Productivity Enhancement in Medicinal Rice

(*Oryza sativa* L.) cv. Njavara

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(*Oryza sativa* L.) cv. Njavara

by

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KERALA, INDIA

2014

DECLARATION

I hereby declare that this thesis entitled **"Productivity Enhancement in Medicinal Rice (*Oryza sativa* L.) cv. Njavara."** is a bonafide record of research done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

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TABLE OF CONTENTS

Sl. No.	Title	Page No.
1.	INTRODUCTION	01
2.	REVIEW OF LITERATURE	04
3.	MATERIALS AND METHODS	19
4.	RESULTS	34
5.	DISCUSSION	84
6.	SUMMARY	107
7.	REFERENCES	112
	ABSTRACT	
	APPENDIX	

LIST OF TABLES

Table No.	Title	Page No.
1.	Physico –chemical properties of soil at experiment site	20
2.	Plant analysis methods	32
3.	Effect of silicon ,seed rate and potassium on plant height (cm) of Njavara	35
4.	Interaction effect of silicon and potassium (SxK) on plant height (cm) of Njavara (40 DAS)	36
5.	Interaction effect of silicon and seed rate (SxR), silicon and potassium (SxK) on plant height (cm) of Njavara (Harvest)	36
6.	Interaction effect of silicon, seed rate and potassium (SxRxK) on plant height (cm) of Njavara	37
7.	Effect of silicon ,seed rate and potassium on tillers m^{-2} of Njavara	39
8.	Interaction effect of silicon and seed rate (SxR) on tillers m^{-2} of Njavara (PI and harvest stage)	40
9.	Interaction effect of silicon and potassium (SxK) on tillers m^{-2} of Njavara (PI stage)	40
10.	Interaction effect of seed rate and potassium (RxK) on tillers m^{-2} of Njavara (PI and harvest stage)	41
11.	Interaction effect of silicon, seed rate and potassium (SxRxK) on tillers m^{-2} of Njavara (PI and harvest stage)	41
12.	Effect of silicon ,seed rate and potassium on LAI of Njavara	43
13.	Interaction effect of silicon and seed rate (SxR), silicon and potassium (SxK) on LAI of Njavara (PI stage)	44
14.	Interaction effect of seed rate and potassium (RxK) on LAI of Njavara (PI stage)	44
15.	Effect of silicon, seed rate and potassium on rooting depth (cm), total biomass (kg ha^{-1}),culm strength (mg cm^{-1}) and number of productive tillers m^{-2} of Njavara	46

Table No.	Title	Page No.
16.	Interaction effect of silicon and seed rate (SxR) on total biomass (kg ha^{-1}) of Njavara	47
17.	Interaction effect of silicon and seed rate (SxR) on culm strength (mg cm^{-1}) of Njavara	47
18.	Interaction effect of silicon and seed rate (SxR), silicon and potassium (SxK) on number of productive tillers m^{-2} of Njavara (Harvest stage)	50
19.	Interaction effect of seed rate and potassium (RxK) on number of productive tillers m^{-2} of Njavara (Harvest stage)	51
20.	Interaction effect of silicon, seed rate and potassium (SxRxK) on number of productive tillers m^{-2} of Njavara (Harvest stage)	52
21.	Effect of silicon, seed rate and potassium on grain weight $panicle^{-1}$, spikelets $panicle^{-1}$,filled grains $panicle^{-1}$,sterility percentage and thousand grain weight (g) of Njavara	54
22.	Interaction effect of silicon and seed rate (SxR) on filled grains $panicle^{-1}$ of Njavara	55
23.	Interaction effect of silicon and seed rate (SxR) on thousand grain weight (g) of Njavara	55
24.	Effect of silicon, seed rate and potassium on grain yield (kg ha^{-1}) and straw yield (kg ha^{-1})	57
25.	Interaction effect of silicon and seed rate (SxR), silicon and potassium (SxK) on grain yield (kg ha^{-1}) of Njavara	58
26.	Interaction effect of seed rate and potassium (RxK) on grain yield (kg ha^{-1}) of Njavara	58
27.	Interaction effect of silicon, seed rate and potassium (SxRxK) on grain yield (kg ha^{-1}) of Njavara	59
28.	Interaction effect of silicon and seed rate (SxR), silicon and potassium (SxK) on straw yield (kg ha^{-1}) of Njavara	60
29.	Effect of silicon, seed rate, potassium and interaction of silicon and seed rate (SxR) on harvest index (HI) of Njavara	62
30.	Weed flora associated with Njavara rice	63

Table No.	Title	Page No.
31.	Effect of silicon, seed rate and potassium on weed biomass (g m^{-2}) of Njavara	64
32.	Effect of silicon, seed rate and potassium on organic carbon, available nitrogen, phosphorus and potassium of the soil after the experiment	66
33.	Effect of silicon, seed rate and potassium on nitrogen, phosphorus and potassium uptakes (kg ha^{-1}) of Njavara	68
34.	Interaction effect of silicon and seed rate (SxR), silicon and potassium (SxK) on nitrogen uptake (kg ha^{-1}) of Njavara	69
35.	Interaction effect of seed rate and potassium (RxK) on nitrogen uptake (kg ha^{-1}) of Njavara	69
36.	Interaction effect of silicon, seed rate and potassium (SxRxK) on nitrogen uptake (kg ha^{-1}) of Njavara	70
37.	Interaction effect of silicon and seed rate (SxR), silicon and potassium (SxK) on phosphorus uptake (kg ha^{-1}) of Njavara	73
38.	Interaction effect of seed rate and potassium (RxK) on phosphorus uptake (kg ha^{-1}) of Njavara	73
39.	Interaction effect of silicon, seed rate and potassium (SxRxK) on phosphorus uptake (kg ha^{-1}) of Njavara	74
40.	Interaction effect of silicon and seed rate (SxR), silicon and potassium (SxK) on potassium uptake (kg ha^{-1}) of Njavara	76
41.	Interaction effect of seed rate and potassium (RxK) on potassium uptake (kg ha^{-1}) of Njavara	76

Table No.	Title	Page No.
42.	Interaction effect of silicon, seed rate and potassium (SxRxK) on potassium uptake (kg ha^{-1}) of Njavara	77
43.	Effect of silicon, seed rate and potassium on net income and B:C ratio of Njavara	78
44.	Interaction effect of silicon, seed rate and potassium (SxRxK) on net income of Njavara	79
45.	Interaction effect of silicon, seed rate and potassium (SxRxK) on B:C ratio of Njavara	80
46.	Effect of silicon, seed rate and potassium on pest (leaf roller) scoring (%) of Njavara	82
47.	Interaction effect of silicon and seed rate (SxR), silicon and potassium (SxK) on pest (leaf roller) scoring (%) of Njavara	83

LIST OF FIGURES

Figure No.	Title	Between Pages
1.	Weather parameters during the cropping period	19-20
2.	Lay out of the field experiment	24-25
3.	Effect of silicon on grain yield of Njavara rice	85-86
4.	Effect of silicon on spikelets panicle^{-1} of Njavara rice	85-86
5.	Effect of silicon on thousand grain weight of Njavara rice	86-87
6.	Effect of silicon on productive tillers m^{-2} of Njavara rice	86-87
7.	Effect of silicon on straw yield of Njavara rice	87-88
8.	Effect of silicon on plant height of Njavara rice at 40 DAS and at harvest	89-90
9.	Effect of silicon on LAI of Njavara rice	89-90
10.	Effect of silicon on culm strength of Njavara rice	89-90
11.	Effect of silicon on nitrogen, phosphorous and potassium uptake of Njavara rice	91-92
12.	Effect of seed rate on grain yield of Njavara rice	91-92
13.	Effect of seed rate on productive tillers m^{-2} of Njavara rice	95-96
14.	Effect of seed rate on thousand grain weight of Njavara rice	95-96
15.	Effect of seed rate on straw yield of Njavara rice	95-96
16.	Effect of seed rate on harvest index of Njavara rice	95-96

Figure No.	Title	Between Pages
17.	Effect of seed rate on plant height of Njavara rice at 40 DAS and at harvest	95-96
18.	Effect of seed rate on tillers m^{-2} of Njavara rice	95-96
19.	Effect of seed rate on LAI of Njavara rice	95-96
20.	Effect of seed rate on rooting depth of Njavara rice	95-96
21.	Effect of seed rate on total biomass of Njavara rice	95-96
22.	Effect of seed rate on nitrogen ,phosphorus and potassium uptake of Njavara rice	95-96
23.	Effect of potassium (NK ratio) on grain yield of Njavara rice	99-100
24.	Effect of potassium (NK ratio) on productive tillers m^{-2} of Njavara rice	99-100
25.	Effect of potassium (NK ratio) on straw yield of Njavara rice	99-100
26.	Effect of potassium (NK ratio) on plant height of Njavara rice at 40 DAS and at harvest	99-100
27.	Effect of potassium (NK ratio) on tillers m^{-2} of Njavara rice	99-100
28.	Effect of potassium (NK ratio) on nitrogen, phosphorus and potassium uptake of Njavara rice	99-100
29.	Effect of silicon, seed rate and potassium (NK ratio) on net income	106-107
30.	Effect of silicon, seed rate and potassium (NK ratio) on B:C ratio	106-107

LIST OF PLATES

Plate No:	Title	Between pages
1.	Njavara seeds	24-25
2.	Njavara plant	24-25
3.	Lay out of the experiment plot	24-25
4.	General view of the experimental field	24-25
5.	Crop at harvest stage	24-25

LIST OF APPENDICES

Sl. No.	Title	Appendix No.
1.	Standard week wise mean weather parameter during cropping period	I

LIST OF ABBREVIATIONS

BCR	–	Benefit cost ratio
CD (0.05)	–	Critical difference at 5 % level
CEC	–	Cation exchange capacity
cfu g^{-1}	–	Colony forming units per gram
cm	–	Centimetre
cm^2	–	Square centimetre
cm^3	–	Cubic centimetre
CO_2	–	Carbon dioxide
cv	–	Cultivar
DAS	–	Days after sowing
day^{-1}	–	Per day
DMP	–	Dry matter partitioning
et al.	–	And others
Fe	–	Iron
Fig.	–	Figure
FYM		Farm yard manure
g	–	Gram
g cc^{-1}	–	Gram per cubic centimetre
g $hill^{-1}$	–	Gram per hill
HI	–	Harvest index
i.e.	–	That is

INM	–	Integrated nutrient management
K	–	Potassium
K_2O	–	Potassium
kg	–	Kilogram
kg^{-1}	–	Per kilogram
kg ha^{-1}	–	Kilogram per hectare
LAI	–	Leaf area index
m	–	Metre
m^{-2}	–	Per square metre
mg	–	Milligram
mm	–	Millimetre
Mn	–	Manganese
MRP	–	Mussorie Rock Phosphate
N	–	Nitrogen
NR activity	–	Nitrate reductase activity
NS	–	Non significant
P	–	Phosphorus
P_2O_5	–	Phosphate
PI stage	–	Panicle initiation stage
$Plant^{-1}$	–	Per plant
POP of KAU	–	Package of Practices Recommendations of Kerala Agricultural University
ppm	–	Parts per million

RDF	–	Recommended dose of fertilizers
RH	–	Relative humidity
Rs	–	Rupees
S	–	Sulphur / Significant
SE	–	Standard error of mean
Si	–	Silicon
t ha^{-1}	–	Tonnes per hectare
viz.	–	Namely
WHC	–	Water holding capacity
Zn	–	Zinc

LIST OF SYMBOLS

%	–	Per cent
μg	–	Micro gram
°C	–	Degree Celsius
@	–	At the rate of
&	–	And

Introduction

1. INTRODUCTION

Rice which accounts for 50-80 percent of daily calorie intake of Asians has an undisputed prominence among cereals and staples. Several rice land races have been evolved through generations of selective preferences. In spite of the introduction of many high yielding modern rice varieties some land races are still popular in farmers fields due to the unique characteristics and special uses. More than 50 traditional rice varieties having medicinal properties were identified by department of Agronomy, Indhira Gandhi Agricultural University, Raipur, India Deepa (2010). Most of the varieties are under cultivation in very restricted areas.

Among the traditional rice strains still being cultivated in Kerala, the medicinal rice Njavara which has been cultivated over 2500 years in the state has a unique position. References to the medicinal and nuetraceutical properties of this rice strain, which is known as *shashstika* in Sanskrit Language and Njavara in the Dravidian Language (both meaning rice variety that matures in 60 days),can be found in various ancient treatises of Ayurveda such as Ashtanga Hridaya written by Vagbatta AD 400-500, (Murthy, 2001). Despite its distinctness among traditional rice strains as a medicinal plant, Njavara is an endemic rice cultivar of Kerala (Harlan, 1975). It is considered as a wonder variety very special to Kerala, which is able to provide healthy and safe food to people of all ages including new born babies.Though this medicinal variety has received the geographical indication intellectual property right in November 2006, the very poor yield and the fragile nature of the plant is restricting its wide spread cultivation. Now a days since crops with medicinal and health promotion qualities are gaining universal recognition, Njavara rice also has become the focus of research interest. Njavara deserves a resurrection as it is really unique with uniravelled medicinal properties and great potentiality to develop as a healthy food. Poor yield, poor tillering, and severe lodging are the constraints of this rice strain which led to the neglection and hence requires recognition for intensifying research extension.

Development of proper agronomic management strategy may help in exploiting the full potential of Njavara in terms of yield and quality and may result in reducing cost of cultivation, leading to categorize the Njavara production a profitable venture. The costly basic input in the cultivation of this strain is quality seed, which accounts about 30 percent of the cost of cultivation. The present cost of Njavara seed is 450/- per kg. The possibility of reducing the seed rate has to be delved by attempting different sowing rates.

Silicon is considered as a beneficial element to rice and the plant absorbs large quantity of silicon and this element is present in all parts of the plant (Grist, 1986). Absence of silicon materially decreases growth and yield of paddy. It plays significant role in imparting resistance to biotic and abiotic stress, increased resistance to lodging, promotion of an erect growth and enhanced crop productivity and hence is of importance in the productivity of Njavara rice. This element has been demonstrated to be necessary for healthy growth and stable production of rice. Hence exploiting the prospect of inclusion of silicon in the nutritional management of Njavara will be a valuable information.

Potassium is yet another essential element for the growth of rice plant and takes part in various physiological processes (Yoshida, 1981). Use of different N and K doses is an important complementary strategy in improving rice yield and quality and reducing cost of production. The N and K ratio of 2:1 (N 80 kg ha^{-1} and K 40 kg ha^{-1}) was found best for getting maximum yield in rice. Contradictory to this report Sriramkumar (2001) observed that Njavara is benefitted by 1:1 N: K ratio with 40:40 kg N and K ha^{-1}. Hence an enhancement in the dose of K and changing the NK ratio may improve the performance of the weak stemmed Njavara rice.

Considering the above aspects the present investigation was undertaken with following objectives

- Study of impact of silicon on growth, lodging and yield of Njavara rice.

- Assess the effects of reduced seed rate on growth, lodging and yield of Njavara rice.
- Impact of modified NK ratio on growth, lodging and yield of Njavara rice.
- To assess the economics of Njavara rice production.

Review of Literature

2. REVIEW OF LITERATURE

Njavara *(Oryza sativa* L.*)* is an ancient rice variety that has been cultivated in Kerala for its medicinal properties for over 2500 years. In the past, the traditional Ayurveda practitioners of Kerala (Vydas) developed several health-conducive practices using Njavara grains.

The research work done in this medicinal rice, Njavara is reviewed in this chapter under the following chapters.

2.1. Effect of silicon on growth, yield and yield attributes

2.2. Effect of silicon on incidence of pest and disease

2.3. Effect of potassium on rice growth, yield and yield attributes and incidence on pest and disease

2.4. Effect of NK ratios on growth, yield and yield attributes of rice

2.5. Effect of seed rate on rice growth, yield and yield attributes

2.1 EFFECT OF SILICON ON GROWTH, YIELD AND YIELD ATTRIBUTES

2.1.1 Effect of Silicon on Growth

Silicon is the second most abundant element in the earth's crust, with soils containing approximately 32 percent Si by weight Lindsay (1979).Silicon generally exists in nature as silicon dioxide or silica. Silicon is deposited as silica in the plant cell walls, improving cell wall structural rigidity and strength, plant architecture and leaf erectness. Silicon in plants can stimulate nutrient uptake and plant photosynthesis, decrease susceptibility to disease and insect damage, alleviate water and various mineral stresses and decrease the toxic effect of aluminium.

Experimental evidence for the function of silica as promoter of growth and yield was perhaps first furnished by (Wolff and Kreuzhage, 1884). Winifred *et al.(*1927) obtained increase in the number of tillers due to silicon application. The work of Okawa and Kinsaku (1936), revealed the influence of silicic acid on increased growth and yield of rice plant.

Sreenivasan (1936) and Ishibashi and Hajima (1937) reported increase in height, dry matter production and root length by the application of sodium silicate in conjunction with green manure. Fritz (1940) observed in water culture experiment that deficiency of silica caused depression of root and shoot growth in cereals. He also observed that silica increased the height of plant, root length and number of tillers. Okamoto (1957) and Azuma *et al*. (1961) reported an increase in the height of the plants and dry matter production. However Yoshida *et al.* (1962) reported that silicon was not essential for the growth and tillering of rice, but was beneficial during the reproductive stage and for good grain output. Silicon is responsible for improved growth in rice (Lewin & Reimann, 1969). Okamoto (1970) reported that supply of silica increased the height of the plants, number of leaves, leaf size, number of vascular bundles in culm, and thickening of lowest elongated internode. Pawar and Hedge (1978) also observed that foliar spray of 100-400 ppm silicon applied twice per week to rice seedling up to the booting stage increased tillering, vegetative growth and photosynthetic efficiency. Later from several studies, it appears that silicon nutrition has direct and indirect beneficial effects on the rice growth largely due to its unique physiological role (Okuda and Takahashi, 1965,Yoshida 1975,Takahashi *et al.,*1990).Wang *et al*.(1994) reported that application of silica increased the plant height. Sunilkumar, (2000) reported an increase in plant height due to silicon application at harvest stage of rice, but tiller production was varied non significantly. Ahmed *et al*. (2013) did not observe any significant effect on plant height due to silicon application.

Liang *et al*. (1994), Carvalho (2000), Sunilkumar,(2000), Silva & Bohnen (2001) and Mauad *et al.* (2003) found no significant change in dry matter yield of vegetative parts of rice with the application of Si. Role of silicon in plant health and growth has been investigated in silicon accumulating crops and it seemed significantly effecting (Jinab *et al.,* 2008). Silicon is an important micronutrient for healthy and competitive growth of all cereals including rice in Asia (Brunings *et al.,* 2009). Similarly, Deren *et al*. (1994) obtained positive responses in the biomass production of rice with the addition of Si.

According to Horigushi (1988), Si improves the oxidizing power of the roots. It is known that Si increases the volume and gives rigidity to the aerenchyma which is an air channel present in the rice roots, and other plants, involved in the exchange of oxygen and other gases within the plant. The maintenance of photosynthetic activity due to Si fertilization could be one of the reasons for the increased dry matter production (Agarie, *et aI*., 1992).The differences in Si accumulation have been attributed to the Si absorbing ability of the roots. Silicon concentrations indifferent plants range from 0.1% (similar to P and S) to more than 10%of whole plant dry matter (Epstein, 1999).

For assessing the role of silica in preventing lodging, culm strength was measured by employing the procedure of Atkins (1938). Shimoyama (1958) mentions that the thickness of a culm wall and a vascular bundle becomes larger when silica is applied. Silica deposited in these plant sections also contributes to an increase in the mechanical strength of a culm. Reviews on the role of Si in plants, therefore stress the association of Si with cell walls and discuss the increased rigidity of cell walls of plants grown with ample available Si (Jones and Handreck, 1967). It is found that silicon gets deposited on the cell walls of the stem, thereby increases culm strength and prevents the tendency to lodge.According to Idris *et al*. (1975), a sufficient supply of Si has an effect on haulm stability and lodging susceptibility. Lee *et al.*(1990) noticed an increase in resistance to lodging due to application of Si fertilizer to rice. Increased plant Si content has been reported to increase mechanical strength of plant tissue, which resulted in reduced lodging (Takahashi *et al.,* 1990; Liang *et aI.,* 1994). Liang *et al.* (1994) reported less than 10 % or practically no lodging in rice fields fertilized with a new silicate material and more than 60 % lodging in control fields.

The mechanical strength of plants resides in cell wall, which enables them to maintain an erect habit (Epstein, 1994). Sufficient supply of Si has an effect on the stability of culms and serves to decrease the risk of lodging. In order to measure culm thickness, samples were taken from the fourth internodes from the top.Takahashi (1995) reported that , thickening of cell walls of the sclerenchyma tissue in the culm and shortening and thickening of internodes or increase in Si content of lower internodes provides mechanical strength to enable plant to resist lodging. Sunilkumar, (2000) reported that silica failed to give any significant effect on culm strength but a favorable increase of 1.7 percent was observed with silicon nutrition.

2.1.2 Effect of Silicon on Yield and Yield Attributes

Rice is a known silicon accumulator and the plant is benefitted from silicon nutrition (Takahashi, 1955.,Yoshida,1978). Mitsui (1956) observed the importance of si in hastening panicle growth and increasing panicle weight. Kido (1958) opined that thousand grain weight was increased by application of calcium silicate. Miyoshi and Ishii (1960) reported better translocation of photosynthates from straw to ear head by the application of silica. Takahashi (1961) concluded that absence of silicon in the reproductive phase caused a decrease in the number of spikelets panicle^{-1}.and percentage of ripe grains. Miyake (1977) suggested that there is a definite need to consider silicon as an agronomically essential element for increasing and for sustaining rice production. Silicate slag application at an optimum rate of 1.5 t-2t ha^{-1} is now widely used in degraded paddy fields and peaty paddy fields in Japan (Kono, 1969.,Takahashi and Miyake,1977). Better filling of grains by the application of silica was earlier reported by Vijayakumar (1977) who found an increase in thousand-grain weight by the application of silica. Silica is a micronutrient required specially for rice.

Lawes (1951) found that sodium and potassium silicate were equally effective in increasing yield of rice.Savant *et al.*(1997; 1999) reported several levels of yield increases due to Si application in rice and sugarcane. Harroda and Takata (1957) obtained fourteen percent increase in grain yield from a soil having a low SiO_2/P_2O_5 ratio by adding calcium silicate. Padmaja and Varghese (1964) observed increase in yield of grain and straw by application of silica and magnesium to rice crop of Kerala soil. The Si applied basally at 40 kg ha^{-1} as calcium magnesium silicate significantly increased the grain yields by more than 500 kg ha^{-1}Chianung and peta, (IRRI,1965). Application of silica up to 1000 kg ha^{-1} has shown increased yield of rice in laterite soils (Potty, 1965). On soils low in silica, the application of silica increases yields of modern rice variety at higher rates of N application (De Detta,1981). Yield increase of 10% are common when silicon is added and at times exceed 30% when leaf blast is severe (Yoshida, 1981).Five to 15% increase in rice yield has been reported by (Takahashi *et al.,* 1990) by the application of silicon. Wang *et al.* (1994) reported that application of silica increased the grain weight and yield. Liang *et al.* (1994) reported increase in rice yield from about 4.6 to 20.7 % with an average increase of 10% due to the basal application of a new silicate fertilizer (containing 230 g water soluble Si per kg) to calcareous soils (up to 8.9% $CaCO_3$).

Sunilkumar, (2000) reported significant influence of silica on upland rice. Both grain and straw yields increased significantly with the application of silica. Silica application resulted in an increase in the number of spikelets per panicle (9 per cent), filled grains per panicle (10.5 per cent) and panicle weight (10 per cent). This superiority in yield contributing characters might be due to better translocation of assimilates, as evidenced from better harvest index (24 per cent increase as compared to control).

