (₹ 38377) and $r_2t_4$ (₹ 38017). The treatment $r_2t_4$ wherein N and K in 1:1 ratio were applied with both N and K in 3 equal splits (1/3 of each applied at basal, 30 DAS and 60 DAS) and**,** $r_3t_3$ wherein N and K in 1:1.5 ratio were applied with 2 equal splits with ½ of each at basal and at 30 DAS, resulted in the highest BCR of 2.04. These treatments were followed by $r_2t_3$ (2.03), and $r_2t_2$ (2.00).

The results of the study indicated that growth, growth attributes and yield of sorghum were favourably influenced by the application of N and K in 1:1.5 ratio. Crop growth was significantly superior especially at early growth stages when N and K were applied in three equal splits with 1/3 of each applied as basal, 30 DAS and 60 DAS. Yield attributes and yield were significantly higher when N and K were applied in two equal split doses as ½ of each at basal and at 30 DAS. Grain yield, net income and benefit-cost ratio were significantly superior with the application of N and K in the ratio 1:1.5, given as two equal split doses, half of each at basal and at 30 DAS.

Results indicated that the high yielding varieties of sorghum respond to the application of potassium in higher ratios with nitrogen and its split application is favourable for higher yield and economic benefit than its one-time application as basal dose. The study suggested that the present POP recommendation of KAU for rainfed sorghum (45:25:25 kg NPK $ha^{-1}$) with full basal application of P and K and two split applications of N (half as basal and remaining half at 30 DAS) could be modified as 50:25:75 kg NPK $ha^{-1}$ with two equal split doses of N and K, half of each at basal and at 30 DAS and entire P as basal dose for rainfed cultivation of high yielding varieties of sorghum in southern Kerala.

FUTURE LINE OF WORK

- Field investigations in sorghum on interactions of potassium with calcium and magnesium for modification of nutrient schedule under irrigated conditions.
- Exploring the possibilities of integrated nutrient management in reducing the quantity of fertilisers in sorghum.

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# NUTRIENT SCHEDULING IN RAINFED SORGHUM

## (*Sorghum bicolor* L. Moench)

*By*

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**ABSTRACT**

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## ABSTRACT

The study entitled "Nutrient scheduling in rainfed sorghum (*Sorghum bicolor* L. Moench)" was undertaken at College of Agriculture, Vellayani, during 2019 – 2021. The main objectives were to standardise the nutrient schedule for rainfed sorghum and to work out the economics.

The field investigation was conducted during summer 2021 and the experiment was laid out in factorial randomised block design with 12 treatment combinations, replicated thrice. The treatments comprised combinations of three N:K ratios ($r_1$ -1:0.5, $r_2$ -1:1 and $r_3$ -1:1.5) and four times of applications ($t_1$- ½ N as basal + ½ N at 30 DAS + full K as basal, $t_2$- $^1/3$ N as basal + $^1/3$ N at 30 DAS+ $^1/3$ N at 60 DAS + full K as basal, $t_3$- ½ N and ½ K as basal + ½ N and ½ K at 30 DAS, $t_4$- $^1/3$ N and $^1/3$ K as basal + $^1/3$ N and $^1/3$ K at 30 DAS + $^1/3$ N and $^1/3$ K at 60 DAS). The sorghum variety used for the study was Co-30.

The results of the study revealed that plants were significantly taller in $r_3$ at 60 DAS (122.33cm), 90 DAS (237.18 cm) and harvest (248.27cm). Plant height was significantly more at 30 and 60 DAS with $t_4$ (27.71 and 122.97 cm respectively) while $t_3$ resulted in significantly taller plants at 90 DAS and harvest (236.38 and 244.47 cm respectively). Among the interactions, $r_3t_4$ and $r_1t_4$ resulted in significantly taller plants at 30 DAS and 60 DAS, while at 90 DAS and harvest, $r_3t_1$ was superior. The N:K ratio $r_3$ (1:1.5) produced significantly more number of leaves per plant at all stages of observation. The treatment $t_4$ recorded significantly more number of leaves at 30 DAS (4.50) while $t_3$ recorded higher number of leaves at later growth stages. Interaction $r_3t_4$ produced significantly higher number of leaves at 60 DAS, 90 DAS and at harvest. Leaf area index recorded was significantly higher with $r_3$ (2.65), $t_4$ (2.62) and the interaction $r_3t_4$ (5.90) at 40 DAS. The crop took least number of days to reach 50 per cent flowering in $r_3$ (57 days), $t_4$ (54.89) and $r_3t_4$ (50.67 days). The dry matter production at harvest was the highest in $t_3$ (6843.00 kg $ha^{-1}$) and was on par with $t_4$. Chlorophyll content was significantly higher at 30 and 60 DAS in $r_3$ and $t_3$ respectively

and $t_3$ was comparable with $t_4$. The interaction $r_2t_4$ recorded higher chlorophyll content at 30 DAS. Rooting depth and root volume were significantly higher in $r_3$ and $t_4$, and interactions $r_3t_2$ and $r_3t_4$ had higher rooting depth and root volume respectively.