Effects of silicon on yield are related to the deposition of the element under the leaf epidermis which results a physical mechanism of defense, reduces lodging, increases photosynthesis capacity and decreases transpiration losses (Korndörfer *et al*., 2004). Many scientists working on role of silicon in plant growth have concluded that reduced amount of silicon in plant develops necrosis, disturbance in leaf photosynthetic efficiency, growth retardation and reduces grain yield in cereals (Shashidhar *et al.*, 2008).Mobasser *et al.* (2008) reported that silicon application does not affect thousand kernel weight in rice. Ahmad *et al.* (2007), Surapornpiboom *et al.*(2008) and Elzbieta (2009)reported that silicon is responsible to control stomatal activity, photosynthesis and water use efficiency which ultimately results in better vegetative growth and straw yield. Malidareh (2011) reported that thousand grain weight was significantly improved by silicon application. According to Ahmed *et al* .(2013) silicon when applied as foliar spray could not exert any significant influence on panicle length, grain length, HI and number of kernals in Basmati rice. But number of spikelet panicle-^{1} and thousand grain weight found to vary significantly registering highest value when foliar spray of silicon at 1% level. Maximum straw yield was produced when 1% silicon was applied as foliar spray (Ahmed *et al.,*2013) and it was significantly superior to control (without silicon). He also reported that significant increase in yield due to silicon application. But all the three levels tested (0.25.0.5 and 1% Si foliar spray) were statically on par.

2.2 EFFECT ON SILICON ON INCIDENCE OF PEST AND DISEASE

The specific mechanisms responsible for Si ability to increase disease tolerance are not fully understood, though thickening of the Si layer in the cuticle and improved stomata control have been suggested as contributing factor (Okuda and Takahashi, 1961; Yoshida, 1965; Ma, 1988).Silicon has a unique physiological role in alleviating both biotic and abiotic stresses in most of the crops (Yoshida, 1975; Epstein, 1994; Savant *et al.,* 1999; Takahashi, 1995; Rodrigues *et al.,* 1998.,Korndorfer *et al.,*1999.,Datnoff*et al.,* 2001:Seebold *et al.,* 2001).Formation of a physical barrier in epidermal cells by Si deposition contributes to plant resistance against diseases and pests (Miyake and Takahashi, 1983; Epstein, 1994).

Si plays a favorable role in plant growth, mineral nutrition, mechanical strength, and resistance to fungal diseases. Silicon deposited in the epidermal tissue mechanically deters hyphae invasion (Takahashi, 1996). Rodrigues *et al.* (1998) reported a significant reduction in sheath blight development in rice with the addition of Si. Silicon can reduce the severity of several important diseases of rice, including blast, brown spot, sheath blight, leaf scald and grain discoloration and of sugarcane, including leaf freckling and ring spot (Datnoff *et al.,* 2001; Savant *et al.,* 1997; Korndorfer *et al.,* 1999).

Seebold *et al.* (2001) reported that the number of sporolating lesions, lesion size, rate of lesion expansion, diseased leaf area, and number of spores per lesions reduced with increasing rate of Si application. In another experiment, Rodrigues *et al.* (2001) reported that Si fertilization increased the host resistance against sheath blight.

A growing body of evidence indicates that adequate uptake of silicon (Si) can substantially increase the tolerance of rice (*Oryza sativa* L.), sugarcane (*Saccharum officinarum* L.) and other crops to both abiotic and biotic stresses (Dantoff *et al.,* 2001; Ma and Takahashi, 2002). Plants deficient in Si are more susceptible to fungal disease, insect feeding, as well as other biotic and abiotic stresses that adversely affect crop production. Low Si uptake has been shown to increase the susceptibility of rice to blast (*Magnaporthe grisea* (Hebert) Barr), leaf blight (*Xanthomonas oryzae pv. Oryzae* (Ishiyama) Swings et al.), brown spot (*Cochliobolus miyabeanus* (Ito and Kuribayashi in Ito) Drechs ex Dastur), stem rot (*Magnaporthe salvinii* Catt.), scald (*Monographella albescens* Theum), and grain discoloration (Volk *et al.,* 1958; Mathai *et al.,* 1977;Webster and Gunnell, 1992; Winslow, 1992., Savant *et al.,* 1997; Epstein, 1999; Kobayashi *et al.,* 2001; ; Rodrigues *et al.,* 2001; Massey and Hartley, 2006).

Several economically important insect pests, such as stem borer Ota *et al.*(1957); Yoshida, (1975); IRRI.(1965); Sawant *et aI.*(1994), brown plant hopper Sujatha *et al.*(1987), green leaf hopper Maxwell *et aI.*(1972), leaf spider Yoshida, (1975), and mites Tanaka and Park(1966) sugarcane stalk borer Coulibaly (1990), have been suppressed by improving Si concentration in plants. The presence of Si crystals in epidermal tissues hinder the feeding of the insect, which in their phase has rather fragile mandibles (Savant *et aI.,* 1997). Plants like sugarcane and rice, with high Si content, seem to interfere in the feeding of larvae, damaging their mandibles. It is possible that plants with higher Si contents in their tissue would have a higher level of resistance to the infections by such pests (Savant *et al., (*1999).

Adequate si uptake also reduces the susceptibility of plants to chewing insects such as stem borer (*Chilo suppressalis*), possibly by rendering plant tissue less digestible and by causing greater damage to the mandibles of feeding insects (Massey and Hartley, 2006).The physiological studies suggests that silicon increases defense response and cell silicification of rice leaves completely contribute to the silicon-induced rice resistance against disease and herbivore insect (Chen *et al.,* 2011).

2.3 EFFECT OF POTASSIUM ON RICE GROWTH, YIELD AND YIELD ATTRIBUTES AND PEST AND DISEASE INCIDENCE

2.3.1 Effect of Potassium on Growth of Rice

Potassium is one of the three essential macronutrients required in the largest amount for plant growth and yield. Potassium when absorbed during vegetative phase will strengthen the cell wall, make the plant physically stronger, enabling it to withstand biotic and abiotic stresses. At reproductive phase it helps in improving size and weight of grain, quality and increases plants resistance to diseases . Potassium is an essential element for the growth of rice plant and takes part in various physiological processes (Yoshida,1981). Application of K at appropriate physiological growth stages may be an effective means for minimizing the losses of applied nutrients, increasing its availability throughout the growth period and thereby resulting in higher yield of rice (Sarkar *et al*., 1995).

Potassium had a key role in rice nutrition. Tanaka *et al.* (1977) indicated that the rice plant was characterised by its high capacity of absorbing as well as exhausting K and thereby they tended to maintain the K concentration in a plant at constant level. Significant increase in plant height with increase in level of K was observed by (Vijayan and Sreedharan 1972 and Venkatasubbiah *et al.,*1982).Sakeena and Salam (1989) opined an increase in plant height of rice with 35 kg K_2O ha^{-1}. Similar results were obtained by (Roy and Kumar 1995). Plant requirements of potassium are high. It is essential for the physiological function of carbohydrate metabolism, N metabolism and synthesis of protein, control and regulation of various essential mineral nutrients, promotion of growth of meristematic tissues and adjustment of stomatal movement and water relation (Tisade *et al.,* 1995).Rice plants were significantly taller at a K level of 60 kg K_2O ha^{-1}over 45 kg K_2O ha^{-1} at maximum tillering and harvest stages (Babu, 1996). Singh *et al*. (2000) reported that taller plants were obtained in rice when 60 and 90 kg K_2O ha^{-1} were applied compared to control. In upland rice, plant height increased with increase in K level upto 45 kg K_2O ha^{-1}(Thomas, 2000; Anu, 2001; Ranjini, 2002). Height of the plant and its effect due to potassium at varying levels was studied by (Mohammed Salim, 2002) and observed that potassium deficiency caused significant reduction in plant height. He also reported that plant height improved with the application of potassium at the rate of 40 ppm in standard culture solution while increasing the level to 200 ppm failed to produce any significant influence. Plant height observed at 20kg K_2O per hectare and 40 kg K_2O per hectare were statistically similar with each other.

Kulkarni *et al*. (1975) opined that tiller production in rice was influenced by K application. Tillering increased with the application of K up to 60 kg K_2O ha^{-1} (Singh and Singh, 1979). Maximum number of tillers was obtained at a K level of 45 kg K_2O ha^{-1} (Thomas, 2000; Anu, 2001; Ranjini, 2002).Mohammed Salim (2002) reported that number of tillers increased with increasing levels of potassium. Bhiah *et al.* (2010) conducted a green house experiment and concluded that K application significantly increased number of tillers in all varieties of rice plant tested. Maximum number was obtained when K was applied through soil as well as spraying.

Potassium helps in root development and enhances the growth of rice plants (Vijayan and Sreedharan, 1972).Mohammed Salim (2002) reported that growth of roots of rice plant increased with increase in application of K from 3-40 ppm. However further increase from 40-200 ppm had no significant effect on root growth.

Kurmi and Das (1993) reported increased DMP at higher levels of potassium. Dry matter accumulation was higher at 50 kg K_2O ha^{-1} (Kale and Chavan, 1996). DMP increased in rice with higher levels of K upto 45 kg K_2O ha^{-1} (Rani *et al*., 1997). Singh *et al*. (1998) opined significant increase in DMP at higher K level irrespective of light condition. Dry matter production in rice increased upto 90 kg K_2O ha^{-1} (Singh *et al*., 2000). Increase in DMP of upland rice was noticed with increase in the dose of K upto 45 kg K_2O ha^{-1} (Thomas, 2000; Anu, 2001; Ranjini, 2002).Mohammed Salim (2002) reported that fresh weight of plant shoot increased with increase in amount of K from 3-40 ppm in culture solution but decreased with further increase in K. Dry weight of rice plant grown at low levels of K was significantly less than plants grown in culture solution of 40 ppm. Further increase in K from 40-200 ppm had no significant effect on dry weight of shoot of rice plant.

2.3.2 Effect of Potassium on Yield and Yield Attributes of Rice

Potassium had a key role in rice nutrition. If K is applied at appropriate physiological growth stages, we can effectively minimise the losses of applied nutrients and increase their availabilities throughout the growth period and thereby resulting in higher yield of rice (Sarkar *et al*., 1995). K application favourably increases the yield attributes in rice. Application of 60 kg K_2O ha^{-1} increased the panicle length in direct seeded upland rice (Singh and Singh, 1975).K absorbed at maximum tillering stage increased number of panicles, spikelets $panicle^{-1}$,and weight of grain (Su,1976.,Mondal and Dasmahapatra,1983).Tandon and Sekhon (1988) reported that panicle weight was increased with increase in the rate of K application. According to Velayudham and Velayudham (1991) application of 30 and 45 kg K_2O ha^{-1} significantly increased the number of grains $panicle^{-1}$ in rice. Maximum number of grains $panicle^{-1}$ in rice was obtained at 45 kg K_2O ha^{-1} (Thakur, 1992). Kurmi and Das (1993) revealed that panicle weight in rice was higher at higher levels of potassium. Krishnappa *et al.* (2006) reported that applied K increased the number of filled $grainspanicle^{-1}$. Increasing potassium rates resulted in the longest panicle of rice which could bear higher number of spikelets $panicle^{-1}$. It was supported by Zayed *et al.*(2007).

Application of potash at 30 kg ha^{-1} increased grain yield significantly (Nair, 1967). Potash application resulted in increased uptake of potassium by grains and straw but it was significant only in the case of grain but it increased the uptake of nitrogen in both grain and straw (Subramanian, 1969). Higher grain and straw yield was reported by (Gurmani *et al.,*1984).Similar results were reported by (Ghosh *et al.* 1994, Mahalle and Thorat1994).Pillai and Anasuya (1997) observed that grain and straw yields increased with increasing K rate upto 75 kg K_2O ha^{-1} above which increase was negligible. Thousand grain weight in rice increased as a result of K application (Sarmah and Baruah, 1997). In direct seeded summer rice, grain yield was favourably influenced by K upto 60 kg K_2O ha^{-1}(Pathak *et al*., 1999). They concluded that application of 30 and 45 kg K_2O ha^{-1} significantly increased rice straw yield and maximum straw yield of 7.1 t ha^{-1} was recorded at 45 kg K_2O ha^{-1}. Thomas (2000) found the economic optimum level of K for upland rice as 45 kg K_2O ha^{-1} and recorded the maximum grain yield of 3.3 t ha^{-1} at this dose.

2.3.3 Effect of Potassium on Pest and Disease Incidence

More than 50 species of pests attack rice crop. Of this *F.Furcifera*is one of the major pest of rice and inflicts heavy damage due to hopper burn (Mahar *et al.,*1978and 1983.,Majid*et al.,*1979.,Sali,1991). Increase in K in rice plant caused reduction in feeding rate of *Nilaparvatha.lugens* (Vaithilingham *et al.,*1976) and rate of population build up of *N. lugens* and green leaf hopper, *Nephotettis* sp. (Subramanian and Balasubramanian,1976.,Narayanaswamy*et al.,*1976, Ittyavirah *et al.,*1979). It is also involved in imparting resistance to drought, frost, pests, diseases and physiological disorders (Balram *et al*., 1977.,Singh and Tripathi,1979).

2.4 EFFECT OF NK RATIO ON GROWTH, YIELD AND YIELD ATTRIBUTES

2.4.1 Effect of NK Ratio on Growth of Rice

Plant height, tiller number and other growth characters of early duration rain fed rice were increased when NK level was raised from 20 : 10 to 80 : 40 kg ha^{-1} (Deshmukh *et al*., 1988). Sudha (1999) found an increase in plant height by the application of 105 kg N and 52.5 kg K_2O ha^{-1}(2:1). Thomas (2000) obtained remarkable increase in growth characters upon addition of 60: 45 kg ha^{-1} of NK compared to lower levels in upland rice. Anu (2001) reported that a fertilizer level of 80: 45 kg ha^{-1} of NK improved the growth characters in upland rice and was superior to lower levels. Ranjini (2002) obtained significant increase in growth characters upon addition of 90: 45 kg ha^{-1} of NK compared to lower levels in upland rice. Significant positive influence of NK ratios on plant height and tillers at 60 DAS and at harvest was obtained by (Mini, 2005).She observed that N: K ratio 100:50 kg ha^{-1} recorded maximum value.

Agricultural Research Organization (2011) reported that nitrogen and potassium are major nutrients in crop fertilization. They also reported that the source of N available to plants and N transformations within the soil, influence K reactions in soil, K absorption by roots, short and long-distance transport within the plant, as well as K demand by crops. NH4+ and K+ share similar valence and size properties, and consequently compete for the same exchangeable and non-exchangeable sites of soil particles. The effects of K+ on fruit quality have been shown to be dependent on the N source (ARO, 2011).

2.4.2 Effect of NK Ratio on Yield and Yield Attributes

According to Mondal and Dasmahapatra (1983), increasing rates of N and K from 40 to 160 kg ha^{-1} increased the number of panicles m^{-2}, percentage of filled grains and thousand grain weight in rice. Studies conducted by Sheela and Alexander (1995) revealed that NK at 67.5: 33.75 kg ha^{-1} produced the maximum value for panicle length, panicle weight and thousand grain weight and produced maximum grain yield of 3.3 t ha^{-1} in rice. Turkhade *et al*.(1996) opined that higher NK rates of 100: 50 kg ha^{-1} produced significantly higher number of grains $panicle^{-1}$. Dhiman *et al*. (1997) observed similar results. When the recommended NK dose of 100: 50 kg ha^{-1} was increased by 25 per cent, there was significant increase in number of both total and filled grains $panicle^{-1}$(Singh *et al*., 1998).

Talukdar and Chakravarthy (1988) reported that maximum yield of rice was obtained at the NK level of 90: 30 kg ha^{-1}. In upland rice, higher values of yield attributing characters and yield were recorded at an NK level of 60: 45 kg ha^{-1} by (Thomas,2000; 80 : 45 kg ha^{-1} by Anu, 2001 and 90: 45 kg ha^{-1} by Ranjini, 2002).Mini(2005)reported that maximum grain yield and straw yield were recorded at NK ratio of 100 kg N:50 kg K_2O ha^{-1}. General interactions between N and K in crop fertilization have been described by Milford and Johnston (2007).

2.5 EFFECT OF SEED RATE ON RICE GROWTH, YIELD AND YIELD ATTRIBUTES

2.5.1 Effect of Seed Rate on Growth

Seeding rate is one of the important factors which affect the yield and economic returns of rice production especially for Njavara rice as seed cost is very high.

Enyi (1965) found that LAI was higher with higher plant population. Hukkeri and Chauhan (1968) observed an increase in total number of tillers with increase in seed rate. He also reported higher dry matter production due to higher seed rate. Sonnier *et al.*(1982) reported that heavier sowing seed rates produced denser stands. Aliaga *et al.* (1986) reported marked response to seed rate in number of emerged plants. Similarly Gautam and Sharma(1987) also obtained a result which revealed that increasing plant density had significant increase in plant dry matter. Higher seeding rates compensate for reduced tiller development and promote more main stem spikes which can be favourable, especially for cultivars that tend to produce fewer tillers (Coventry *et al.,* 1993; Staggenborg *et al.,* 2003). Njavara is a poor tillering rice variety and hence higher seed rate might have compensated this.

2.5.2 Effect of Seed Rate on Yield and Yield Attributes

Sasak *et al.* (1966) reported increase in panicle weight with increase in seeding density. He also reported that increase in seed rate will increase thousand grain weight. Dawood *et al.*(1971) observed that panicle length tended to increase with increased seed rate. Singh (1971) observed that panicle length was higher with higher seed rate. Mukherjee and Chaterjee (1970), Gautam and Sharma (1983) found that number of spikelets panicle^{-1} increased when a change of seed rate was made in increasing seed rate from 60-90 kg ha^{-1}. Heavy seed rate is common practices of direct seeded farmers in the Mekong delta of Vietnam. Seed rate is normally ranged between 200-250 kg/ ha. It gave two major disadvantages as consumption large amount of seeds and more problems of insects and diseases (Tan *et al*., 1998 and Tan 2000).

Enyi (1965) reported that higher plant population resulted in higher yield of straw. Sasak *et al.* (1966) reported rice yield per unit area increased with increase in seed rate. Verma (1972) also reported that higher plant population leads to improvement in straw yield and harvest index. Rice is a kind of high-yield and high-efficient grain crops and seeding rate is one of the important factors which affect the yield and economic returns of rice production Li (2004). Depending on cultivar, this seeding rate can vary from 85 lb/acre to as much as 110 lb/acre (Frizzell *et al.,* 2005).Optimal spacing for light interception,water absorption and nutrient uptake are the main factors causing the differences in low spacing. Economic analysis demonstrated that net returns from 7 inch row (increased plant population) spacing is greater than 10inch row spacing (Frizzell *et al.,* 2005).Wen-jing He (2012) reported that among the yield components, panicles, grains panicles, seed-setting rate and harvest index are effected very significantly by the seeding rate while to 1000 seed weight the influence don't reach the level of significant difference. He also suggested that when the seeding rate is 39.387 kg/hm^2, the yield reaches the maximum value of 11536.95 kg/hm^2.

From this review it is clear that silicon & potassium are playing a key role in rice nutrition and silicon has been demonstrated to be necessary for healthy growth and stable production of rice. Poor tillering and lodging being the main constraints of Njavera rice, higher seeding rate may also benefit economic Njavara rice production. Hence the present investigation was taken up for studying the impact of varying seeding rates and different levels of Silicon and K (NK ratio) on growth & yield of Njavara rice.

Materials and Methods

3. MATERIALS AND METHODS

The field experiment entitled "Productivity enhancement in medicinal rice cv. *Njavara* (*Oryza sativa.L)* was conducted during the third crop season of 2012-13 with the objective of assessing the impact of silicon, modified NK ratios and seed rate on the growth, lodging, yield and economics of Njavara rice. The materials used and the methods adopted in the investigation are presented in this chapter.

3.1 MATERIALS

3.1.1 Experimental Site

The investigation was conducted in the wet land of the Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala. The farm is located at 8.5 ^{0} N latitude and 76.9 ^{0} E longitude and at an altitude of 29 m above mean sea level (MSL).

3.1.2 Climate and Season

Vellayani experiences warm humid tropical climate. The investigation extended for a period of four months from December 2012 to March 2013. The data on various weather parameters like weekly rainfall, maximum and minimum temperature, evaporation and relative humidity during the period under study are presented in Appendix 1 and graphically represented in Fig 1.

3.1.3 Soil

Soil samples were collected prior to the experiment from different locations in the plot at 30 cm depth and a composite sample was used for the determination of the soil properties. The important physico chemical site belonged to the textural class of sandy clay loam with a pH of 5.8. It was low in cation exchange

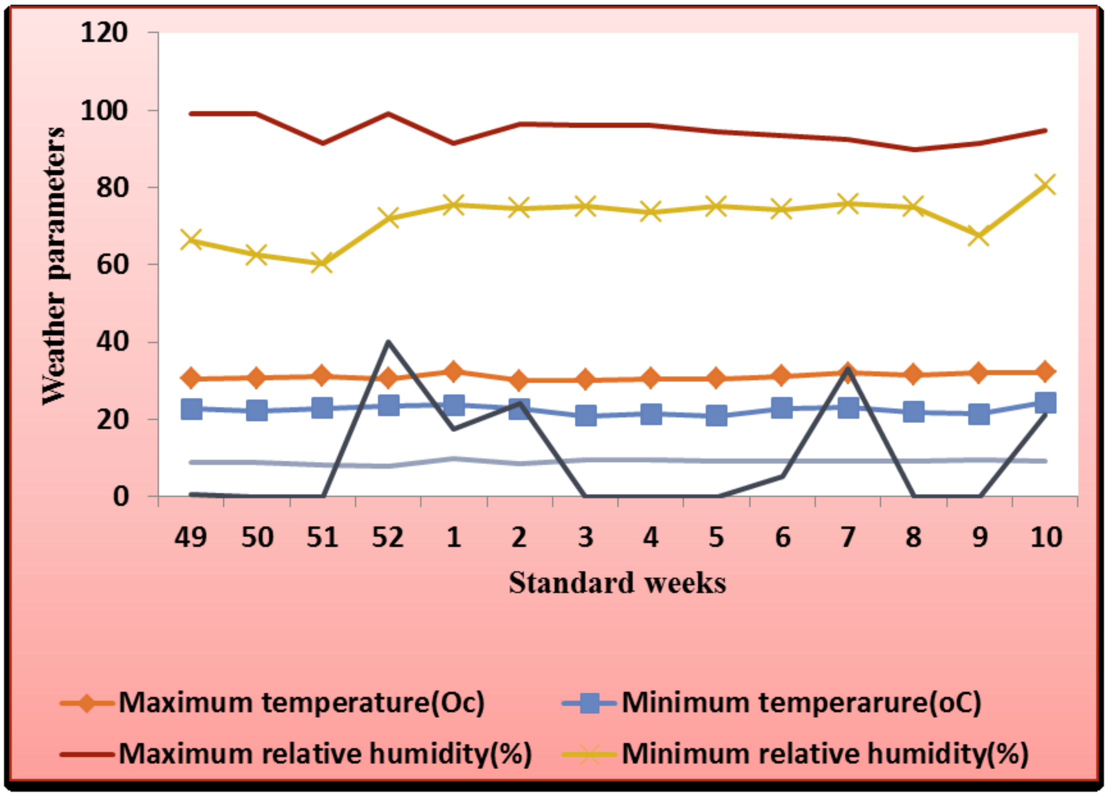

Fig 1. Weather parameters during the cropping period

(December 2012-March 2013)

capacity (CEC), organic carbon and available nitrogen and medium in available phosphorus and potassium.

3.1.4 Cropping History of the Experimental Site

The field was left fallow in the previous cropping period and hence severely infested with the aquatic weed, water cabbage.

Table 1. Physico-chemical properties of soil at experiment site

Parameters	Content (%)	Status	Methodology
Mechanical composition			
Coarse sand (per cent)	47.65		Bouyoucos Hydrometer method (Bouyoucos,1962)
Fine sand (per cent)	10.90		
Silt (per cent)	9. 05		
Clay (per cent)	32.40		
Texture	47.65	Sandy clay loam	
Chemical properties			
Soil reaction (pH)	5.8	Slightly acidic	1:2.5 soil solution ratio using pH meter with glass electrode (Jackson,1973)
CEC (c mol/kg)	14.65	-	Ammonium saturation using neutral normal ammonium acetate (Jackson, 1973)
Organic carbon (per cent)	1.14	Medium	Walkley and Black's rapid titration (Jackson, 1973)
Available N (kg ha^{-1})	310.5	Medium	Alkaline permanganate method (Subbiah&Asija,1956)
Available P_2O_5 (kg ha^{-1})	27.2	Medium	Bray colorimetric method (Jackson, 1973)
Available K_2O(kg ha^{-1})	184	Medium	Ammonium acetate method (Jackson, 1973)

3.1.5 Variety

Njavara*,* a traditional land race of rice known for its medicinal value was used for the study. Of the two types (black and yellow glumed), black glumed type was selected as the test crop. This tall indicas has extra short duration (60-100 days) and drought tolerance. Most of the plants lodge before maturity due to weak culm.

3.1.6 Source of Seed Material

The seeds for the study were obtained from the Navara Eco Farm, Karukamanikalam, Chittur College (post), Palakkad, Kerala.

3.1.7 Manures and Fertilizers

Farmyard manure, purchased from local source was used as organic nutrient source for the experiment. Urea (46.2 % N), mussorie rock phosphate (20 % P_2O_5) and muriate of potash (60 % K_2O) were used as the inorganic sources of nitrogen (N), phosphorus (P) and potassium (K) respectively. Source of silicon used was sodium silicate (SiO_2).

3.2 METHODS

3.2.1 Design and Layout

The field experiment was laid out in split plot design with three replications as detailed below. The detailed lay out plan is given in Fig 2.

Experimental design	:	Split Plot
Main plot treatments	:	9
Sub plot treatments	:	3
Number of treatments	:	27
Number of replications	:	3

Gross plot size	:	5.40 mx4.40 m
Net plot size	:	5 m x 4 m
Method of sowing	:	Broadcasting
Total number of plots	:	81

3.2.2 Treatment Details

Treatments consisted of 9 main plot treatments and 3 sub plot treatments. The 9 main plot treatments were formed by the combination of 3 levels silicon and 3 rates of seeds and the sub plot treatments include 3 levels of potassium.

Main Plot Treatment:

Silicon levels – 3	**Seed rates – 3**
S_1- 0 kg SiO_2 ha^{-1}	R_1-50 kg ha-^{1}
S_2- 50 kg SiO_2 ha^{-1}	R_2-75 kg ha^{-1}
S_3- 100 kg SiO_2 ha^{-1}	R_3-100 kg ha^{-1}

Main plot treatment combinations: 9

1. s_1r_1
2. s_1r_2
3. s_1r_3
4. s_2r_1
5. s_2r_2

6. s_2r_3
7. s_3r_1
8. s_3r_2
9. s_3r_3

Subplot treatments: 3 levels of K (3 N: K Ratios)

K_1 - 40 kg ha^{-1}(N: K ratio 1:1)

K_2- 80 kg ha^{-1}(N: K ratio 1:2)

K_3- 120 kg ha^{-1}(N: K ratio 1:3)

Total treatment combinations: 27

1. $s_1r_1k_1$
2. $s_1r_1k_2$
3. $s_1r_1k_3$
4. $s_1r_2k_1$
5. $s_1r_2k_2$
6. $s_1r_2k_3$
7. $s_1r_3k_1$
8. $s_1r_3k_2$
9. $s_1r_3k_3$
10. $s_2r_1k_1$
11. $s_2r_1k_2$
12. $s_2r_1k_3$
13. $s_2r_2k_1$
14. $s_2r_2k_2$
15. $s_2r_2k_3$
16. $s_2r_3k_1$
17. $s_2r_3k_2$
18. $s_2r_3k_3$
19. $s_3r_1k_1$
20. $s_3r_1k_2$
21. $s_3r_1k_3$
22. $s_3r_2k_1$
23. $s_3r_2k_2$

24. $s_3r_2k_3$
25. $s_3r_3k_1$
26. $s_3r_3k_2$
27. $s_3r_3k_3$

3.2.3 Crop Husbandry Practices

3.2.3.1 Seeds and Sowing

Seeds were weighed and soaked for 12 hours and taken out and kept for germination. The seeds exhibited 100% germination. The germinated seeds were weighed and kept in muslin cloth bag separately as per the main treatments before sowing.

3.2.3.2 Main Field Preparation

The experimental area was well ploughed, puddled, levelled and brought to a weed free condition. The plots were laid out into 9 main plots with 3 subplots in three replications. The plots were separated with bunds of 25 cm width. Irrigation channels of 60 cm width were provided between the blocks. Individual plots of size 5.4 m x4.4m were perfectly levelled.

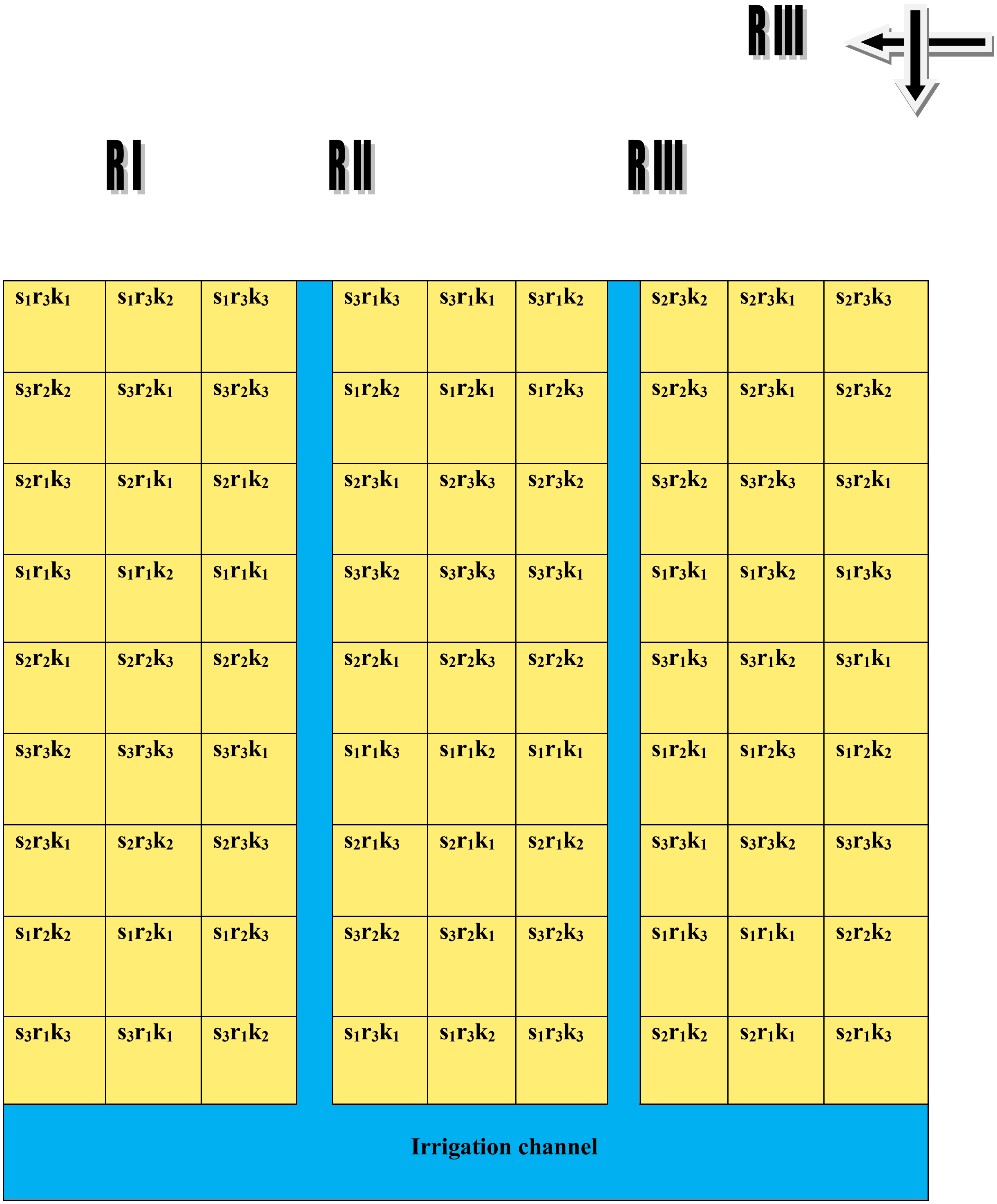

Fig 2. Lay out plan of the field experiment

Plate 1. Njavara seeds

Plate 2. Njavara plant

Plate 3. Layout of the experimental plot

Plate 4. General view of the experimental field

Plate 5. Crop at harvest stage

3.2.3.3 Application of Manures and Fertilizers

Nitrogen, phosphorus and FYM were applied as per Package of Practices recommendations of Kerala Agricultural University and potassium was applied as per treatments. Lime @ 600 kg ha^{-1} was applied in two split doses, the first dose of 350 kg ha^{-1} as basal at the time of first ploughing and second dose of 250 kg ha^{-1} as top dressing one month after sowing. The entire dose of phosphorus and 1/3 the dose of nitrogen and 1/2 the dose of potassium (according to the sub plot treatment basis) were applied one week after sowing. Silicon (SiO_2) according to the main plot treatment basis was applied after two weeks of sowing. The remaining 2/3 nitrogen was applied in two equal spits at the time of tillering and rest was applied at the time of panicle initiation stage (PI). Half the dose of potassium as per the treatment was also applied at panicle initiation stage.

3.2.3.4 After Cultivation

Almost uniform germination was obtained. Some plots were damaged by rat attack and gap filling was done in those plots. Five hills were selected randomly from each plot and tagged as observational plants. Manual weeding was done at 20, 40 and 60 DAS. Water level was maintained to a height of 2-3 cm up to seven days from sowing and thereafter 5 cm water depth was maintained. Water was drained 13 days before harvest.

3.2.3.5 Plant Protection

Acephate (2g/l) was sprayed against leaf roller when crop was at 42 days. For scoring leaf roller attack twenty hills were selected at random and total number of leaves and number of leaves damaged by the pest were counted. Then the percentage of infested leaves were calculated from the data.

3.2.3.6 Harvest

The crop was harvested on 91st day after sowing (straw just turned yellow). The net plot area was harvested separately, threshed, winnowed and weight of grain and straw from individual plots were recorded. The border rows were harvested separately.

3.3 OBSERVATIONS

Plant Sampling

Five plants were selected randomly from the net plot area of each plot as observation plants and these plants were tagged for periodical observations on growth and yield parameters and yield.

3.3.1 Crop Growth Characters

3.3.1.1 Plant Height

Plant height was recorded at 20 DAS, 40 DAS, 60 DAS, and at harvest stages from the five observation plants. The height was measured from the base of the plant to the tip of the longest leaf or tip of the longest ear head, whichever was longer and the average was recorded in centimeters.

3.3.1.2 Number of Tillers m^{-2}

Number of tillers m^{-2} was recorded at panicle initiation stage (PI) and at harvest stage. Tiller count was taken from the tagged observational hills at panicle initiation stage (PI) and at harvest stages and the mean was worked out and expressed as number of tillers m^{-2}.

3.3.1.3 Leaf Area Index (LAI)

LAI was computed at PI using the method described by (Gomez 1972). The maximum width 'w' and length 'l' of all the leaves of the five sample hills were recorded and LAI was calculated using the relationship.

Leaf area of a single leaf = l x w x k

k - Adjustment factor (0.75 at maximum tillering, flowering, panicle initiation and 0.67 at harvest stage).

$$\text{LAI} = \frac{\text{Sum of leaf area of 5 sample hills (cm}^2\text{)}}{\text{Area of land covered by the 5 sample hills (cm}^2\text{)}}$$

3.3.1.4 Culm Strength

The procedure of (Atkins 1938) was adopted for computing culm strength. Five plants were selected randomly and cut at ground level, leaf lamina and panicle were removed. Remaining culms were dried for two days under shade. The culms were cut into pieces of equal length and made into bundles and weighed. The culm strength was expressed in mg cm^{-1}.

3.3.1.5 Total Biomass

Total biomass was worked out at harvest stage. The sample plants were uprooted, washed, dried under shade and later over dried at 80+/-5°C to constant weight and worked out to kg ha^{-1}.

3.3.1.6 Rooting Depth and Spread

The sample plants uprooted at harvest stage were used for measuring root depth and spread and recorded in cm.

3.3.2 Yield Attributes and Yield

3.3.2.1 Productive Tillers m^{-2}

The number of productive tillers was noted from five observation hills at harvest and number of productive tillers $m^{-2}$was worked out.

3.3.2.2 Grain Weight Panicle^{-1}

At harvest the grain weight panicle^{-1} was noted from 5 observation plants in the net plot and expressed as g plant^{-1}

3.3.2.3 Spikelets Panicle^{-1}

At harvest the number of spikelets panicle^{-1} was counted from 5 panicles selected randomly from the observation plants and the average was recorded.

3.3.2.4 Filled Grains Panicle^{-1}

The number of filled grains in five panicles selected randomly from the observation plants was counted and the mean value was expressed as number of filled grains per panicle.

3.3.2.5 Sterility Percentage

Sterility percentage was worked out using the following relationship.

$$\text{Sterility percentage} = \frac{\text{Number of unfilled grains per panicle}}{\text{Total number of grains per panicle}} \times 100$$

3.3.2.6 Thousand Grain Weight

One thousand grains were counted from the cleaned and dried produce from each treatment and weight was recorded in grams.

3.3.2.7 Grain Yield

The net plot area was harvested individually; threshed, dried, winnowed and the dry weight was recorded as kg ha^{-1}.

3.3.2.8 Straw Yield

Straw harvested from each net plot was dried under sun and the weight was recorded as kg ha^{-1}.

3.3.2.9 Harvest Index (HI)

From grain and straw yield, the harvest index was worked out using the following equation as suggested by (Donald and Hamblin 1976).

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

3.3.3 Weed Characters

3.3.3.1 Weed Flora

Major weed species that infested the experimental site during the period of experiment were identified and grouped into grasses, sedges and broad leaved weeds at 20, 40 and 60 DAS.

3.3.3.2 Weed Biomass

Weed samples were pulled out along with roots, washed and dried under shade and later they were oven dried at 80 ± 5°C to a constant weight. The dry weight of weeds was recorded and expressed as g m^{-2}.

3.4. SOIL ANALYSIS

Soil samples were collected from the experimental plots for analyzing various physico-chemical properties. Composite soil samples were collected before the start of the experiment and also after harvest and analyzed to determine the pH, available N, P, K and organic carbon.

3.4.1 Chemical Properties

3.4.1.1 Cation Exchange Capacity

The neutral normal ammonium acetate method suggested by (Jackson 1973) was used for estimating CEC and expressed as c mol kg^{-1}.

3.4.1.2 Soil Reaction (pH)

The pH was determined in a 1:2.5 soil -water suspension using Elico digital pH meter (Jackson, 1973).

3.4.1.3 Available Nitrogen

Available nitrogen content of the soil was estimated by alkaline permanganate method (Subbiah and Asija, 1956) and expressed as kg ha^{-1}.

3.4.1.4 Available Phosphorus

Available phosphorus in soil was determined by Bray I (0.03 N ammonium fluoride in 0.025 N hydrochloric acid) method as described by

(Jackson 1973) and readings were taken in Spectrophotometer and expressed as kg ha^{-1}.

3.4.1.5 Available Potassium

Available potassium was determined in the neutral normal ammonium acetate extract and estimated using EEL Flame photometer (Jackson, 1973) and expressed as kg ha^{-1}.

3.4.1.6 Organic Carbon

The wet digestion method suggested by (Walkley and Black 1947) was employed for the estimation of organic carbon using ferroin as indicator. It was expressed as percentage (%).

3.5. PLANT ANALYSIS

Sample plants collected from each plot at harvest were separated into straw and grain, sun dried, and then oven dried to a constant weight and the samples were ground, digested and used for analysis of nutrient content.

Nutrient uptake was worked out using the following equation and expressed as kg ha^{-1}.

$$\text{Nutrient uptake} = \frac{\text{Nutrient content x Dry matter production}}{100}$$

Table 2. Plant analysis methods

SL.No	Nutrient	Method	References
1.	Nitrogen	Microkjeldahl method	Jackson,1973
2.	Phosphorus	Diacid extract estimated colorimetrically in a Spectronic-20 Spectrophotometer by Vanado molybdophosphoric yellow colour method	Jackson,1973
3.	Potassium	Diacid extract method using Flame photometer	Jackson,1973

3.6 ECONOMIC ANALYSIS

The economics of cultivation was worked out based on the costs of the various inputs and produce at the time of experimentation.

3.6.1 Net Income

Net income was computed using the formula.

Net income (Rs. ha^{-1}) = Gross income - Total expenditure

3.6.2 Benefit Cost Ratio (BCR)

Benefit Cost Ratio was computed using the formula

$$BCR = \frac{\text{Gross income}}{\text{Total expenditure}}$$

3.7 STASTICAL ANALYSIS

The data recorded during the field investigation, on various characters were statistically analyzed with split plot design as suggested by (Gomez and Gomez 1984) for test of significance. Wherever the treatment differences were found significant, the critical differences were worked out at 5 per cent probability level and the values furnished. Treatment differences that were not significant are denoted as NS.

Results

4. RESULTS

An investigation entitled ‘Productivity enhancement in medicinal rice cv. Njavara’ was carried out at the Instructional Farm, College of Agriculture, Vellayani during the period from December 2012 to March 2013.The experiment was aimed at studying the impact of silicon, modified NK ratios (K levels) and reduced seed rates on the growth and yield of Njavara rice. The data were stastically analyzed and results are presented in this chapter under different headings.

4.1. GROWTH ATTRIBUTES

4.1.1 Plant Height

Height of the plant as influenced by silicon, seed rate and potassium (NK ratio) are presented in the tables 3 to 6.

Silicon, seed rate, and potassium levels (NK ratios) produced significant difference in plant height only at 40 DAS and at harvest. The plants at harvest stage were tallest at S_1 level (0 kg ha^{-1}) of silicon. Seed rate @ 50 kg ha^{-1}(R_1) and 75kg ha^{-1} (R_2) were on par and plants were significantly taller than plants at 100 kg ha^{-1}seed rate (R_3). Potassium at K_2 (NK ratio 1:2) recorded significantly superior plant height of 105.3 cm as compared to other two levels.

SxR interaction and RxK interaction were not significant at all growth stages. But SxK interactions was significant at 40 DAS and harvest.

SxRxK interaction was significant only at harvest stage and the highest plant height was recorded by s_3 r_2k_2 closely followed by s_2 r_2k_1.These treatments were on par with all other treatments except $s_3r_3k_1$, $s_3r_3k_3$,$s_3r_2k_2$,$s_2r_3k_1$,$s_2r_3k_2$,$s_2r_3k_3$,$s_2r_2k_3$,$s_2r_1k_1$,$s_1r_1k_1$.

4.1.2 Tillers m^{-2}

The data on number of tillers m^{-2} at PI stage and harvest stage are presented in tables 7.

Table 3. Effect of silicon, seed rate and potassium on plant height (cm) of Njavara

Plant height(cm)				
Treatments	20DAS	40 DAS	60 DAS	HARVEST
S_1 (0 kg ha^{-1})	36.69	85.70	99.43	105.54
S_2 (50 kg ha^{-1})	36.42	83.97	98.48	103.70
S_3 (100 kg ha^{-1})	36.41	86.70	94.06	103.06
SE m(±)	0.5	0.51	1.97	0.33
CD(0.05)	NS	1.54	NS	1.00
R_1 (50 kg ha^{-1})	36.73	86.18	98.25	104.67
R_2 (75 kg ha^{-1})	36.40	83.83	94.34	104.95
R_3 (100 kg ha^{-1})	36.38	86.70	99.39	102.68
SE m(±)	0.5	0.51	1.97	0.33
CD(0.05)	NS	1.54	NS	1.00
K_1 (NK-1:1)	36.58	86.45	94.74	103.45
K_2 (NK-1:2)	36.05	85.17	99.32	105.30
K_3 (NK-1:3)	36.89	84.76	97.92	103.50
SE m(±)	0.56	0.89	2.3	0.58
CD(0.05)	NS	2.67	NS	9.86

Table 4. Interaction effect of silicon and potassium (SxK) on plant height (cm) of Njavara(40 DAS).

Plant height (cm)			
Potassium levels (N : K ratio)			
Treatments	K1 40 kg ha^{-1}(1:1)	K2 80 kg ha^{-1}(1:2)	K3 120 kg ha^{-1}(1:3)
S_1 (0 kg ha)	87.57	84.04	85.50
S_2 (50 kg ha)	84.03	83.33	84.52
S_3 (100 kg ha)	87.74	88.11	84.26
SE m(±)	0.92		
CD(0.05)	2.64		

Table 5. Interaction effect of silicon and seed rate (SxR), silicon and potassium (SxK) on plant height (cm) of Njavara (Harvest).

Plant height (cm)						
Treatments	Seed rate (R)			Potassium levels (NK ratio)		
Silicon	R_1 50 kg ha^{-1}	R_2 75 kg ha^{-1}	R_3 100 kg ha^{-1}	K_1 40 kg ha^{-1} (1:1)	K_2 80 kg ha^{-1} (1:2)	K_3 120kg ha^{-1} (1:3)
S_1	101.24	106.15	104.8	104.97	105.33	106.31
S_2	104.86	105.34	100.97	103.82	104.27	103.0
S_3	103.35	103.35	100.86	101.56	106.28	101.42
SE m (±)	0.58			0.83		
CD(0.05)	1.73			2.38		

Table 6. Interaction effect of silicon, seed rate and potassium (SxRxK) on plant height (cm) of Njavara (Harvest)

Plant height (cm)			
Potassium levels (N : K ratio)			
Treatments	K_1 (1 :1)	K_2 (1 :2)	K_3 (1 :3)
s_1r_1	103.20	104.60	104.93
s_1r_2	104.20	107.20	107.30
s_1r_3	107.76	104.20	106.70
s_2r_1	103.86	106.33	104.20
s_2r_2	108.06	104.46	103.50
s_2r_3	99.53	102.03	101.36
s_3r_1	104.56	105.53	104.83
s_3r_2	104.13	108.33	97.60
s_3r_3	96.00	105.00	101.60
SE m(±)	1.4		
CD (0.05)	4.12		

The main effects of silicon and seed rate could not exert any significant influence on number of tillers m^{-2} at panicle initiation stage, but at harvest stage both silicon and seed rate produced significant variation. Highest number of tillers m^{-2}at harvest stage was recorded by S_2 (50 kg ha^{-1}) and lowest number of tillers m^{-2} was recorded by S_1(0 kg ha^{-1}).

Among seed rates R_1 recorded highest tillers m^{-2} at harvest stage and R_2 recorded lowest number.

But potassium (NK ratio) levels produced significant effect on number of tillers at both stages and the highest number of tillers m^{-2} of 400.82 was recorded by K_2(NK ratio 1:2) at PI stage and at harvest stage. Lowest number of tillers m^{-2} (375.64) was recorded by the K_2 (NK ratio 1:1) at PI stage and (351.14) by the K_1(NK ratio 1:1) at harvest stage.