Length of panicle was significantly higher in $r_3$ (24.80 cm) and $t_3$ (20.22 cm). The treatment combination $r_2t_3$ resulted in significantly longer panicles. Grain weight per panicle (46.47 g) was significantly higher in $r_2$. Grain yield was significantly higher with $r_2$ (3449.33 kg $ha^{-1}$) and was comparable with $r_3$ (3298.67 kg $ha^{-1}$). The highest grain yield (3532.22 kg $ha^{-1}$) was recorded by $t_3$, followed by $t_4$ (3350.11 kg $ha^{-1}$) which were on par. The treatment combination $r_3t_3$ resulted in the highest grain yield (3635.67 kg $ha^{-1}$) and was on par with all other treatments except $r_1t_1$ and $r_1t_2$. Harvest index was significantly superior in $r_2$ (1:1) and $r_3$ (1: 1.5), both producing a value of 0.45 compared to $r_1$ (0.39).

N uptake and K uptake were the highest in $r_2$ and were on par with $r_3$ while P uptake was the highest in $r_3$ comparable with $r_2$. The highest N uptake was recorded with $t_3$ which was comparable with $t_4$. The treatment $t_3$ which was comparable with $t_4$ resulted in significantly higher P uptake. K uptake was the highest with $t_3$ (272.82 kg $ha^{-1}$) and was comparable with $t_2$. The treatment $r_2$ resulted in significantly higher pH (5.70) and was comparable with $r_3$ (5.67). Both $t_3$ and $t_1$ recorded higher soil pH of 5.70 after the experiment. Highest organic carbon content was recorded with $r_3$ (0.83 per cent), $t_3$ (0.89 per cent) and $r_3t_3$ (1.06 per cent), and $r_3$ was on par with $r_2$ whereas $t_3$ was comparable with $t_4$. Significantly higher available N content was recorded with $r_3$ and $t_4$, and $t_4$ was comparable with $t_3$. The treatment combination $r_3t_3$ which was on par with $r_2t_4$ recorded significantly higher available N content. Available P content was significantly higher with $r_2$, $t_3$ and $r_2t_3$. Net income was the highest (₹ 39737 $ha^{-1}$) with $r_3t_3$ while $r_2t_4$ and $r_3t_3$ resulted in the highest BCR of 2.04.

Considering the growth, yield and economics, the modified fertilizer dose of 50: 25: 75 kg $ha^{-1}$ NPK with N and K in two equal split doses, half of each at basal and at 30 DAS and P as basal dose can be recommended for cultivating high yielding sorghum varieties as rainfed crop in southern Kerala.

# സംഗ്രഹം

കേരള കാർഷിക സർവകലാശാലയുടെ കീഴിൽ പ്രവർത്തിക്കുന്ന വെള്ളായണി കാർഷിക കോളേജിൽ 2019-2021 കാലയളവിൽ നടത്തിയ "മണിച്ചോളത്തിലെ പോഷക മൂലക ക്രമീകരണം" എന്ന പഠനത്തിന്റെ പ്രസക്ത കണ്ടെത്തലുകൾ ചുവടെ ചേർക്കുന്നു. മുഖ്യ പോഷക മൂലകങ്ങളുടെ തോതും നൽകേണ്ട സമയവും ചിട്ടപ്പെടുത്തുകയും അവയുടെ സാമ്പത്തിക വശത്തെ കുറിച്ച് മനസിലാക്കുകയുമായിരുന്നു പ്രസ്തുത പഠനത്തിന്റെ ലക്ഷ്യങ്ങൾ.