SxR interaction was significant at both the stages. Maximum number of tillers m^{-2} of 442.81 was recorded by s_3r_1 at PI stage and by s_2r_3(425.44) at harvest stage which were significantly superior to all other treatments..Lowest number of tillers m^{-2} was recorded by s_2r_3 and s_1r_2 at PI and at harvest stage respectively and these were significantly inferior to all other treatments.

SxK interaction had a significant effect on number of tillers m^{-2}at PI stage only and RxK interaction had a significant effect on number of tillers m^{-2}at PI stage and at harvest stage. The highest number of tillers $m^{-2}$was recorded by s_2k_3 (418.63) which was on par with s_2k_2 and s_1k_2.

RXK was significant at both the stages and highest number of tillers m^{-2} was recorded by r_2k_2 which was on par with all other treatments except r_1k_2 and r_2k_1 at PI stage. At harvest stage r_3k_2 recorded highest tiller number and was on par with all treatments except r_2k_1, r_1k_2 and r_3k_1.

SxRxK interaction was also significant at both the stage .The highest number of tillers m^{-2} was recorded by $s_1r_1k_1$.and $s_2r_3k_2$ at PI and harvest stage respectively.

Table 7. Effect of silicon, seed rate and potassium on tillers m^{-2} of Njavara

Tillers m^{-2}		
Treatments	PI stage	Harvest
S_1 (0 kg ha^{-1})	383.65	354.67
S_2 (50 kg ha^{-1})	400.87	385.42
S_3 (100 kg ha^{-1})	389.62	373.03
SE m(±)	5.7	13.11
CD(0.05)	NS	4.37
R_1 (50 kg ha-^{1})	394.87	369.1
R_2 (75 kg ha-^{1})	379.88	360.4
R_3 (100 kg ha-^{1})	399.39	383.5
SE m(±)	5.7	13.11
CD(0.05)	NS	4.37
K_1 (NK-1:1)	375.64	351.14
K_2 (NK-1:2)	400.82	381.71
K_3 (NK-1:3)	397.68	380.27
SE m(±)	5.95	4.69
CD(0.05)	17.08	15.8

Table 8. Interaction effect of silicon and seed rate (SxR) on tillers m^{-2}of Njavara (PI and harvest stage)

Tillers m^{-2}						
Treatments	PI			Harvest		
Silicon	R_1	R_2	R_3	R_1	R_2	R_3
S_1	408.45	364.54	377.93	359.0	342.3	362.3
S_2	384.63	375.18	340.25	373.5	357.2	425.4
S_3	442.81	391.53	399.19	374.5	381.7	362.7
		SR			SR	
SE m(±)		10.02			22.7	
CD(0.05)		17.08			7.57	

Table 9. Interaction effect of silicon and potassium (SxK) on tillers m^{-2}of Njavara at PI stage

Treatments	Tillers m^{-2}		
Silicon	$K_{1(1:1)}$	$K_{2(1:2)}$	$K_{3(1:3)}$
S_1	371.73	404.11	375.1
S_2	368.15	415.85	418.63
S_3	387.04	382.5	339.33
		SK	
SE m(±)		10.3	
CD(0.05)		29.58	

Table 10. Interaction effect of seed rate and potassium (RxK) on tillers m^{-2} of Njavara (PI and harvest stage)

Tillers m^{-2}						
Treatments	PI			Harvest		
Seed rate	$K_{1(1:1)}$	$K_{2(1:2)}$	$K_{3(1:3)}$	$K_{1(1:1)}$	$K_{2(1:2)}$	$K_{3(1:3)}$
R_1	409.06	376.56	398.98	371.18	355.32	380.92
R_2	332.43	416.38	385.43	314.9	394.15	372.26
R_3	409.51	403.23	405.68	367.28	395.66	387.63
		RK			RK	
SE m(±)		10.30			9.71	
CD(0.05)		29.58			27.87	

Table 11. Interaction effect of silicon,seed rate and potassium (SxRxK) on tillers m^{-2} of Njavara (PI and harvest stage)

Tillers m^{-2} Potassium levels (NK ratio)						
Treatments	PI			Harvest		
	K_1(1:1)	K_2(1:2)	K_3(1:3)	K_1(1:1)	K_2(1:2)	K_3(1:3)
s_1r_1	459.60	384.55	381.20	385.74	345.78	346.4
s_1r_2	301.00	440.10	352.60	282.33	412.70	332
s_1r_3	354.60	387.70	391.50	336.06	370.53	380.5
s_2r_1	391.10	371.75	391.05	381.36	358.46	380.86
s_2r_2	288.25	419.60	417.01	270.83	397.76	403.16
s_2r_3	425.10	456.20	447.15	405.76	442.30	428.26
s_3r_1	376.50	373.40	424.70	346.43	361.73	415.5
s_3r_2	408.05	389.45	402.25	391.7	372.00	381.63
s_3r_3	376.60	384.65	371.05	360.03	374.15	354.13
SE m(±)		17.85			16.81	
CD(0.05)		51.24			48.28	

4.1.3 Leaf Area Index (LAI)

The data on leaf area index are presented in tables 12 to 14.

Result of the study indicated significant difference in leaf area index due to silicon application at panicle initiation stage. The highest leaf area index of 1.94 was recorded by S_3 (silicon -100kg ha^{-1}) and lowest value of 1.79 was recorded by S_2(silicon -50kg ha^{-1})

Effect of seed rate on the leaf area index was also significant at panicle initiation stage .The the highest LAI of 1.94 was recorded by R_2 and R_3 . Lowest recorded a value of 1.79 by R_1.

NK ratio failed to produce any significant effect on the leaf area index.

SxR interaction was found significant at panicle initiation stage. Highest and lowest LAI values were recorded by s_1r_2 and s_2r_1.SxK interaction effect on LAI was non-significant. RxK interactions were significant only at PI stage and the highest value of 2.12 was recorded by r_3k_1. SxRxK interaction was non-significant.

4.1.4 Rooting Depth

The data on rooting depth are presented in table 15.

Result of the study indicated no significant difference in rooting depth due to silicon and potassium levels (NK ratio).

The effect of seed rate on rooting depth was significant and the highest rooting depth of 11.56cm was recorded by R_1 (seed rate-50kg ha^{-1}) which was on par with R_3(seed rate-100kg ha^{-1}).The lowest rooting depth of 10.52cm was recorded by R_2 (seed rate-75kg ha^{-1}).

SxR, SxK, RxK and SxRxK interactions had no significant effect on rooting depth.

Table 12. Effect of silicon, seed rate and potassium on LAI of Njavara

LAI	
Treatments	PI stage
S_1 (0 kg ha-^{1})	1.9
S_2 (50 kg ha-^{1})	1.79
S_3 (100 kg ha-^{1})	1.94
SE m (±)	0.03
CD(0.05)	0.09
R_1 (50 kg ha-^{1})	1.79
R_2 (75 kg ha-^{1})	1.94
R_3 (100 kg ha-^{1})	1.94
SE m (±)	0.03
CD(0.05)	0.09
K_1 (NK-1:1)	1.99
K_2 (NK-1:2)	1.93
K_3 (NK-1:3)	1.84
SE m (±)	0.04
CD(0.05)	NS

Table 13. Interaction effect of silicon and seed rate (SxR) and silicon and potassium (SxK) on LAI of Njavara (PI stage)

LAI						
Treatments	Seed rate			Potassium levels (NK ratio)		
Silicon	R_1	R_2	R_3	K_1 (1:1)	K_2 (1:2)	K_3 (1:3)
S_1	1.85	2.1	1.88	1.97	1.94	1.92
S_2	1.61	1.81	1.96	1.76	1.83	1.78
S_3	1.92	1.91	1.98	1.95	2.03	1.83
	SR	SK				
SE m (±)	0.05	0.07				
CD(0.05)	0.15	NS				

Table 14. Interaction effect of seed rate and potassium (RxK) on LAI of Njavara (PI stage)

LAI			
Treatments	K_1 (NK :1 :1)	K_2 (NK :1 :2)	K_3 (NK :1 :3)
R_1	1.78	1.83	1.76
R_2	1.78	1.98	2.04
R_3	2.12	1.98	1.73
	RK		
SE m (±)	0.07		
CD(0.05)	0.21		

4.1.5 Total Biomass

The data on total biomass are presented in tables 15 and 16.

The total biomass production was not significantly influenced by silicon and potassium levels (NK ratio) .

The effect of seed rate on total biomass was significant and R_1 (seed @50 kg ha^{-1}) recorded the maximum value of 6317 kg ha^{-1} . Lowest total biomass of 5317 kg ha^{-1} was recorded by R_3 (seed @100 kg ha^{-1}).

Total biomass production was significantly influenced by SxR. The highest total biomass of 7260 kg ha^{-1}was recorded by s_1r_1 which was on par with s_3 r_1, and s_3 r_2. Lowest total biomass of 4570 kg ha^{-1} was recorded by s_3r_3.

SxK, RxK and SxRxK interactions had no significant effect on total biomass.

4.1.6 Culm Strength (mgcm^{-1})

Data on culm strength are presented in the tables 15 and 17

Significant difference in culm strength due to silicon application was observed. The highest culm strength of 31.99 mg cm^{-1} was obtained for S_3 (silicon - 100kg ha^{-1})

Seed rate and potassium (NK ratio) did not influence the culm strength significantly.

SxR interaction was significant and the highest culm strength of 33.54 mg cm^{-1} was recorded by s_3r_1 which was significantly superior to all other treatments. Lowest culm strength of 26.08 mg cm^{-1} was recorded by s_2r_2. Culm strength did not vary significantly due to SxK, RxK and SxRxK interactions.

Table 15. Effect of silicon, seed rate and potassium on rooting depth (cm), total biomass (kg ha^{-1}), culm strength (mg cm^{-1}) and number of productive tillers m^{-2} of Njavara

Treatments	Rooting depth(cm)	Total Biomass (kg ha^{-1})	Culm strength (mg cm^{-1})	No of productive tillers m^{-2}
S_1	10.97	6046	29.44	271.4
S_2	11.62	5739	28.49	302.45
S_3	10.95	6012	31.99	328.0
SE m (±)	0.28	96.38	1.60	15.44
CD(0.05)	NS	NS	0.53	5.15
R_1	11.56	6317	30.18	294.8
R_2	10.52	6164	29.11	295.0
R_3	11.45	5317	30.63	312.2
SE m (±)	0.24	96.38	1.60	15.44
CD(0.05)	0.74	279.66	NS	5.15
K_1(NK-1:1)	11.13	5515	29.81	279.4
K_2(NK-1:2)	11.50	5752	30.02	314.9
K_3(NK-1:3)	10.91	6530	30.08	307.7
SE m (±)	0.25	95.77	1.75	13.59
CD(0.05)	NS	NS	NS	4.19

Table 16. Interaction effect of silicon and seed rate (SxR) on total biomass (kg ha^{-1}) of Njavara

Total biomass (kg ha^{-1})			
Treatments Silicon	R_1	R_2	R_3
S_1	7260	5689	5182
S_2	5340	5678	6202
S_3	6342	7126	4570
	SR		
SE m (±)	346.86		
CD(0.05)	1215.78		

Table 17. Interaction effect of silicon and seed rate (SxR) on culm strength (mg $cm^{-1)}$

of Njavara

Culm strength(mg $cm^{-1)}$			
Treatments Silicon	R_1	R_2	R_3
S_1	28.11	29.66	30.55
S_2	28.88	26.08	30.5
S_3	33.54	31.58	30.84
	SR		
SE m (±)	2.78		
CD(0.05)	0.92		

4.2 YIELD AND YIELD ATTRIBUTES

4.2.1 Number of Productive Tillers m^{-2}

The data on the effect of silicon, seed rate and potassium on productive tillers m^{-2} are presented in tables 15, 18, 19 and 20

Silicon application significantly influenced the number of productive tillers . With increase in silicon level the number of productive tillers m^{-2} also increased significantly registering the highest value of 328.10 by S_3.

The effect of seed rate on productive tillers m^{-2} was also found to be significant. The highest number of productive tillers $m^{-2}$of 312.2 was recorded by R_3 (seed rate-100kg ha^{-1}) .The lowest number of productive tillers $m^{-2}$of 294.81 was recorded by R_1 (seed rate-50kg ha^{-1}).

NK ratio produced significant effect on productive tillers m^{-2} and K_2 (NK ratio 1:2) recorded the highest number of productive tillers m^{-2} . Lowest number of productive tillers m^{-2} was recorded by the K_1 (NK ratio 1:1).

All the interaction effects namely SxR, SxK, RxK, and SxRxK influenced the number of productive tillers m^{-2} significantly.

In SxR interaction the highest number of productive tillers m^{-2} of 340.25 was recorded by s_2r_3 which was on par with s_3r_1 and s_3r_2. Lowest number of productive tillers $m^{-2}$was recorded by s_1r_1.

In SxK interaction highest number of productive tillers m^{-2} was recorded by $s_3k_3$which was on par with s_3k_2 .The lowest number was produced by s_1k_1 and the treatment was significantly inferior to all other treatments.

For RxK interaction highest number of productive tillers m^{-2} was recorded by $r_3k_3$which was on par with r_2k_2. Lowest number of productive tillers $m^{-2}$was recorded by r_2k_1 (251.0).

SxRxK interaction was significant and maximum number of productive tillers m^{-2} of 356.6 was recorded by $s_3r_1k_3$ and was on par with $s_3r_1k_2$ significantly. Lowest productive tillers m^{-2} of 193.05 was recorded by $s_2r_2k_1$.

4.2.2 Grain Weight Panicle^{-1}(g plant^{-1})

The data on grain weight panicle^{-1} are presented in table 21.

Grain weight panicle $^{-1}$was not significantly influenced by silicon application, seed rate or potassium (NK ratio) levels.

The interaction effects also had no significant effect on grain weight panicle^{-1}.

4.2.3. Spikelets Panicle^{-1}

The data on spikelets panicle^{-1} is presented in table 21.

Silicon application significantly influenced spikelets panicle^{-1}. The highest number of spikelets panicle $^{-1}$ of 66.14 was obtained for S_2 (silicon - 50kg ha^{-1}). Lowest number of spikelets panicle^{-1} of 60.07 was recorded by S_1 (silicon - 0kg ha^{-1})

Seed rate and potassium could not exert any significant influence on spikelets panicle^{-1}.

None of the interactions had significant effect on spikelets panicle^{-1}.

4.2.4. Filled Grains Panicle $^{-1}$

The data on filled grains panicle^{-1} are presented in table 21 and 22.

Result of the study indicated no significant difference in filled grains panicle^{-1} due to silicon application,seed rate and potassium levels (NK ratios).

SxR interaction was significant and the highest filled grains panicle^{-1}of 51.7 was recorded by s_1r_3 which was on par with s_1r_1,s_2r_1, s_2r_2,.s_2r_3,s_3r_1, s_3 r_3. Lowest filled grains panicle^{-1}of 38.01 was recorded by s_1r_3 which was on par with s_1 r_1, s_2r_3,s_3 r_2,.s_3r_3. SxK, RxK and SxRxK interactions were not significant.

Table 18. Interaction effect of silicon - seed rate (SxR) , silicon -potassium (SxK) on number of productive tillers m^{-2} of Njavara

Number of productive tillers m^{-2}						
Treatments	Seed rate			Potassium (N :K ratios)		
Silicon	R_1	R_2	R_3	K_1 (1:1)	K_2 (1:2)	K_3 (1:3)
S_1	256.9	274.3	283.1	242.8	299.5	271.9
S_2	288.4	278.8	340.2	272.3	316.4	318.6
S_3	339.0	331.9	313.2	323.0	328.7	332.5
	SR			SK		
SE m (±)	26.75			22.83		
CD(0.05)	8.92			7.95		

Table 19. Interaction effect of seed rate and potassium (RxK) on number of productive tillers m^{-2} of Njavara(Harvest stage)

Number of productive tillers m^{-2}			
Treatments	K_1 (NK : 1 :1)	K_2 (NK : 1 :2)	K_3 (NK : 1 :3)
R_1	281.7	314.5	288.1
R_2	251.0	325.1	308.9
R_3	305.4	305.0	326.0
SE m (±)	22.83		
CD(0.05)	7.95		

Table 20. Interaction effect of silicon, seed rate and potassium (SxRxK) on number of productive tillers m^{-2} of Njavara (Harvest stage)

Number of productive tillers m^{-2}			
Treatments	K_1 (NK : 1 :1)	K_2 (NK : 1 :1)	K_3 (NK : 1 :1)
s_1r_1	251.1	291.0	228.8
s_1r_2	226.5	328.6	267.7
s_1r_3	251	278.9	319.4
s_2r_1	285.0	301.1	279.0
s_2r_2	193.0	307.6	335.8
s_2r_3	338.9	340.7	341.1
s_3r_1	309	351.6	356.6
s_3r_2	333.6	339.1	323.2
s_3r_3	326.4	295.6	317.7
SE m (±)	39.54		
CD (0.05)	13.77		

4.2.5. Sterility Percentage

The data on sterility percentage are presented in table 21.

Result of the study indicated no significant difference in sterility percentage due to silicon, seed rate and potassium levels (NK ratio)

The interactions SxR, SxK, RxK and SxRxK had no significant effect on sterility percentage.

4.2.6 Thousand Grain Weight (g)

The data on thousand grain weight are presented in table 21 and 23.

Result of the study indicated significant difference in thousand grain weight due to silicon application. The highest thousand grain weight of 15.86 g was obtained for S_3 (silicon - 100kg ha^{-1}) and lowest by S_1 (silicon - 0kg ha^{-1}).

The effect of seed rate on thousand grain weight was significant. The highest thousand grain weight of 15.26 g was recorded by R_1 which was on par with R_2 .

NK ratio could not produce any significant effect on thousand grain weight.

SxR interaction was significant. The highest thousand grain weight of 16.35g was recorded by s_2r_3 which was on par with s_3r_2 .

SxK and RxK interactions had no significant effect on thousand grain weight. Similarly SxRxK interaction was also found to be non significant.

4.2.7 Grain Yield

The data on grain yield are presented in tables 24, 25, 26 and 27

Grain yield did not vary significantly due to silicon application. However the highest grain yield of 2338 kg ha^{-1}was obtained for S_2 (silicon - 50kg ha^{-1}) though not significant.

The effect of seed rate on grain yield was significant and R_3(seed @100 kg ha^{-1}) recorded the maximum yield of 2356 kg ha^{-1}. This was on par with R_2(seed @75 kg ha^{-1}) and significantly superior to R_1.

Table 21. Effect of silicon, seed rate and potassium on grain weight panicle^{-1} spikelets panicle^{-1},filled grains panicle^{-1},sterility percentage and thousand grain weight of Njavara

Treatments	Grain weight panicle^{-1} (g plant $^{-1}$)	Number of spikelet's panicle^{-1}	Number of filled grains panicle^{-1}	Sterility percentage	Thousand grain weight(g)
S_1	0.62	60.07	44.41	28.80	14.55
S_2	0.72	66.14	47.40	24.76	14.98
S_3	0.68	65.11	45.34	29.43	15.86
SE m (±)	0.04	1.14	1.69	2.15	0.18
CD(0.05)	NS	3.42	NS	NS	0.56
R_1	0.68	61.55	44.41	25.00	15.26
R_2	0.66	64.37	47.40	27.26	15.14
R_3	0.70	65.40	45.34	30.74	14.99
SE m (±)	0.04	1.14	1.69	2.15	0.18
CD(0.05)	NS	NS	NS	NS	0.56
K_1(NK-1:1)	0.72	64.51	45.65	27.70	14.77
K_2(NK-1:2)	0.46	62.74	44.25	28.67	14.76
K_3(NK-1:3)	0.80	64.07	47.26	26.62	15.85
SE m (±)	0.14	1.217	1.40	1.91	0.21
CD(0.05)	NS	NS	NS	NS	NS

Table 22. Interaction effect of silicon and seed rate (SxR) on filled grains panicle $^{-1}$ of Njavara

Treatments	Filled grains panicle $^{-1}$		
Silicon	R_1	R_2	R_3
S_1	38.01	43.44	51.77
S_2	46	47.22	49
S_3	44.83	51.22	39.98
	SR		
SE m (±)	2.92		
CD(0.05)	8.78		

Table 23. Interaction effect of silicon and seed rate (SxR) on thousand grain weight (g) of Njavara

	Thousand grain weight(g)		
Treatments	Seed rate		
Silicon	R_1	R_2	R_3
S_1	14.12.	14.02	15.53
S_2	14.51	14.07	16.35
S_3	15.7	16.2	15.68
	SR		
SE m (±)	0.32		
CD(0.05)	0.97		

NK ratio could not produce any significant effect on grain yield. Among the interaction effects, SxR caused significant variation in grain yield ha^{-1}. The highest grain yield of 2513kg ha^{-1} was recorded bys_2 r_3 which was on par with s_1 r_3, s_2r_1 and s_3r_2 .Lowest grain yield of 2025Kg ha^{-1} was recorded by s_1r_1.

SxK and RxK interactions had no significant effect on grain yield. SxRxK interaction caused significant variation in grain yield. The highest grain yield of 2678 kg ha^{-1} was recorded by $s_2r_3k_2$ followed by $s_2r_2k_3$. Lowest grain yield of 1785kg ha^{-1} was recorded by $s_2r_2k_1$.

4.2.8 Straw Yield

The data on straw yield are presented in tables 24, and 28

There was no significant difference in straw yield due to silicon application. The effect of seed rate on straw yield was significant and R_1(seed @50 kg ha^{-1}) recorded the maximum value of 4163 kg ha^{-1} which was on par with R_2

NK ratio could not exert any significant effect on straw yield.

SxR interaction was significant. The highest straw yield of 5243kg ha^{-1} was recorded by s_1r_1. Lowest straw yield of 2432 kg ha^{-1} was recorded by s_3r_3 and this was significantly inferior to all other treatments.

SxK, RxK and SxRxK interactions had no significant effect on straw yield.

4.2.9 Harvest Index (HI)

The data on harvest index are presented in table 29.

Harvest index did not vary significantly due to silicon application. The effect of seed rate on harvest index was significant and R_3 (seed @100 kg ha^{-1}) recorded the maximum value of 0.21 which was significantly superior to all other levels. Lowest harvest index of 0.17 was recorded by R_1.

Table 24. Effect of silicon, seed rate and potassium on grain yield and straw yield (kg ha^{-1})

Treatments	Grain yield	Straw yield
S_1	2214	3832
S_2	2337	3402
S_3	2180	3831
SE m(±)	53.5	39
CD(0.05)	NS	NS
R_1	2154	4163
R_2	2222	3942
R_3	2356	2961
SE m(±)	53.5	39
CD(0.05)	160.39	398
K_1(NK-1:1)	2201	3314
K_2(NK-1:2)	2229	3523
K_3(NK-1:3)	2301	4229
SE m(±)	45.75 NS	40 NS
CD(0.05)	NS	NS

Table 25. Interaction effect of silicon and seed rate (SxR) , silicon and potassium (SxK) on grain yield (kg ha^{-1})of Njavara

	Grain yield (kg ha^{-1})					
Treatments	Seed rate			Potassium levels(N:K Ratio)		
Silicon	R_1	R_2	R_3	K_1 (1 :1)	K_2 (1 :2)	K_3 (1 :3)
S_1	2025.	2199.	2418	2331	2162	2149
S_2	2346.	2154	2513	2190	2362	2460
S_3	2091	2313	2137	2083	2164	2294
	SR			SK		
SE m(±)	92.66			79.65		
CD(0.05)	277.8			NS		

Table 26.Interaction effect of seed rate and potassium (RxK) on grain yield(kg ha^{-1}) of Njavara

	Grain yield (kg ha^{-1})		
Treatments	Potassium levels(N:K Ratio)		
Seed rate	K_1 (NK : 1 :1)	K_2 (NK : 1 :2)	K_3 (NK : 1 :3)
R_1	2099	2147	2215
R_2	2166	2167	2332
R_3	2339	2374	2356
SE m(±)	79.25		
CD(0.05)	NS		

Table 27. Interaction effect of silicon, seed rate and potassium (SxRxK) on grain yield(kg ha^{-1})of Njavara.

Grain yield (kg ha^{-1})			
Treatments	K_1(NK :1 :1)	K_2(NK :1 :2)	K_3 (NK :1 :3)
s_1r_1	2182	2008	1884
s_1r_2	2430	2083	2083
s_1r_3	2380	2395	2480
s_2r_1	2306	2251	2480
s_2r_2	1785	2157	2519
s_2r_3	2480	2678	2380
s_3r_1	1810	2182	2281
s_3r_2	2281	2261	2395
s_3r_3	2157	2048	2207
SE m(±)	37.26		
CD (0.05)	394.07		

Table 28. Interaction of silicon and seed rate in (SxR) , silicon and potassium (SxK) on straw yield (kg ha^{-1})of Njavara

Straw yield (kg ha^{-1})						
Treatments	Seed rate			Potassium		
Silicon	R_1	R_2	R_3	K_1 (1:1)	K_2 (1:2)	K_3 (1:3)
S_1	5243	3490	2763	3920	3457	4119
S_2	2994	3523	3689	2928	3292	3986
S_3	4251	4813	2432	3093	3821	4581
	SR			SK		
SE m(±)	96.93			45.04		
CD(0.05)	279.7			NS		

NK ratio could not produce any significant effect on harvest index.

SxR interaction exerted significant variation in HI. The highest harvest index of 0.21 was recorded by s_1r_3 and $s_2r_1$which was on par with s_1 r_2, s_2r_3,s_3r_3 .Lowest harvest index of 0.15kg $ha^{-1}$was recorded by $s_1r_1$which was on par with s_3 r_1,s_3 r_2.

SxK, RxK and SxRxK interactions had no significant effect on harvest index.

4.3. OBSERVATION ON WEEDS

4.3.1 Major Weed Flora in Experimental Field

The different weed species observed in the experimental field were categorized into grasses, sedges and broad leaved weeds. List of weed species observed is given in Table 30

4.3.2. Weed Biomass

Result are presented in table 31.

Silicon, seed rate, potassium and their different interactions could not exert any significant variation on weed biomass at any of the growth stages.

4.4 SOIL ANALYSIS

4.4.1. Organic Carbon Content

The data on organic carbon content are presented in table 32.

Result of the study indicated no significant variation in organic carbon content due to silicon application, seed rate and potassium (NK ratio). All interaction effects were also non significant on organic carbon content of soil.

4.4.2. Available Nitrogen

The data on nitrogen content are presented in table 32.

There was no significant difference in available nitrogen content of soil after the experiment due to silicon, seed rate and potassium (NK ratio) application.

Table 29. Effect of silicon, seed rate and potassium and interaction of silicon and seed rate in (SxR) on harvest index of Njavara

Harvest index				
Treatments	Seed rate			
Silicon	R_1	R_2	R_3	Mean
S_1	0.15	0.18	0.21	0.18
S_2	0.21	0.18	0.20	0.19
S_3	0.17	0.17	0.20	0.18
Mean	0.17	0.18	0.21	
	S	R	K	SR
SE m(±)	0.006	0.006	0.006	0.010
CD(0.05)	NS	0.017	NS	0.03

Table 30. Weed flora associated with Njavara rice

Common name	Scientific name	Family	Malayalam name
GRASSES			
Water cabbage	*Limnocharis flava*(L.) Buchenau	Limnocharitacea	Nagapola
Blood grass	*Isachne miliacea* Roth exRoem et Schult.	Poaceae	Changalipullu
Swamp rice grass	*Leersia hexandra* Sw.	Poaceae	Neervalipullu
Love grass	*Eragrostis tennella (Linn.)P Beauv*	Poaceae	Darbhapullu
SEDGES			
Tall flat sedge	*Cyperus exaltatus* Retz.	Cyperaceae	Warapullu
Bul rush	*Schoenoplectus lateriflorus*(J.F.Gmel.)Lye	Cyperaceae	Pongalchalli
Forked fimbry	*Fimbristylis dichotoma(L.)* Vahl	Cyperaceae	-
Greater club rush	*Scirpus grossus*L.f	Cyperaceae	Kora
BROADLEAVED WEEDS			
Pickerel weed	*Monochoria vaginalis*(Burm. f.) Presl. Ex Kunth.	Pontedariaceae	Neelolpalam
Water primose	*Ludwigia parviflora*Roxb.	Onagraceae	Neergrampu
Water spinach	*Ipomoea aquatic* Forsk.	Convolvulaceae	-
Baby tears	*Lindernia rotundifolia*blancvert	Scrophulariaceae	-

Table 31. Effect of silicon, seed rate and potassium on weed biomass (g m^{-2}) of Njavara

Treatments	20 DAS	40 DAS	60 DAS
S_1	29.29	48.40	97.91
S_2	28.03	52.74	98.94
S_3	26.55	51.85	101.54
SE m(±)	1.28	2.2	4.2
CD(0.05)	NS	NS	NS
R_1	28.88	51.37	98.51
R_2	28.48	98.50	
R_3	26.51	50.74	101.38
SE m(±)	1.28	2.2	4.2
CD(0.05)	NS	NS	NS
K_1(NK-1:1)	27.85	51.25	97.55
K_2(NK-1:2)	27.96	50.77	99.18
K_3(NK-1:3)	28.07	50.96	101.67
SEm(±)	1.44 NS	2.3 NS	5.05 NS
CD(0.05)	NS	NS	NS

The interaction effects, SxR, SxK, RxK and SxRxK were also found to be non significant.

4.4.3 Available phosphorus content

The data on available phosphorus content are presented in table 32.

Available phosphorus content of soil after the experiment was not significantly varied due to silicon, seed rate and potassium (NK ratio) application.

The interaction effects, SxR, SxK, RxK and SxRxK were also found to be non significant

4.4.4. Available Potassium Content

The data on available potassium content are presented in table 32.

Silicon, seed rate and potassium levels (NK ratio) did not cause any significant difference in available potassium content of soil after the experiment.

All interaction effects were also non significant on potassium content.

4.5. UPTAKE OF NUTRIENTS

4.5.1. Nitrogen Uptake

The data on nitrogen uptake are presented in tables 33, 34, 35 and 36.

Result of the study indicated significant difference in nitrogen uptake due to silicon application. The highest nitrogen uptake of 49.35 was obtained for S_2 (silicon - 50 kg ha^{-1}) and significantly superior to other two levels. Lowest nitrogen uptake of 39.05 was recorded by S_3 (silicon - 100 kg ha^{-1}) which was on par with S_1 (silicon - 0 kg ha^{-1}).

Table 32 Effect of silicon, seed rate, potassium on organic carbon, nitrogen ,phosphorus, and potassium status of the soil after the experiment.

Treatments	Organic carbon%	Availabe nitrogen kg ha^{-1}	Available phosphorus kg ha^{-1}	Available potassium kg ha^{-1}
S_1	1.50	243.07	29.01	336.41
S_2	1.46	234.66	29.51	339.45
S_3	1.48	235.88	37.28	340.69
SE m(±)	0.028	3.92	4.43	2.38
CD(0.05)	NS	NS	NS	NS
R_1	1.48	242.08	37.58	339.69
R_2	1.46	238.37	27.41	339.22
R_3	1.51	233.17	30.80	337.64
SE m(±)	0.028	3.92	4.43	2.38
CD(0.05)	NS	NS	NS	NS
K_1(NK-1:1)	1.49	239.02	30.96	337.22
K_2(NK-1:2)	1.50	238.11	35.2	341.06
K_3(NK-1:3)	1.45	236.49	29.63	338.27
SE m(±)	0.027	3.95	4.72	2.18
CD(0.05)	NS	NS	NS	NS

The effect of seed rate on nitrogen uptake was significant and R_3 (seed @100 kg ha^{-1}) recorded the maximum value of 52.23 . Lowest nitrogen uptake 40.54 was recorded by R_1 (seed @50 kg ha^{-1}).

NK ratio also caused significant variation on nitrogen uptake.The highest nitrogen uptake 45.99 was recorded by K_3 (NK ratio 1:3) which was on par with K2 (NK ratio 1:2).The lowest nitrogen uptake of 39.56 was recorded by K_1 (NK ratio 1:1).

SxR interaction was found significant and the highest nitrogen uptake of 62.63 was recorded by s_2 r_3. Lowest nitrogen uptake 37.04 was recorded by s_2r_1.

SxK interactions had no significant effect on nitrogen uptake.

Nitrogen uptake was significantly influenced by RxK interactions. The highest nitrogen uptake of 60.81 was recorded by r_3 k_2. Lowest nitrogen uptake was recorded by r_1 $k_1$which was on par with r_1 k_2.

SxRxK interaction caused significant variation on nitrogen uptake. In this interaction highest nitrogen uptake of 69.15 was recorded by s_2 r_3k_2. This was significantly superior to all other treatments. Lowest nitrogen uptake of 30.52 was recorded by $s_1r_1k_1$(Silicon @ 0kg ha^{-1},seed rate@ 50kg $ha^{-1}$and Potassium @40kg ha^{-1}) .

4.5.2. Phosphorus Uptake

The data on phosphorus uptake are presented in tables 33, 37, 38 and 39.

Phosphorus uptake differed significantly due to silicon application. The highest phosphorus uptake of 24.67 was obtained for S_2 (silicon – 50 kg ha^{-1}) and significantly superior to all other treatments. Lowest phosphorus uptake of 19.52 was recorded by S_3 (silicon - 100kg ha^{-1}).

Table 33. Effect of silicon, seed rate and potassium on nitrogen uptake (kg ha^{-1}) of Njavara

Treatments	Nitrogen uptake (kg ha^{-1})	Phosphorus uptake (kg ha^{-1})	potassium uptake (kg ha^{-1})
S_1	45.36	21.88	67.08
S_2	49.35	24.67	62.00
S_3	39.05	19.52	64.77
SE m(±)	0.632	1.58	1.15
CD(0.05)	1.30	7.15	3.5
R_1	40.54	18.70	58.18
R_2	43.21	21.60	59.92
R_3	52.23	26.11	79.08
SE m(±)	0.632	1.58	1.15
CD(0.05)	1.30	7.15	3.5
K_1(NK-1:1)	39.56	19.78	63.65
K_2(NK-1:2)	45.96	22.98	60.0
K_3(NK-1:3)	45.99	22.99	66.26
SE m(±)	0.688	1.54	1.40
CD(0.05)	2.96	6.66	4.02

Table 34. Interaction effect of silicon and seed rate (SxR) , silicon and potassium (SxK) on nitrogen uptake (kg ha^{-1}) of Njavara

Nitrogen uptake						
Treatments	Seed rate			Potassium		
Silicon	R_1	R_2	R_3	K_1 (1:1)	K_2 (1:2)	K_3 (1:3)
S_1	47.14	44.72	53.02	41.16	45.26	40.90
S_2	37.04	46.38	62.63	43.85	53.24	52.97
S_3	37.46	38.64	41.05	33.69	39.38	44.11
	SR			SK		
SE m(±)	0.876			2.02		
CD(0.05)	3.31			NS		

Table 35. Interaction effect of seed rate and potassium (RxK) on nitrogen uptake (kg ha^{-1}) of Njavara

Nitrogen uptake			
Treatments	K_1 (NK :1 :1)	K_2 (NK :1 :2)	K_3 (NK :1 :3)
R_1	34.62	37.65	47.92
R_2	37.60	43.26	47.80
R_3	48.24	60.81	47.51
SE m(±)	1.21		
CD(0.05)	5.01		

Table 36. Interaction effect of silicon, seed rate and potassium (SxRxK) on nitrogen uptake (kg ha^{-1})of Njavara

Treatement	K_1	K_2	K_3
s_1r_1	30.52	38.70	39.66
s_1r_2	46.68	46.67	40.19
s_1r_3	46.05	60.18	52.60
s_2r_1	41.76	45.43	60.93
s_2r_2	36.44	46.17	60.04
s_2r_3	55.45	69.15	54.53
s_3r_1	49.06	36.50	35.05
s_3r_2	41.78	41.79	55.87
s_3r_3	41.27	56.46	49.55
	srk		
SE m(±)	2.7		
CD (0.05)	6.08		

The effect of seed rate on phosphorus uptake was significant and R_3 (seed @100 kg ha^{-1}) recorded the maximum value of 26.11. Lowest phosphorus uptake of 18.7 was recorded by R_1 (seed @ 50 kg ha^{-1}).

Phosphorus uptake differed significantly due to potassium (NK ratio) application. The highest phosphorus uptake of 22.99 was recorded by K_3 (NK ratio 1:3) which was on par with K_2 (NK ratio 1:2) and significantly superior to K_1 (NK ratio 1:1).

SxR interaction was found significant. The highest phosphorus uptake of 31.31 was recorded by s_2r_3 and significantly superior to all other treatments. Lowest phosphorus uptake of 18.85 was recorded by $s_1r_1$which was on par with s_3r_3.

SxK interactions had significant effect on phosphorus uptake The highest phosphorus uptake of 26.62 was recorded by s_2k_2. Lowest phosphorus uptake 16.84 was recorded by s_3k_1 which was on par with s_1k_1, s_1k_3, s_3k_2, s_3k_3 .

RxK interaction had significant effect on phosphorus uptake. The highest phosphorus uptake of 30.40 was recorded by r_3 k_2 which was significantly superior to all other treatments. Lowest phosphorus uptake of 15.81 was recorded by $r_1k_1$which was on par with r_1 k_2.

SxRxK interaction on P uptake was also significant registering the highest value by s_2 r_3k_2 which was on par with s_2 r_3k_1. Lowest phosphorus uptake of 14.35 was recorded by $s_1r_1k_2$

4.5.3. Potassium Uptake

The data on potassium uptake are presented in tables 33, 40, 41 and 42.

There was significant difference in potassium uptake due to silicon application. The highest potassium uptake of 67.08 kg ha^{-1} was obtained for S_1 (silicon – 0 kg ha^{-1}) which was significantly superior to all other treatments.Lowest potassium uptake of 62 kg ha^{-1} was recorded by S_2.

The effect of seed rate on potassium uptake was significant and R_3 (seed @100 kg ha^{-1}) recorded the maximum value of 79.08 kg ha^{-1}. The result indicated an increase in potassium uptake with increase in seed rate. Lowest potassium uptake is 58.18 kg ha^{-1} was recorded by R_1 (seed @50 kg ha^{-1}).

There was significant variation on Potassium uptake due to K application (NKratio). The highest potassium uptake was recorded by K_3 (NK ratio 1:3) which was on par with K_2 (NK ratio 1:2). The lowest potassium uptake was recorded by K_1 (NK ratio 1:1)

SxR interaction effect on potassium uptake was found significant. The highest potassium uptake is 97.05 kg ha^{-1} was recorded by s_2 r_3. Lowest potassium uptake is 41.88 was recorded by s_2r_{12}.

SxK interaction had significant effect on potassium uptake The highest potassium uptake of 68.95 was recorded by s_1k_2 which was on par with s_2k_2..Lowest potassium uptake 50.77 of was recorded by s_2k_2.

RxK interaction had significant effect on potassium uptake. The highest potassium uptake of 80.71 was recorded by r_3k_2. Lowest potassium uptake of 57.18 was recorded by r_2k_3 which was on par with r_1 k_2.

SxRxK interaction was found to be significant. Here highest potassium uptake of 78.06 recorded by s_2 r_1k_1. Lowest potassium uptake of 43.48 was recorded by $s_1r_2k_1$ which was on par with s_1 r_1k_1, s_1 r_1k_2, s_1 r_1k_3, $s_3r_1k_1$

4.6. ECONOMIC ANALYSIS

4.6.1. Net Income

The data on net income are presented in table 43 and 44.

Table 37. Interaction of silicon and seed rate (SxR) , silicon and potassium (SxK) on phosphorus uptake (kg ha^{-1}) of Njavara

Phosphorus uptake (kg ha^{-1})						
Treatments	Seed rate			Potassium		
Silicon	R_1	R_2	R_3	K_1 (1:1)	K_2 (1:2)	K_3 (1:3)
S_1	18.85	22.29	26.51	20.58	22.63	20.45
S_2	18.52	23.19	31.31	21.92	26.62	26.48
S_3	18.73	19.32	20.52	16.84	19.69	22.05
	SR			SK		
SE m(±)	3.62			3.54		
CD(0.05)	13.27			12.42		

Table 38. Interaction effect of seed rate and potassium (RxK) on phosphorus uptake (kg ha^{-1}) of Njavara

Phosphorus uptake (kg ha^{-1})			
Treatments	K_1 (NK :1 :1)	K_2 (NK :1 :2)	K_3 (NK :1 :3)
R_1	15.81	16.77	21.41
R_2	19.30	21.64	23.80
R_3	24.12	30.40	23.70
SE m(±)	1.89		
CD(0.05)	5.44		

Table 39. Interaction effect of silicon, seed rate and potassium (SxRxK) on phosphorus uptake (kg ha^{-1})of Njavara

Treatment	K_1	K_2	K_3
s_1r_1	21.44	27.25	27.72
s_1r_2	15.86	25.70	21.29
s_1r_3	23.61	18.57	24.95
s_2r_1	25.76	25.3	15.10
s_2r_2	22.46	19.90	15.09
s_2r_3	19.77	16.83	18.63
s_3r_1	22.00	28.30	26.03
s_3r_2	29.35	28.48	21.93
s_3r_3	23.63	26.83	20.81
	srk		
SE m(±)	2.46		
CD (0.05)	6.91		

Silicon caused significant variation in net income. Highest net income was obtained for S_1 and was on par with S_2 but significantly superior to S_3.

Seed rate did not have any significant influence on net income.

NK ratio significantly influenced net income and highest net income of Rs.72102/- was obtained for K_3(NK:1:3) which was significantly superior to K_2 and K_1.Lowest net income was for K_1(NK:1:1)

SxRxK interaction was found to be significant. In this interaction highest net income of Rs.93120/- was recorded by s_1 r_2k_1 followed by $s_2r_1k_3$ .Lowest net income of Rs.32664/- was recorded by $s_3r_3k_2$

4.6.2. B: C Ratio

The data on B: Cratio is presented in table 43 and 45.

Silicon influenced the B: C ratio significantly. Highest B:C ratio was for S_1 and lowest for S_3.

Seed rate influenced the B: C ratio significantly and highest B: C ratio was for R_3 which was significantly superior to other two levels.

SxRxK interaction was found to be significant. In this interaction highest B: C ratio of 1.97 was recorded by s_1 r_2k_1. Lowest B: C ratio of 1.29 was recorded by $s_3r_3k_2$.

4.7. PEST AND DISEASE SCORING

The data on pest scoring are presented in table 46 and 47

Result of the study indicated no significant difference in pest score due to silicon application. However the highest pest scoring of 25.03 was obtained for S_1 (silicon - 0kg ha^{-1}) though not significant.

Table 40. Interaction effect of (SxR), silicon and potassium interaction (SxK) on potassium uptake (kg ha^{-1}) of Njavara

Potassium uptake (kg ha^{-1})						
Treatments	Seed rate			Potassium		
Silicon	R_1	R_2	R_3	K_1(1:1)	K_2 (1:2)	K_3 (1:3)
S_1	60.82	71.84	68.58	64.37	68.95	67.92
S_2	57.07	41.88	97.05	59.15	50.77	66.08
S_3	56.67	66.04	71.61	67.43	62.10	64.78
	SR			SK		
SE m(±)	2.02			2.42		
CD(0.05)	6.06			6.98		

Table 41. Interaction effect of seed rate and potassium (RxK) on potassium uptake (kg ha^{-1})of Njavara

Potassium uptake (kg ha^{-1})			
Treatments	K_1 (NK : 1 :1)	K_2 (NK : 1 :2)	K_3 (NK : 1 :3)
R_1	76.35	65.77	62.44
R_2	67.226	65.35	57.18
R_3	67.38	80.71	69.16
SE m(±)	2.42		
CD(0.05)	6.98		

Table 42. Interaction effect of silicon, seed rate and potassium (SxRxK) on potassium uptake (kg ha^{-1})of Njavara

Treatment	K_1	K_2	K_3
s_1r_1	65.35	65.57	51.53
s_1r_2	43.48	53.69	58.35
s_1r_3	64.27	77.61	63.87
s_2r_1	78.06	66.40	66.77
s_2r_2	64.95	60.59	60.09
s_2r_3	74.45	55.32	71.39
s_3r_1	65.63	55.33	59.03
s_3r_2	63.24	61.78	53.10
s_3r_3	63.42	69.20	62.22
	srk		
SE m(±)	4.28		
CD (0.05)	12.08		

Table 43. Effect of silicon, seed rate and potassium on net income and B:C ratio

Treatments	Net income	B:C ratio
S_1	75976	1.79
S_2	73328	1.69
S_3	53623	1.48
SE m(±)	2101.053	0.022
CD(0.05)	6299.31	0.087
R_1	65936	1.64
R_2	67961	1.64
R_3	73894	1.79
SE m(±)	2101.053	0.022
CD(0.05)	NS	0.087
K_1(NK-1:1)	64695	1.64
K_2(NK-1:2)	66130	1.64
K_3(NK-1:3)	72102	1.69
SE m(±)	1814.047	0.024
CD(0.05)	5322.260	NS

Table 44. Interaction effect of silicon, seed rate and potassium (SxRxK) on net income of Njavara

Treatement	K_1	K_2	K_3
s_1r_1	85640	73815	63975
s_1r_2	93120	62595	65899
s_1r_3	77981	77267	83498
s_2r_1	74499	73389	92665
s_2r_2	33814	62267	86455
s_2r_3	79985	88547	68340
s_3r_1	33646	64480	70264
s_3r_2	66572	60154	70750
s_3r_3	36999	32664	47080
srk			
SEm(±)	10024.14		
CD(0.05)	21835.48		

Table 45. Interaction effect of silicon, seed rate and potassium (SxRxK) on B:C ratio of Njavara

Treatement	K_1	K_2	K_3
s_1r_1	1.96	1.83	1.74
s_1r_2	1.97	1.66	1.69
s_1r_3	1.77	1.75	1.80
s_2r_1	1.77	1.75	1.92
s_2r_2	1.35	1.60	1.81
s_2r_3	1.72	1.78	1.61
s_3r_1	1.34	1.61	1.65
s_3r_2	1.59	1.53	1.62
s_3r_3	1.33	1.29	1.40
srk			
SE m(±)	0.078		
CD(0.05)	0.242		

The effect of seed rate on pest score was found to be significant. The highest pest score of 27.96 was recorded by R_2 (seed rate-75kg ha^{-1}) .The lowest pest score of 20.25 was recorded by R_1(seed rate-50kg ha^{-1}).

NK ratio could not produce any significant effect on pest score.

Coming to the interaction effects, SxR was found significant. The highest pest score of 31.77 was recorded by $s_3r_2$which was on par with s_1 r_2,.Lowest pest score of 15.22 was recorded by s_3r_1.

SxK and RxK interaction had no significant effect on pest score. Silicon- seed rate-potassium interaction (SxRxK) was also found to be non significant.

No disease incidence was observed throughout the cropping season.

Table 46. Effect of silicon, seed rate and potassium on pest scoring (%)

Treatments	Pest scoring (%)
S_1	25.44
S_2	24.11
S_3	21.88
SE m(±)	0.83
CD(0.05)	NS
R_1	20.25
R_2	27.96
R_3	24.85
SE m(±)	0.83
CD(0.05)	2.50
K_1(NK-1:1)	24.14
K_2(NK-1:2)	25.11
K_3(NK-1:3)	23.81
SE m(±)	0.98
CD(0.05)	4.33

Table 47. Interaction effect of silicon and seed rate (SxR) , silicon and potassium (SxK) on pest scoring(Leaf roller) of Njavara.