പ്രസ്തുത പരീക്ഷണത്തിന് റാൻഡമൈസ്ഡ് ബ്ലോക്ക് ഡിസൈൻ എന്ന സ്റ്റാറ്റിസ്റ്റിക്കൽ പഠന രീതിയാണ് അവലംബിച്ചത്. കോ-30 എന്ന മെച്ചപ്പെട്ട മണിച്ചോള ഇനമായിരുന്നു പരീക്ഷണത്തിനുപയോഗിച്ചത്. പാക്യജനകം, ക്ഷാരം എന്നിവയുടെ 3 വ്യത്യസ്ത അനുപാതങ്ങൾ (1:0.5, 1:1,1:1.5), അവയുടെ വിവിധ വളപ്രയോഗ സമയങ്ങൾ (ടി$_1$ -മുഴുവൻ ക്ഷാരം അടിവളമായി നൽകുകയും, പാക്യജനകം പകുതി അടിവളമായും ബാക്കി നട്ടു 30 ദിവസത്തിനുശേഷവും നൽകുക, ടി$_2$ -മുഴുവൻ ക്ഷാരം അടിവളമായി നൽകുകയും, പാക്യജനകം 1/3 വീതം മൂന്നുതവണകളായി അടിവളമായും, നട്ടു 30 ദിവസത്തിനുശേഷവും 60 ദിവസത്തിനുശേഷവും നൽകുക, ടി$_3$- പാക്യജനകം, ക്ഷാരം എന്നിവ പകുതി വീതം രണ്ടു തുല്യ തവണകളായി അടിവളമായും നട്ടു 30 ദിവസത്തിനുശേഷവും നൽകുക, ടി$_4$- പാക്യജനകം, ക്ഷാരം എന്നിവ 1/3 വീതം

മൂന്നുതവണകളായി അടിവളമായും, നട്ടു 30 ദിവസത്തിനുശേഷവും 60 ദിവസത്തിനുശേഷവും നൽകുക) എന്നിവയായിരുന്നു ടി പരീക്ഷണത്തിലെ പഠന മുറകൾ.

മണിച്ചോളത്തിന്റെ വളർച്ചയ്ക്ക് കൂടിയ നിരക്കിൽ ക്ഷാരം നൽകുന്നത് സഹായകരമാണെന്ന് കാണുകയുണ്ടായി. പാകൃജനകം, ക്ഷാരം എന്നിവ പകുതി വീതം രണ്ടു തുല്യ തവണകളായി അടിവളമായും നട്ടു 30 ദിവസത്തിനുശേഷവും നല്കുന്നത് ഉത്പാദനം വർദ്ധിപ്പിക്കുമെന്നും പഠനത്തിൽ തെളിഞ്ഞു. മണി ചോളത്തിൻറ്റെ ഉയർന്ന ഉത്പാദനത്തിനും അറ്റാദായത്തിനും പാകൃജനകവും ക്ഷാരവും 1:1.5 എന്ന അനുപാതത്തിൽ 2 തുല്യതവണകളായി അടിവളമായും നട്ടു 30 ദിവസത്തിനുശേഷവും നല്കുന്നത് ഉത്തമമാണെന്ന് പഠനത്തിൽ വ്യക്തമായി.

മഴയെ ആശ്രയിച്ചു കൃഷിചെയ്യുന്ന മണിച്ചോളത്തിന് 50:25:75 എന്ന തോതിലുള്ള പരിഷ്കരിച്ച വളപ്രയോഗ ശുപാർശ (പാകൃജനകം, ക്ഷാരം എന്നിവ പകുതി വീതം രണ്ടു തുല്യ തവണകളായി അടിവളമായും നട്ടു 30 ദിവസത്തിനുശേഷവും നൽകുകയും മുഴുവൻ ഭാവഹവും അടിവളമായി കൊടുക്കുകയും) മെച്ചപ്പെട്ട ഉത്പാദനവും അറ്റാദായവും ലഭിക്കുവാൻ സഹായകരമാണെന്നു പഠനത്തിൽ കണ്ടെത്തി.