Pest scoring (%)						
Treatments	Seed rate			Potassium		
Silicon	R_1	R_2	R_3	K_1 (1:1)	K_2 (1:2)	K_3 (1:3)
S_1	21.38	28.66	24.55	25.55	24.11	25.44
S_2	23.66	23.44	23.33	21.11	25.22	24.11
S_3	15.22	31.77	26.66	25.77	26	21.88
	SR			SK		
SE m(±)	1.44			1.70		
CD(0.05)	NS			NS		

Discussion

5. DISCUSSION

Present investigation entitled 'Productivity enhancement of medicinal rice Njavara (*Oryza sativa*)' was aimed at studying the impact of silicon, reduced seed rate and modified N:K ratios on growth, yield and economics of Njavara. The data collected on various growth and yield parameters, plant nutrient uptake and soil nutrient content are analyzed statistically and the result are discussed in this chapter in different sections as given below.

1) Effect of silicon on growth, yield attributes, yield and nutrient uptake of Njavara
2) Effect of seed rate on growth, yield attributes, yield and nutrient uptake of Njavara
3) Effect of potassium on growth, yield attributes, yield and nutrient uptake of Njavara
4) Effect of interaction of silicon, seed rate and potassium on growth, yield attributes, yield and nutrient uptake of Njavara
5) Economics of Njavara production

5.1 Effect of Silicon on Growth, Yield Attributes, Yield and Nutrient Uptake of Njavara

The performance of Njavara was studied under three levels of silicon viz, 0 kg ha^{-1}(S_1), 50 kg ha^{-1}(S_2), and 100 kg ha^{-1}(S_3) SiO_2 ha^{-1} and the results obtained are discussed here. Silicon caused significant variation on plant height, LAI at panicle initiation stage, culm strength, number of productive tillers m^{-2}, spikelets panicle^{-1}, thousand grain weight and uptake of major nutrients.

The result of the study indicated that silicon could not exert any significant influence on grain yield of Njavara (Fig.3). This is in agreement with the report of Jianfeng Ma *et al*. (1989). According to him the effect of silicon on grain and straw weight was small when silicon was either added or removed during vegetative and ripening stage. In this experiment silicon was supplied to the crop as basal dose and hence may be the reason for the non significant influence. Non significance in yield may due to the non significant influence of yield contributing parameters like number of filled grains panicle^{-1}, sterility percentage and grain weight panicle^{-1}. But supplementation of silicon up to 50 kg ha^{-1}(S_2) produced a small improvement (5 percentage increase) in yield over control (S_1).The yield recorded for this treatment was 2337 kg ha^{-1}.Yield is actually a reflection of yield contributing characters and probably the higher values exhibited by this treatment for most of the yield contributing characters may be the reason for getting yield improvement (Table 21). SunilKumar (2002) also reported yield improvement in upland rice due to silicon application. According to Ma *et al*. (2001) silicon has the ability to stimulate canopy photosynthesis by improving leaf erectness, prevention of lodging and alleviating various mineral stresses. According to Matoh *et al*. (1991), if high amount of silicon accumulate in plant tissue, it helps to alleviate the water stress in the plant through reducing transpiration and also high accumulation of silicon improved the photosynthetic capacity by keeping the leaf blade erect thereby enhancing the light interception of plant.

Silicon application significantly influenced number of spikelets panicle^{-1}and thousand grain weight. The number of spikelets panicle^{-1}was maximum for silicon @ 50 kg ha^{-1} (S_2) and lowest by silicon @ 0 kg ha^{-1} (S_1) (Fig.4) .Results found for silicon in terms of yield components like number of spikelets panicle^{-1} (Ma *et a.l*,1989 , Deren *et al*., 1994,Takahashi *et al.,* 1995;) sterility percentage, (Barborose and Filho,1987,Takahashi, 1995) and thousand grain weight (Balastra.*et al.,*1989) are in agreement with the result of this experiment, who observed positive response to application of silicon. Thousand grain weight ranged from 14.55g for the treatment without silicon to 15.86g forS_3 (silicon@100 kg ha^{-1}) showing an increase with increase in silicon application (Fig.5). But Ma.*et al.* (1989), Deren *et al.* (1994) and Carvalho (2000) did not observe significant increase in thousand grain weight in rice. Yoon-Ha-Kim (2012) reported that spikelets panicle^{-1},spikelet filling and grain weight were regulated by silicon application. But panicle m^{-2} was considerably increased by

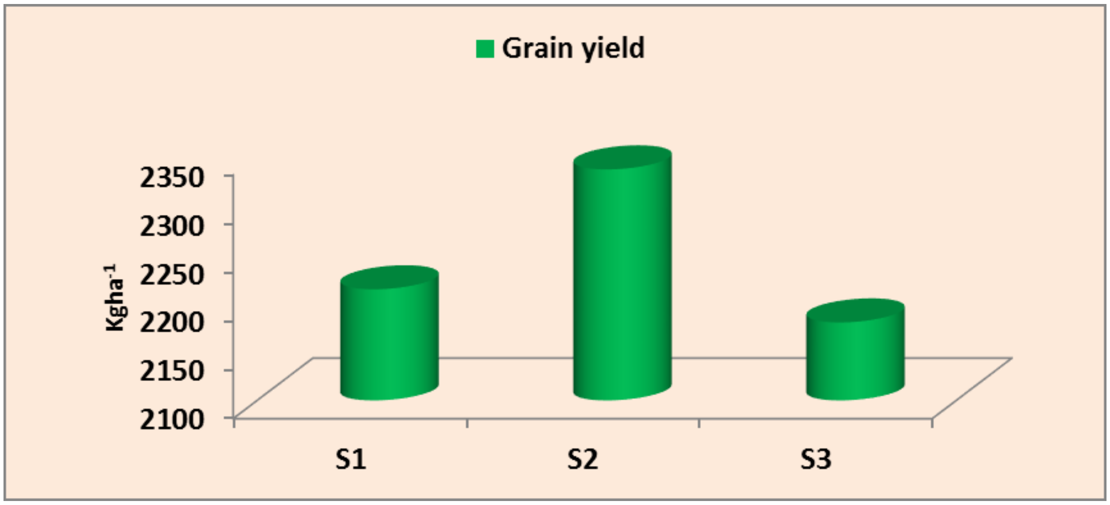

Fig 3. Effect of silicon on grain yield of Njavara rice

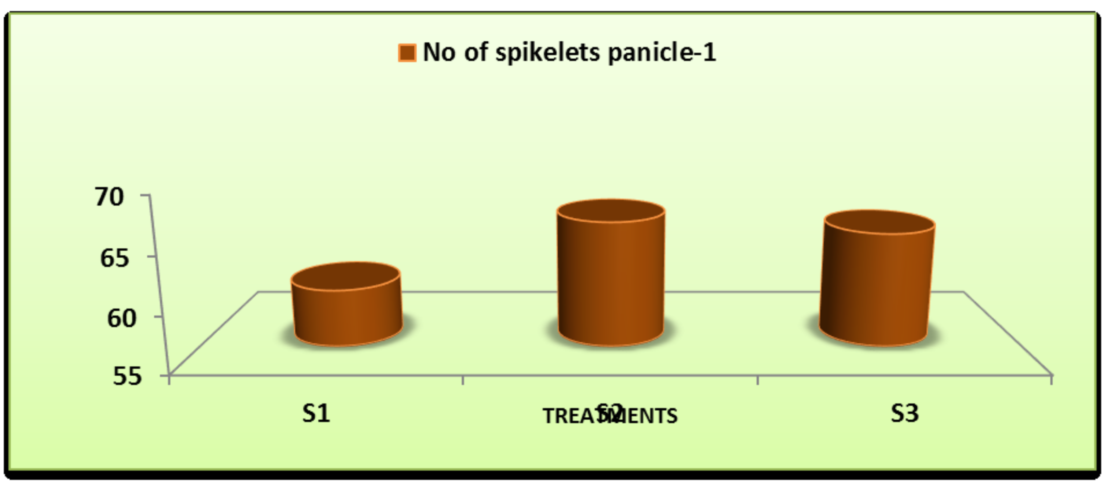

Fig 4. Effect of silicon on spikelets panicle^{-1} of Njavara rice

silicon and hence grain yield was also increased. According to Ma *et al.* (1989) reproduction stage is most effected by absence of silicon with a reduction up to 40% in number of grain bearing spikelets and 10% in the total no of spikelets panicle^{-1}.This is in corroboration with the present result where a 10% and 7% reduction was observed for number of spikelets panicle^{-1} and filled grains panicle^{-1} respectively due to the absence of silicon (Table 21).

As reported earlier, number of filled grains panicle^{-1}, sterility percentage and grain weight panicle^{-1} did not differ significantly with silicon application. But the highest grain weight panicle^{-1}, number of filled grains panicle^{-1}, harvest index and lowest sterility percentage were recorded by the treatment receiving 50 kg SiO_2 kg ha^{-1} though not significant. Both the absence of silicon and application of higher dose of silicon at 100 kg ha^{-1} resulted in the reduction of above parameters. According to Detman *et al*. (2012) silicon exerted a forward effect on photosynthesis which was fundamentally associated with increased mesophyll conductance. The reduction in the yield component of rice viz, number of filled grains panicle^{-1},grain weight panicle^{-1} and harvest index observed when quantity of silicon was enhanced to 100 kg ha^{-1} may be due to the inherent inability of medicinal Njavara rice to accumulate more silicon with its thin weak stem and poor production potential. Though rice in general is reported to accumulate large quantity of silicon (approximately 10% of its dry matter), the ability of Njavara rice is not yet investigated and may be lesser than that of other rice varieties. Sterility percentage was also lowest when silicon was applied at 50 kg ha^{-1}, though the effect was not significant. Sunilkumar (2000) reported that number of filled grains panicle^{-1}and HI increased significantly with silicon application up to 100 kg ha^{-1}in upland rice. An increase in HI due to silicon application was reported by Detman *et al.* (2012).

Number of productive tillers m^{-2} was significantly increased with increase in silicon application (Fig.6). Number of productive tillers m^{-2} ranged from 294.8 for treatment without silicon to 328.1 for treatment with 100 kg silicon. Productive tillers were found to increase significantly when fertilized with

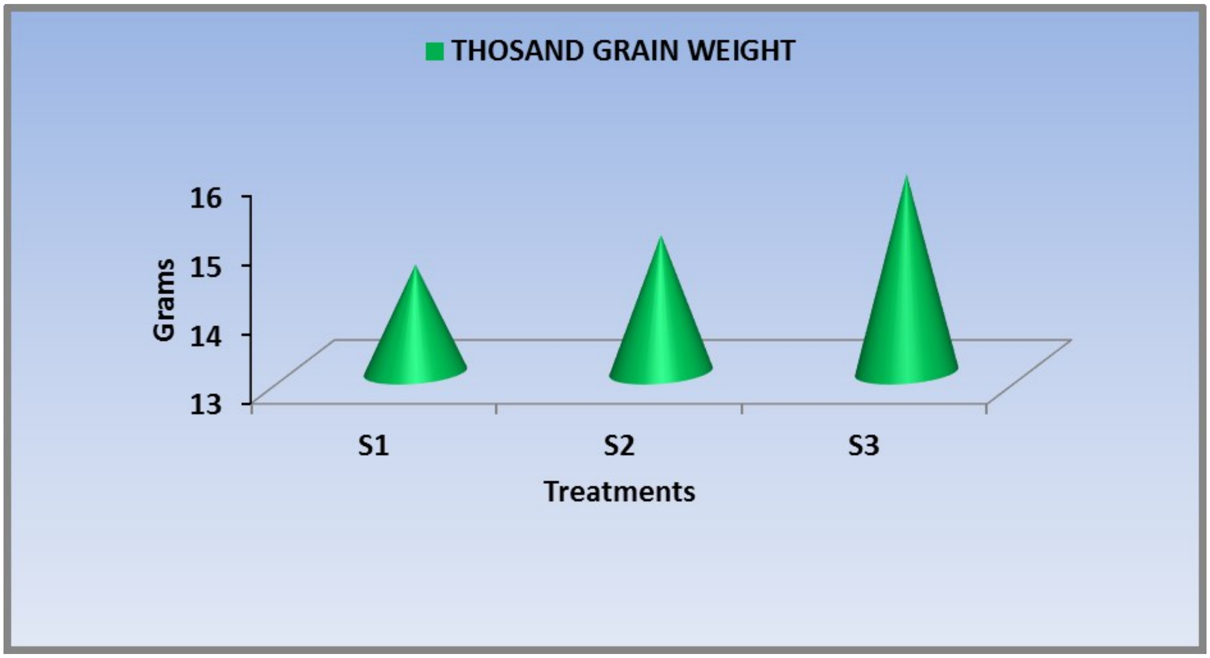

Fig 5. Effect of silicon on thousand grain weight of Njavara rice

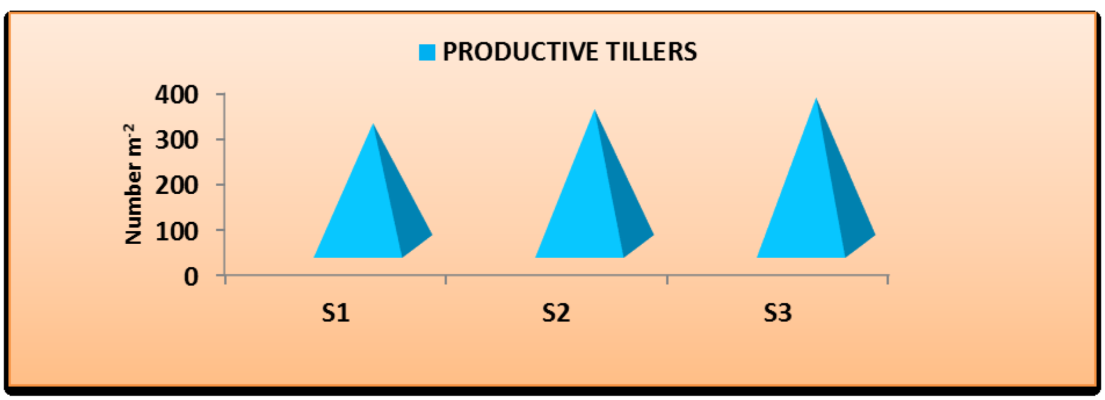

Fig 6. Effect of silicon on productive tillers m^{-2} of Njavara rice

silicon and increase was up to 10-17 %. This is contradictory to the report of Sunilkumar (2000) who observed non significance in productive tiller number due to silicon application.

Straw yield did not vary significantly due to the silicon application (Fig.7). Contradictory report showing significant variation in straw yield due to silicon application is available (Sunilkumar, 2000., Dustan Salman *et al.*, 2011).

Height of the plant varied significantly due to silicon application only at 40 DAS and at harvest (Fig.8). At 40 DAS tallest plants of 86.70 cm was observed when silicon was applied at100 kg ha^{-1}. According to Ma *et al.* (2001) silicon is reported to be a beneficial element for growth of rice plant. But at harvest stage a significant reduction in plant height was observed and silicon at 100 kg ha^{-1} produced shortest plants. Yoshida *et al*. (1962) stated that silicon is not essential for growth and tillering of rice. According to Dantoff *et al.* (2001) absorbed silica is located on leaf surface and hence decreases cuticular transpiration and it decreases plant elongation. Reduced plant height due to silicon application was reported by (Bakhat *et al*., 2009) in maize and by (Yoon-Ha –Kim 2012) in rice. Dastan Salman *et al*. (2011) reported that silicon application decreased stem length by 9.1% and maximum stem length was for control where no silicon was applied. Here in this experiment also highest plant height of 105.54 cm at harvest stage was obtained for treatment without silicon ($S_{1)}$.

Total number of tillers m^{-2} varied significantly due to silicon application at harvest stage, while the effect was non significant at PI stage (Fig.9). At both the stages S_2(50 kg SiO_2 ha^{-1}) recorded highest value. This may be due to the impact of silicon on tiller production by changing photosynthetic activity (Adatia and Busford,1986) and by changing cell wall extensibility in young growing regions (Takahashi, 1961 and Hossain *et al.*,2002 and 2007) and concluded that absence of silicon decrease number of tillers . Beneficial effect of applied silicon on tiller number has been reported by (Burbay *et al.*, 1988). Sunilkumar (2000) also reported significant increase in total number of tillers per plant in rice with

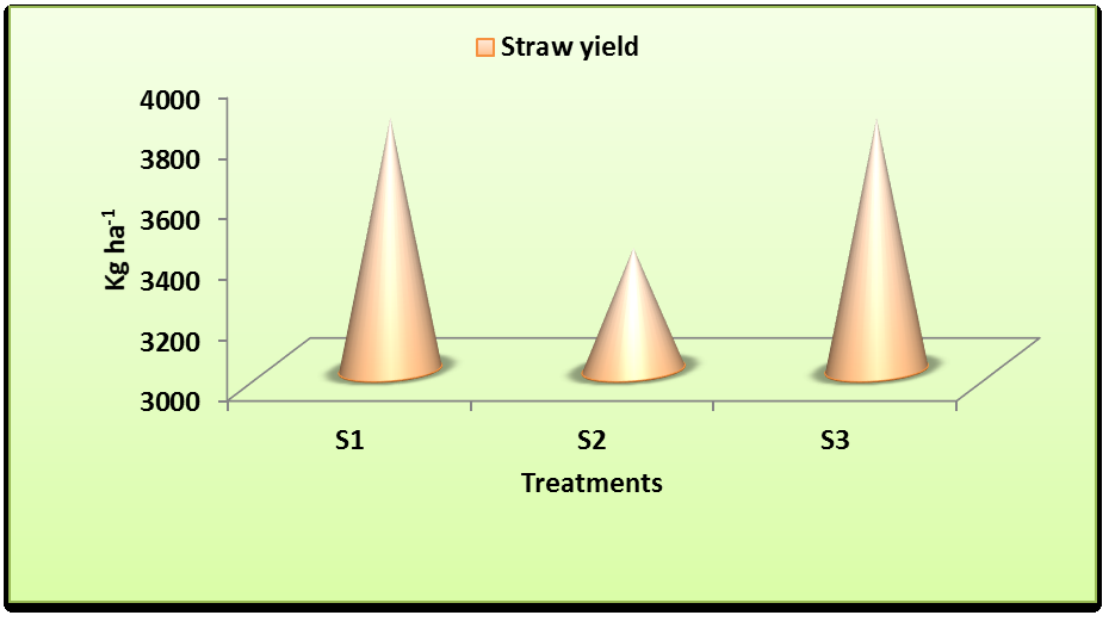

Fig 7. Effect of silicon on straw yield of Njavara rice

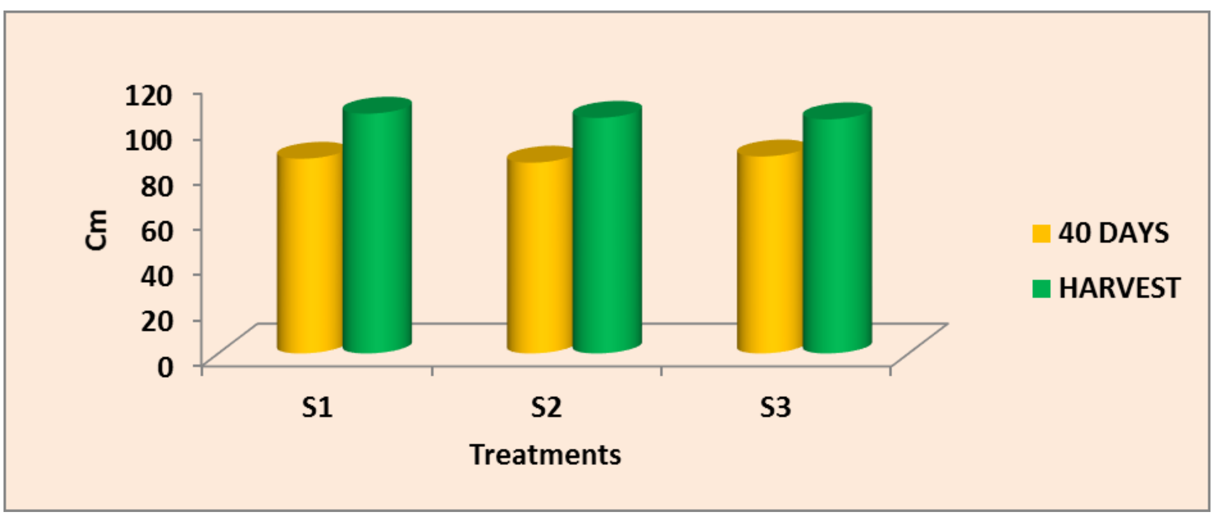

Fig 8. Effect of silicon on plant height of Njavara rice at 40 DAS and at harvest

silicon application at 60 DAS after sowings. A reduction in tiller number per m^{-2} was observed when silicon application was increased to 100 kg ha^{-1}.

Leaf area is an important index in determining crop growth as it directly involved in many plant processes. LAI varied significantly due to silicon application at panicle initiation stage and the value ranged from 1.5 to 1.94 for 0 kg SiO_2ha^{-1} (S_1) and 100 kg SiO_2ha^{-1}(S_3) respectively (Fig.9) . LAI increased with increase in silicon application. According to Yoon-Ha-Kim (2012) due to Si application, form for light interception of rice leaf was improved, so photosynthetic capacity also increased. Here LAI was 1.79 when silicon was applied at 50 kg ha^{-1} (S_2) and this treatment registered the highest grain yield of 2337 kg ha^{-1} (though not significant). This led to suggest that LAI of 1.79 may be the optimum value for Njavara rice, again confirming the inability of this cultivar to effectively utilised higher levels of silicon. Pawar and Head, (1978) observed that foliar spray of 100-400 ppm silicon applied to rice seedlings increased tillering ,vegetative growth and photosynthetic efficiency.

Culm strength expressed in mg cm^{-1} is taken as a measure of lodging resistance. Culm strength significantly increased due to silicon application registering highest value of 31.99 mg cm^{-1} when silicon was applied at 100 kg ha^{-1} (Fig.10).According to Yoon-Ha-Kim (2012) silicon significantly increased the pushing resistance from 12.2 to 16.7% and recorded lower lodging index. According to Mobasser *et al.* (2009) and Terrashaima *et al.* (1991), pushing resistance and lodging index in rice are determined by morphometric character of rice such as root morphology and stem bending characterizing. Kim *et al*. (2002) suggested that silicon accumulation in rice directly increased epidermal cell wall thickness of rice. The resistance to lodging is increased due to silicon application mainly due to the rigidity of the stalk.(Idris *et al* ,1975 ., Zhao and Jiang ,1987., Hossain *et al*.,1988.)

Application of silicon did not cause any significant variation in rooting depth. Rooting depth of Njavara ranges from 10.95 to 11.97 cm. But contradictory to this report increase in rooting activity with addition of silicon was reported by Takahashi (1995) and Sunilkumar (2000).

Total biomass did not vary significantly due to silicon application. A similar non-significant report on shoot biomass of silicon treated rice plant with control was reported by (Yoon-Ha-Kim, 2012) .Silicon could have little effect on vegetative stage as reported by Ma *et al* (1989) may be the reason for this. Since no organic molecule is known to be associated to silicon in plants as suggested by Exley (1998), the influence of this element in determining the biomass may be very little.

The highest nitrogen uptake of 49.35 kg $ha^{-1}$was obtained for the treatment receiving silicon at 50 kg ha^{-1}(S_2) and significantly superior to the other two levels (fig.11). The highest silicon levels of 100 kg ha^{-1} and lowest levels silicon @ 0 kg ha^{-1}(S_1) were on par. S_2 (50 kg SiO_2 ha^{-1}) registered 8 percent increase in nitrogen uptake as compared to S_1levels.The general improvement in plant growth and yield at 50 kg SiO_2 ha^{-1} (S_2) may be the reason for increased nitrogen uptake. According to Savant *et al.* (1997) silicon application enhanced more optimal use of nitrogen.

As in the case of nitrogen, phosphorus uptake was also highest for S_2 registering 8% improvement over control (Fig.11). This is in accordance with the findings of Rani and Narayan, (1994) where an increase in P uptake was observed with silicon application.

Potassium uptake also followed the similar trend as that of N and P with S_1 registering the maximum uptake of K (Fig.11). The percentage increase of K uptake over 100 kg ha^{-1} was 3.56 %.This is in accordance with the findings of Rani and Narayan, (1944) and Sunilkumar (2000) where an increase in P uptake was observed with silicon application.

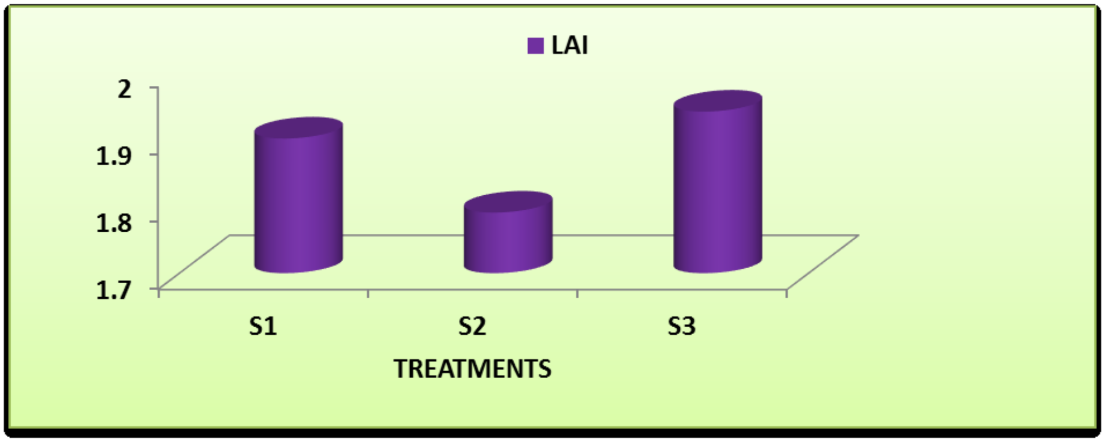

Fig 9. Effect of silicon on LAI of Njavara rice

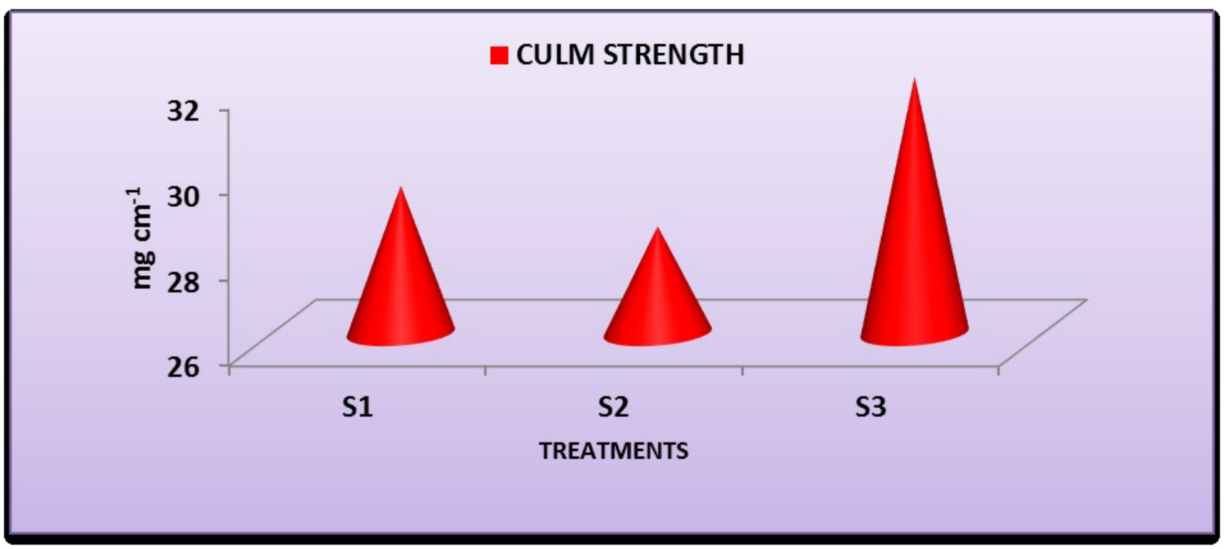

Fig 10. Effect of silicon on culm strength of Njavara rice

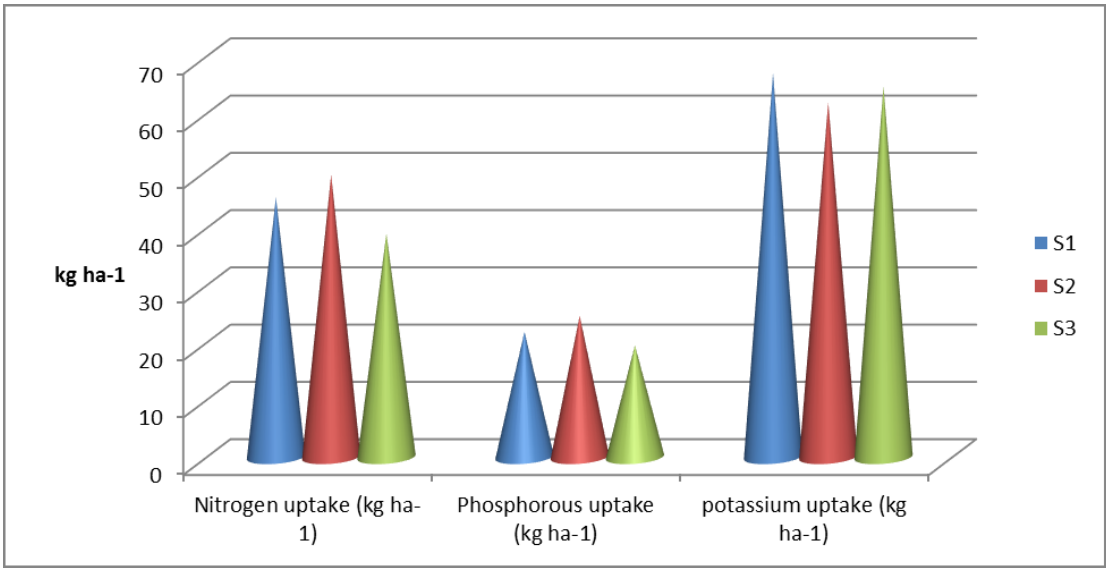

Fig 11. Effect of silicon on nitrogen ,phosphorous and potassium uptake of Njavara rice

5.2 Effect of Seed Rate on Growth, Yield Attributes, Yield and Nutrient Uptake of Njavara

Optimum plant densities vary greatly between areas, climatic conditions, soil, sowing time, and varieties (Darwinkel *et al.,* 1977). Seed is the basic and most costly input in Njavara rice production. Hence reducing the seed rate can save money and enhance the profit of production. It is in this content the performance of Njavara was studied under three levels of seed rate viz, 50 kg ha^{-1}(R_1), 75 kg ha^{-1}(R_2), and 100 kg ha^{-1}(R_3) and the results obtained are discussed here.

Seed rate caused significant variation on plant height at 40 DAS and at harvest stage, tillers m^{-2} at harvest stage, LAI at panicle initiation stage, rooting depth, total biomass, number of productive tillers m^{-2}, thousand grain weight, grain yield, straw yield, harvest index and uptake of major nutrients.

Seed rate at different levels exerted significant influence on grain yield of Njavara rice (Fig.12). Highest grain yield of 2356 kg ha^{-1} was recorded for R_3 (100 kg seed ha^{-1}) which was significantly superior to other two level . Six to nine percent increase in yield was obtained for the treatment over the other two levels. The increase in yield due to highest seed rate may be due to higher number of productive tillers and thousand grain weight as observed from table 15 and 21. Higher grain yield with increasing seed rate has earlier been reported by (Singh *et al.,* 1997). Production of more panicles per plant at higher plant density associated with higher seed rate led to significant increase in the economic sink strength. The higher the plant population resulted in more utilization of all natural resources particularly soil nutrients, moisture, CO_2 and radient energy. Higher seed rate actually resulted in increased plant population in the field when compared to 50 and 75 kg ha^{-1} As a result the space available for individual plant will be less. A plant is able to express its full yield potential, when they are planted at wider spacing. When sown densely competition among plants will be more resulting in yield reduction of individual plants. But the yield per unit area is increased by efficient utilization of growth factors. Maximum yield per unit area can be obtained when the individual plants are also subjected to severe competition as reported by Reddy and Reddy (1992) which confirms the present result. Sasak *et al*. (1966) reported that rice yield per unit area increased with increase in seed rate. Similarly Hukkeri and Chauhan (1968) observed that higher yield with higher seed rate was due to increased number of total tillers and high percentage of productive tillers. Anilkumar (1989) also reported that higher yield and higher percentage of productive tillers due to higher seed rate.

As reported earlier productive tillers m^{-2} was significantly increased due to higher seed rate registering a similar increase of 6 percent as that of grain yield (Fig.13). The highest productive tillers m^{-2} of 312.2 was recorded by the treatment receiving 100 kg seed ha^{-1} (R_{3}). This is in agreement with the findings of Ramesh and Chandrasegharan (2007) who suggested that the panicles per unit area observed as productive tillers m^{-2} found to increase with increase in seed rate. The production of panicle both per plant and per unit area are important yield contributing character and are found to be higher with higher seed rate. Possibly an increase in the tiller production might have led to the production of more panicles bearing tillers per unit area. This is in agreement with the finding of Thakur (1993). Similarly increased effective tillers per unit area under higher seed rate in wheat as compared to lower seed rate was reported by Upadhyay *et al.* (1993)

Grain weight $panicle^{-1}$ and number of spikelet $panicle^{-1}$ were not differed significantly due to seed rate. But highest value for these parameters was obtained for treatment with 100 kg seed ha^{-1}though not significant. Akamatsu (1969) and Anilkumar (1989) also reported non significant influence of seed rate on number of spikelet $panicle^{-1}$. But Mukhergee and Chatergee, (1970) found that number of spikelets $panicle^{-1}$ increased when a change of seed rate was made in IR_{8} variety from 60-90 kg ha^{-1}.

Sterility percentage also registered non significant influence due to seed rate. The sterility percentage was higher for treatment with higher seed rate and

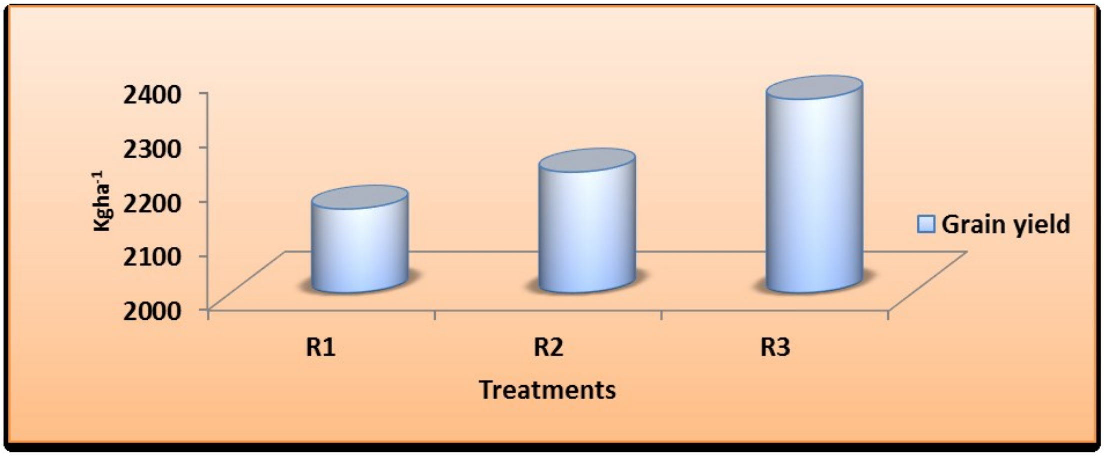

Fig 12. Effect of seed rate on grain yield of Njavara

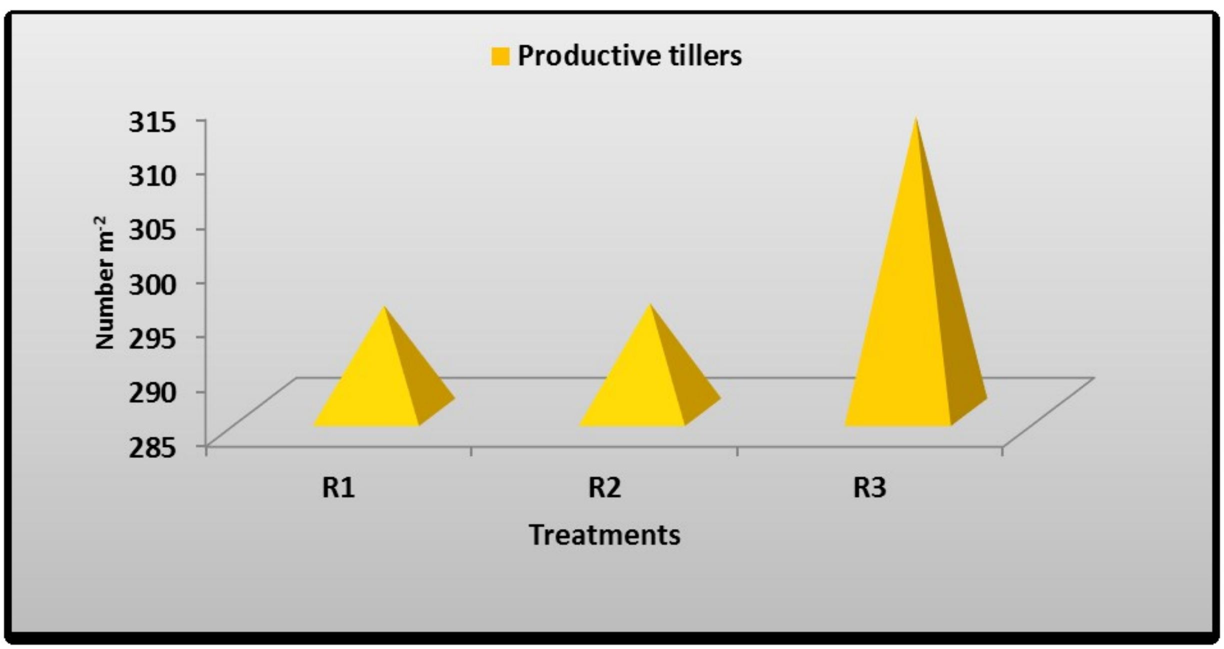

Fig 13. Effect of seed rate on productive tillers m^{-2} of Njavara rice

may probably due to the denser stand of plants in the field attracting more pest resulting in chaffy grain. But this enhancement could not reach the level of significance and at the same time was not reflected in grain yield also.

In thousand grain weight significant reduction was observed due to higher seed rate (Fig.14). This may be due to increased number of spikelets panicle^{-1} and increased number of productive tillers m^{-2} at higher seed rate. As the number increases there may be a reduction in weight per number. Similar report of significant reduction in thousand grain weight with increase in seed rate was reported by Pillai (1969). With increase in seed rate there may be an overcrowding of plants resulting in mutual shading leading to a reduced accumulation of photosynthate in grains. Reddy and Reddy (1992) reported test weight as the stable character under wide range of plant population contradicting the present result. A similar report of non significant influence of other yield contributing character by (Anilkumar , 1989).

Straw yield showed significant reduction due to seed rate enhancement and value ranged from 2961kg ha^{-1} to 4163 kg ha^{-1} registering the lowest and highest values for 100 kg ha^{-1}and 50kg ha^{-1} (Fig.15). This result is contradictory to general assumption and main reason may be due to the enhanced translocation of assimilates to sink as a result of mutual competition exerted by increased plant population at 100 kg seed ha^{-1}. The data on HI confirms this result. Contradictory to the result Enyi (1965) reported that higher plant population resulted in higher yield of straw. Verma (1972) also reported that higher plant population lead to improvement in straw yield and dry matter accumulation in rice. Similar report of higher straw yield with higher seed rate was given by Joseph (2001).

Harvest index (HI) is actually an expression of sink producing ability of plant and this was seen improved by enhancing seed rate (Fig.16). Harvest index vary significantly due to seed rate and highest value was recorded by R_3 level (seed @ 100 kg ha^{-1}). The value ranges from 0.17 to 0.21with R_3 (seed @ 100 kg ha^{-1}) registering the highest value. The increase in harvest index is also another factor that contribute to increased grain yield which indicates a positive influence in translocation of assimilates to sink. Contradictory to this result a non significant variation of HI due to seed rate was reported by Verma, (1972) and Anilkumar (1989). HI is a parameter which decides the yielding ability of crop and generally it is considered as a varietal character. But here significant variation due to seed rate reveal that for Njavara variety rice it can be managed by agronomic practices.

The result of height of plant indicated that there was significant difference in plant height only at 40 DAS and at harvest (Fig.17). In early stage seed @100 kg ha^{-1}(R_3) reported tallest plants. According to Stewart (1914), stand density above optimum may increase plant height. The increase in plant height at early stage may be due to increased single plant competition for resources at higher stand density. When sown densely competition among plants is more for growth factors (Reddy and Reddy, 1992) and hence the performance of individual plant is maximum when subjected to severe competition if resources are sufficient. Since plants at 40 DAS are very small in size the niche resources will be sufficient so as to put forth potential growth. But at harvest stage seed @ 50 kg ha^{-1} (R_1) produced taller plants of 105 cm. Decrease in plant height at higher plant density may be due to the internal competition that sets in between vegetative and reproductive parts. As plant density increases the internal competition is severe (Reddy and Reddy 1992) resulting in change in the allocation of assimilates, most of it moving to reproductive part.

Plant density is the most important factor affecting tillering in any crop. Tillers m^{-2} varied significantly due to seed rate and the highest value of 383.5 was recorded by seed rate at 100 kg ha^{-1} at harvest stage (Fig.18). The plants were able to produce more tillers at 100 kg ha^{-1} indicating the absence of overcrowding even at this higher level of seed rate (Counce and Wells, 1991). Miller *et al*. (1991) also reported similar trend of increasing tiller count with increasing plant densities. The result is in conformity with the findings of Sharma and Ghosh (1998) who reported that seedling emergence and tiller numbers increased proportionally with increasing seed rate. Joseph (2001) also reported increase in tillers m-^{2} with higher seed rate.

The total leaf area per unit ground area (LAI) is an important indicator of total source available to the plant for the production of photosynthate which accumulate in the developing sink (Fig.19). LAI was found to increase with increase in seed rate and an LAI of 1.94 was recorded for the treatments receiving higher seed rate of 75 and 100 kg ha^{-1} while seed rate @ 50 kg ha^{-1} produced only an LAI of 1.79 (Fig.22) . This observation is actually what is expected because at higher seed rate, stand density will be more and thus leafiness also will be more. Similar to this result Enyi,(1965) found that LAI was higher with higher plant population. Similarly highest LAI of 3.69 at highest seed rate was reported by Ramesh and Chandrasegharan (2007). Joseph (2001) also reported that adoption of higher seed rate produced higher LAI.

Rooting depth also varied significantly and lowest rooting depth of 10.52 cm was registered by 75 kg ha^{-1}(Fig.20).The plants receiving 50 and 100 kg ha^{-1} registered rooting depth of 11.56 and 11.45 cm respectively. The reason for such a performance is difficult to explain as root growth is greatly influenced by niche resource availability. Rooting depth in rice varies with variety and environment and when seed rate is varied the number of plants per unit area also changed and proximity to neighbouring plants differed. This lead to the variation in mutual interference between neighbouring plants and this might have caused variation in rooting depth of plants.

Total biomass varied significantly due to seed rate (Fig.21). Biomass value ranged from 5377 to 6317 kg ha^{-1}. Highest biomass yield was recorded for the treatment receiving 50 kg ha^{-1}(R_1).This may be due to the highest straw yield reported for the treatment in the present experiment table

Culm strength did not vary significantly due to seed rate. This observation is also an indication that in Njavara rice, seed rate at 100 kg ha^{-1} is not causing any severe competition between plants leading to weakening and thinning of stem and hence the stem strength is maintained.

Seed rate caused significant variation in uptake of major nutrient like N, P, and K (Fig.22).Highest N uptake was recorded by R_3 (seed rate @ 100 kg ha^{-1}) registering 28 % increase over lowest seed rate. P uptake was also highest for seed @ 100 kg ha^{-1}registering 39 % increase over lowest seed rate. Similarly K uptake was also highest for the same treatment registering 35 % an increase over lowest seed rate. Plant demand is an important determinant of nutrient uptake. So when higher seed rate is used it resulted in higher stand density and the demand for nutrients will be more and hence the uptake also. Kumar *et al.* (2006) and Otteson *et al.* (2007) reported that increasing sowing rates with optimum fertilizer application resulted in increased NPK uptake in wheat.

5.3 Effect of NK Ratio (Potassium) on Growth, Yield Attributes, Yield and Nutrient Uptake of Njavara

Potassium is an essential element for the growth of rice plant and takes part in various physiological processes. Potassium is the major nutrient taken up by plants in large quantities.

Three levels of potassium (NK ratios) viz, NK 1:1 (K_1-40 kg K_2O ha^{-1}), NK 1:2(K_2-80 kg K_2O ha^{-1}) and NK1:3 (K_3-120 kg K_2O ha^{-1}) was tested in the experiment to study the effect on growth and yield of Njavara rice.

NK ratio (Potassium levels) exerted significant influence on plant height at 40 DAS and at harvest stage, tillers m^{-2}, number of productive tillers m^{-2}, and uptake of N, P and K. The other parameters did not vary significantly due to K application.