# APPENDIX I

**Weather parameters during the period of field experiment (January- April 2021)**

| Standard week | Mean temperature ($^0$C) | | Mean RH (per cent) | | Rainfall (mm) | Sunshine hrs |
|---|---|---|---|---|---|---|
| | Max | Min | Max | Min | | |
| 1 (1 Jan – 7 Jan) | 32.0 | 23.6 | 94.7 | 84.0 | 32.2 | 3.9 |
| 2 (8 Jan- 14 Jan) | 30.4 | 24.0 | 94.4 | 87.9 | 45.0 | 0.9 |
| 3 (15 Jan – 21Jan) | 32.0 | 24.2 | 92.7 | 77.3 | 1.4 | 4.8 |
| 4 (22 Jan - 28 Jan) | 32.6 | 22.2 | 92.1 | 71.6 | 0 | 8.5 |
| 5 (29 Jan - 4 Feb) | 33.0 | 23.7 | 91.4 | 69.1 | 0 | 8.7 |
| 6 (5 Feb - 11Feb) | 33.0 | 21.4 | 92.0 | 72.0 | 0 | 9.1 |
| 7 (12 Feb - 18 Feb) | 33.0 | 20.4 | 89.0 | 71.0 | 0 | 9.1 |
| 8 (19 Feb – 25 Feb) | 33.3 | 23.4 | 90.6 | 72.0 | 0 | 8.3 |
| 9 (26 Feb-4 March) | 33.4 | 22.5 | 88.4 | 67.6 | 0 | 8.6 |
| 10 (5 Mar- 11 March) | 34.0 | 20.4 | 89.9 | 66.3 | 0 | 8.1 |
| 11 (12 march-18march) | 34.3 | 23.0 | 87.7 | 64.7 | 0 | 8.8 |
| 12 (19 March- 25 March) | 34.1 | 25.4 | 88.9 | 68.3 | 0 | 6.8 |
| 13 (26 March- 1 April) | 34.1 | 25.8 | 90.0 | 72.0 | 70.5 | 7.6 |
| 14 (2 April-8 April) | 34.3 | 26.4 | 88.2 | 76.1 | 0 | 8.9 |
| 15 (9 April- 15 April) | 33.5 | 25.6 | 87.3 | 79.0 | 64.3 | 6.6 |
| 16 (16 April – 22 April) | 33.4 | 25.4 | 87.3 | 79.3 | 1.5 | 6.6 |
| 17 (23 April – 29 April) | 34.2 | 26.1 | 88.0 | 77.3 | 6.4 | 8.2 |

## APPENDIX II

## AVERAGE LABOUR COST, INPUT COST AND MARKET PRICE OF PRODUCE

| | **Cost (₹)** |
|---|---|
| **Labour wages** | |
| Men | 750 per day |
| Women | 750 per day |
| **Seed** | |
| Sorghum | 70 $kg^{-1}$ |
| **Manures and fertilizers** | |
| Farmyard manure (FYM) | 1600 $t^{-1}$ |
| Urea | 8 $kg^{-1}$ |
| Rajphos | 15 $kg^{-1}$ |
| Muriate of Potash (MOP) | 23 $kg^{-1}$ |
| Lime | 18 $kg^{-1}$ |
| **Market price of produce** | |
| Sorghum grain | 15 $kg^{-1}$ |
| Sorghum fodder | 4 $kg^{-1}$ |

## APPENDIX III

## QUANTITY OF FERTILISERS GIVEN PER HECTARE AND THEIR SCHEDULE OF APPLICATION

| Treatments | Urea (kg) | Rajphos (kg) | MOP (kg) | Schedule of application |
|---|---|---|---|---|
| $r_1t_1$ | 108.60 | 120.00 | 41.60 | 54.3 kg urea at basal +54.3 kg urea at 30 DAS+41.6 kg MOP at basal |
| $r_1t_2$ | 108.60 | 120.00 | 41.60 | 36.2 kg urea at basal +36.2 kg urea at 30 DAS+36.2 kg urea at 60 DAS + 41.6 kg MOP at basal |
| $r_1t_3$ | 108.60 | 120.00 | 41.60 | 54.3 kg urea +20.8 kg MOP at basal and at 30 DAS |
| $r_1t_4$ | 108.60 | 120.00 | 41.60 | 36.2 kg urea + 13.8 kg MOP at basal ,30 DAS and 60 DAS |
| $r_2t_1$ | 108.60 | 120.00 | 83.30 | 54.3 kg urea at basal +54.3 kg urea at 30 DAS+83.3 kg MOP at basal |
| $r_2t_2$ | 108.60 | 120.00 | 83.30 | 36.2 kg urea at basal +36.2 kg urea at 30 DAS+36.2 kg urea at 60 DAS + 83.3 kg MOP at basal |
| $r_2t_3$ | 108.60 | 120.00 | 83.30 | 54.3 kg urea +41.65 kg MOP at basal and at 30 DAS |
| $r_2t_4$ | 108.60 | 120.00 | 83.30 | 36.2 kg urea + 27.7 kg MOP at basal ,30 DAS and 60 DAS |
| $r_3t_1$ | 108.60 | 120.00 | 125.00 | 54.3 kg urea at basal +54.3 kg urea at 30 DAS+125 kg MOP at basal |
| $r_3t_2$ | 108.60 | 120.00 | 125.00 | 36.2 kg urea at basal +36.2 kg urea at 30 DAS+36.2 kg urea at 60 DAS + 125 kg MOP at basal |
| $r_3t_3$ | 108.60 | 120.00 | 125.00 | 54.3 kg urea +62.5 kg MOP at basal and at 30 DAS |
| $r_3t_4$ | 108.60 | 120.00 | 125.00 | 36.2 kg urea + 41.6 kg MOP at basal ,30 DAS and 60 DAS |

*On soil test basis