The result of the study indicated that NK ratio (Potassium levels) could not exert any significant influence on grain yield of Njavara (Fig.23). Yield being the result of the several yield contributing parameters, the effect of the potassium on these parameters also needs critical analysis. Most of the yield

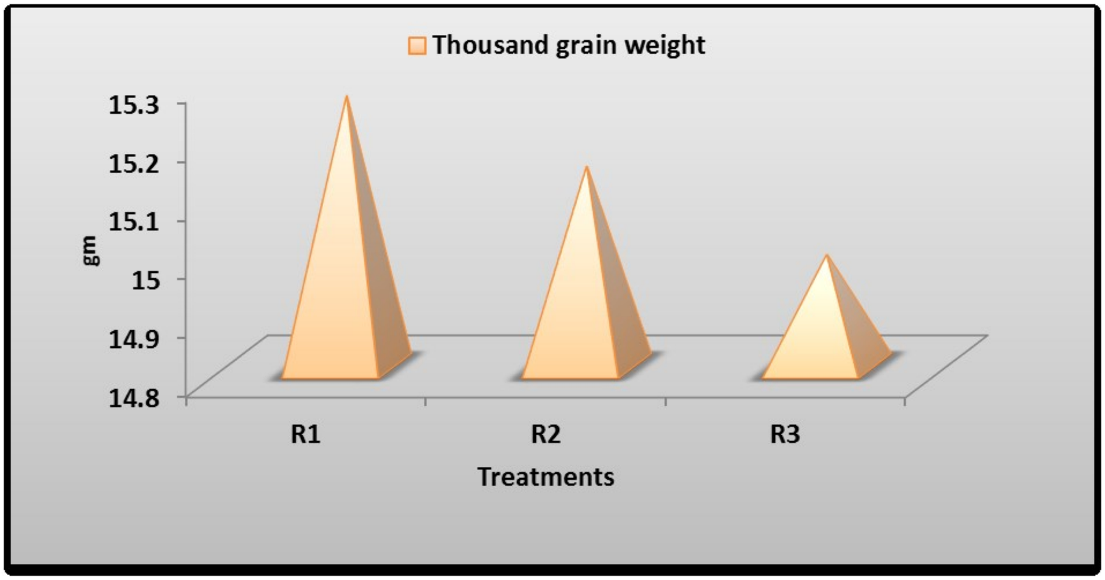

Fig 14. Effect of seed rate on thousand grain weight of Njavara rice

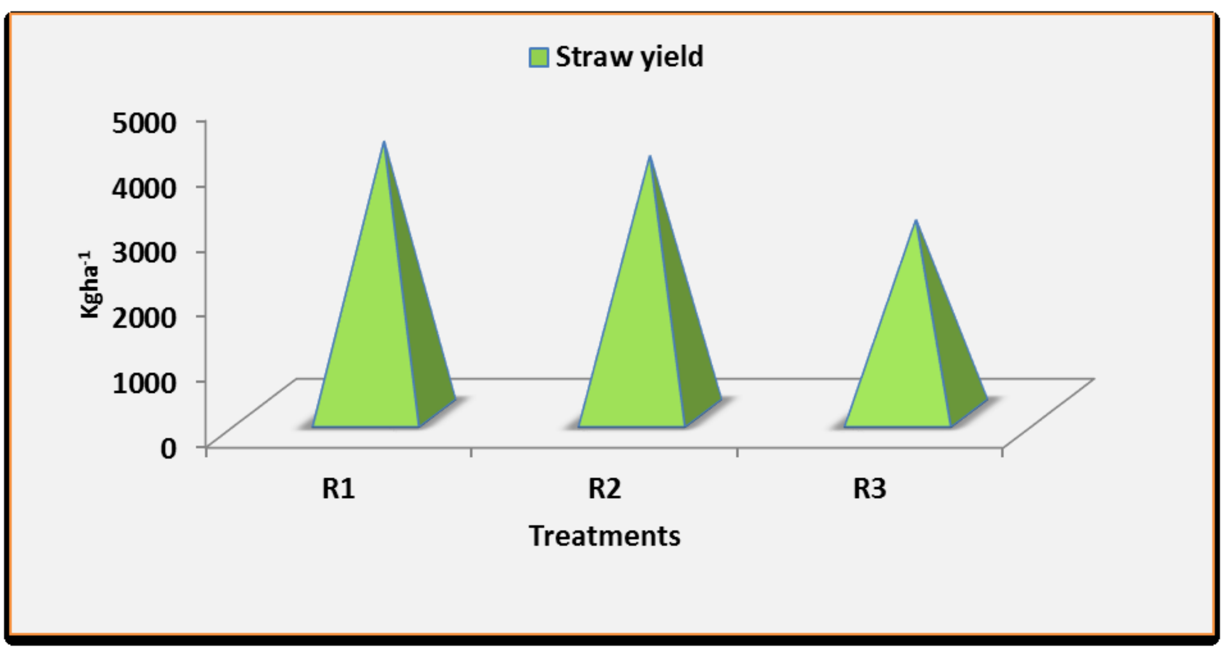

Fig 15. Effect of seed rate on straw yield of Njavara rice

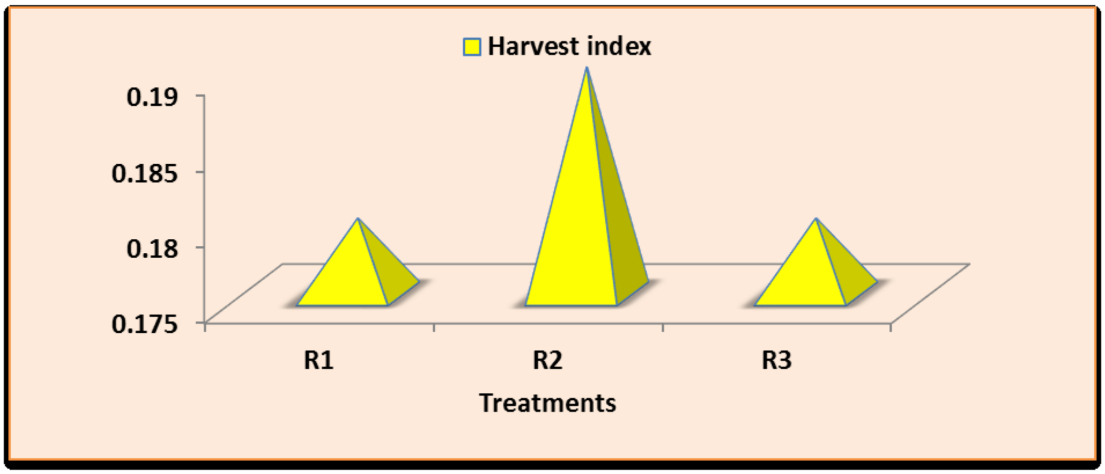

Fig 16. Effect of seed rate on harvest index of Njavara rice

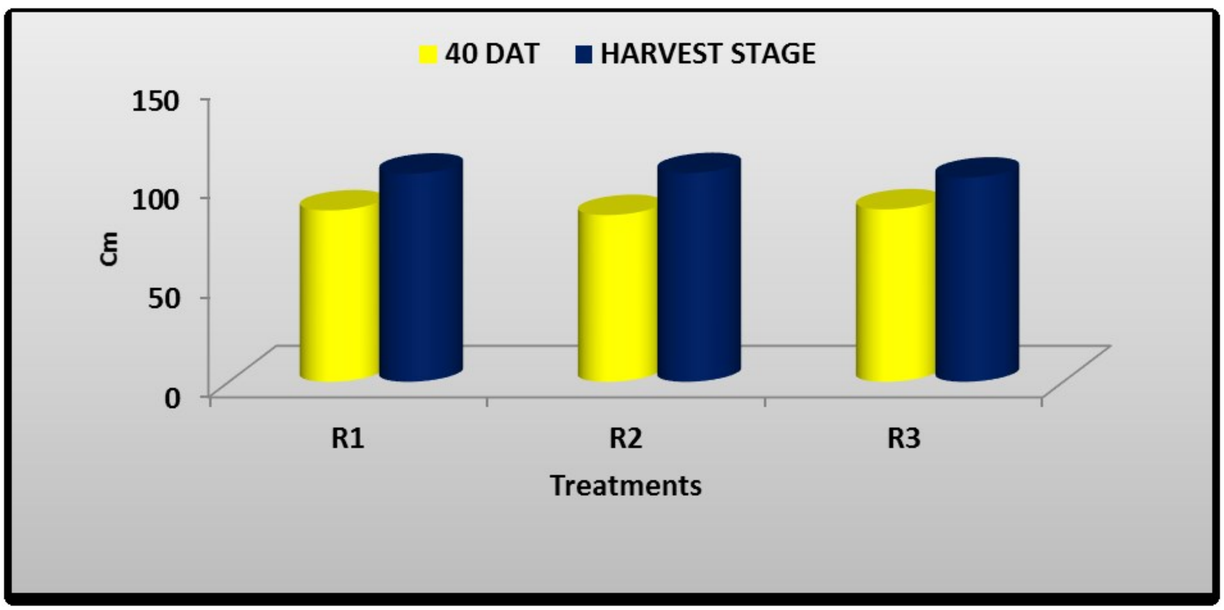

Fig 17. Effect of seed rate on plant height of Njavara rice at 40 DAS and at

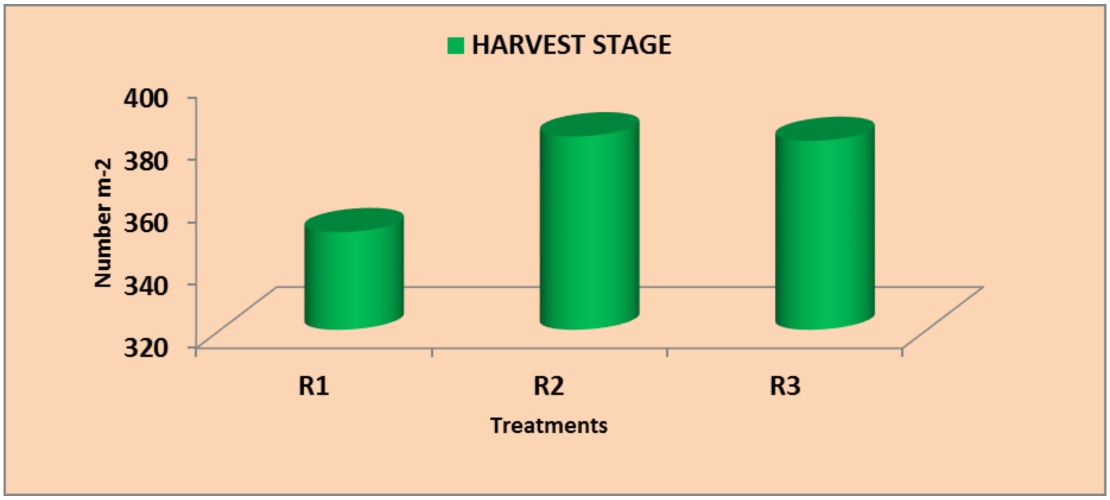

Fig 18. Effect of seed rate on tillers m^{-2} of Njavara rice

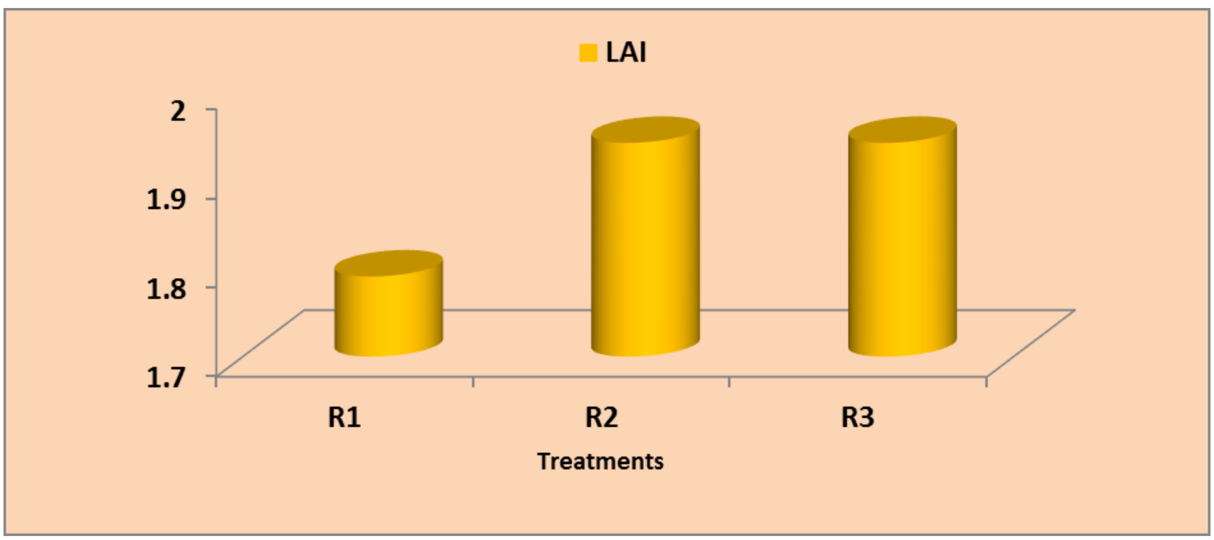

Fig 19. Effect of seed rate on LAI of Njavara rice

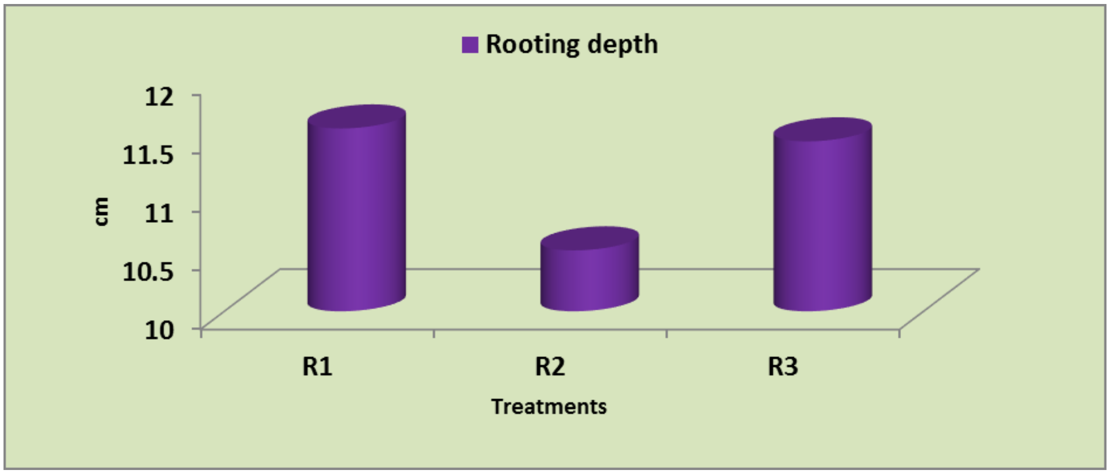

Fig 20. Effect of seed rate on rooting depth of Njavara rice

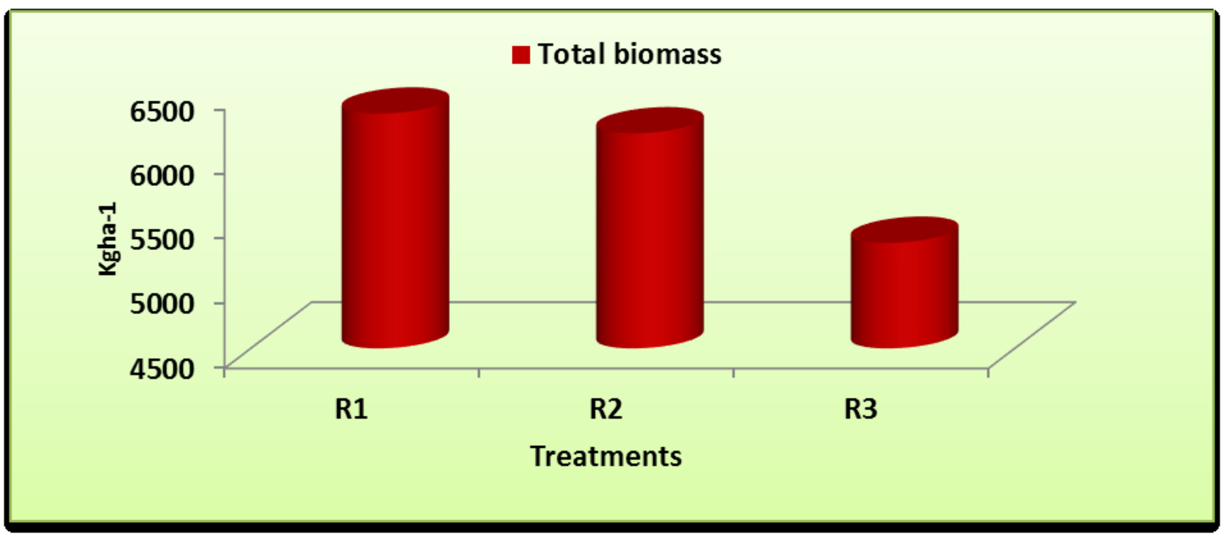

Fig 21. Effect of seed rate on total biomass of Njavara rice

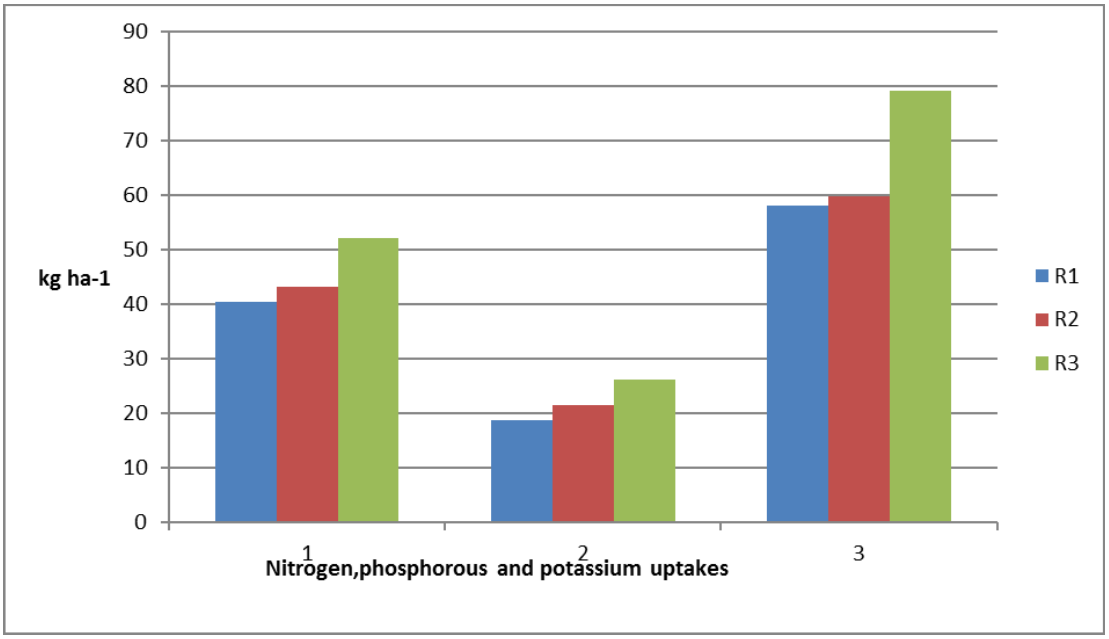

Fig 22. Effect of seed rate on nitrogen ,phosphorous and potassium uptake of Njavara rice

contributing parameters did not show any significant variation due to NK ratio (Potassium levels).

Grain weight panicle^{-1}, filled grains panicle^{-1}, Spikelets panicle^{-1} sterility percentage and thousand grain weight were also not significant due to NK ratio (Potassium levels). However the values were at the higher range for higher NK ratio (Potassium levels), thus reflecting the combined effect of these yield contributing parameters reflected on grain yield. The sterility percentage was lowest at K_3 ,120 kg ha^{-1} (NK 1:3), which again was non significant, but could positively contribute to enhanced grain yield. Soil analysis data revealed that the potassium status of the soil before the experiment was at medium levels in the selected experimental plot and probably this may be the reason for low response to potash by the crop. Besides, Njavara plants are comparatively showing poor response to applied nutrients as reported by (Sriramkumar 2011). He suggested that for Njavara rice the nutrient recommendation for better yield, is 40:20:40 kg NPK ha^{-1}. In this experiment lowest dose fixed itself was therefore sufficient for the crop and may be the reason for lack of response. Potassium is primarily involved in the production and translocation of starch (Russel, 1973). But lack of response due to K application has been reported by many workers (Chan, 1929., Lord,1931., Mariakulanda,1957., Abhichandini,1959 and Pawar,1960). However Aiyer (1948) observed symptoms due to deficiency of potassium in paddy soils.

There was no significant variation in number of filled grains per panicle due to N: K ratio. Potassium @ 120 kg ha^{-1} (NK: 1:3) recorded small increase over the lowest level of 40 kg K_2O ha^{-1} (NK: 1:1). But Thomas (2000) reported significant variation in this character due to K application. Potassium stimulated the build up and translocation of carbohydrates and grain development which increased the number of filled grains. Deshmukh *et al.* (1988) reported the combined application of N and K at higher levels resulted in favourable response of yield attributes of rice. But for Njavara rice, this was not obtained and can be attributed to its inherently low potential of this variety.

Result found for K in terms of yield components like number of productive tiller m^{-2} was found to be significant (Fig.24). The highest number of productive tiller m^{-2} was recorded by NK ratio 1:2 (80 kg ha^{-1}) compared to other two levels. Lowest number of productive tiller m^{-2} was recorded by NK ratio 1:1 (40 kg ha^{-1}) and NK ratio 1:2 (80 kg ha^{-1}) recorded 9% increase over this treatment.

Straw yield did not vary significantly due to potassium application (Fig.25) .Highest straw yield was recorded by K at the rate of 120 kg ha $^{-1}$(NK ratio: 1:3) though not significant. Potassium performs important roles in enzyme formation, photosynthesis, and nitrogen use and plant water relations. The non significant influence of potassium may be due to the inherent inability of the Njavara rice for utilizing more quantity of potassium. Anu (2001), Ranjini (2002) and Mini (2005) found that straw yield was maximum when N:K ratio was 2:1., which suggest the low requirement of K as compared to N for rice.

Coming to growth attributes K exerted significant influence on plant height at 40 DAS and at harvest stage (fig.26). (40 kg ha^{-1}) N:K 1:1 recorded higher plant height at 40 DAS. Potassium applied at 80 kg ha^{-1} (NK:1:2) recorded significantly superior plant height of 105.3 cm as compared to other two levels at harvest stage. It is well known that K promotes the growth of meristematic tissues. (Tisdale *et al.*1995) , Sircar and Datta (1954)from their studies on the effect of potash deficiency on growth and yield of paddy , found that at highest level of potash a significant increase in vegetative growth was noticed and a progressive reduction in height, tiller counts and grain yield were observed when potash was not applied. Significant increase in plant height with increase in level of K was observed by Vijayan and Sreedharan, (1972) and Venkatasubbiah *et al.* (1982). Sakeena and Salam (1989) opined an increase in plant height of rice with 35 kg K_2O ha^{-1}. Similar results were obtained by Roy and Kumar (1995). In upland rice, plant height increased with increase in K level upto 45 kg K_2O ha^{-1}(Thomas, 2000; Anu, 2001; Ranjini, 2002 and Mini, 2005) . Bhiah *et al.* (2010) reported increased plant height due to potassium application.

Total number of tiller m^{-2} varied significantly at PI stage and at harvest (Fig.27). Potassium at 80 kg ha^{-1}(NK: 1:2) recorded higher tiller m^{-2} at PI stage and at harvest. Similar to this report Kulkarni *et al*. (1975) opined that tiller production in rice was influenced by K application. Tillering increased with the application of K up to 60 kg K_2O ha^{-1}(Singh and Singh, 1979). K application favourably increased the yield attributes in rice. Potassium absorbed at maximum tillering stage increases number of panicles, spikelets $panicle^{-1}$,and weight of grain (Su,1976 and Mandal and Dasmahapatra,1983).According to Datta and Surjit (1981),K increased the P response of plant and thus favoured tillering in rice. Reyhaneh *et al* . (2012) reported that number of tillers m^{-2} increased significantly by the application of potassium over control. Potassium is an element favouring protein synthesis, might have exerted some influence on growth and tiller production. Contradictory to this Deshmukh *et al.* (1988) observed that N:K ratio 2:1 increased the tiller number of rice. Maximum number of tillers were obtained at K level of 45 kg K_2O ha^{-1}(Thomas, 2000 ; Anu, 2001; Ranjini, 2002) which is not in agreement with the present result.

LAI was not significantly influenced by K application. Higher LAI value of 1.99 was observed at 40 kg K_20 ha^{-1} (NK :1:1).This is contradictory to the report of Anu (2001) and Ranjini (2002) who got highest value of NK ratio 2:1. Here also the potassium levels could not exert any significant influence and this may be due to the poor source capacity of Njavara plant.

Rooting depth was unaffected by N:K ratio (potassium levels). Rooting depth ranged from 10.91 cm for the treatment receiving 120 kg K_20 ha^{-1} (NK: 1:3) to 11.50 cm for 40 kg K_20 ha^{-1}(NK:1:1).Contradictory to the result, significant improvement in root growth by K application in standard rice varieties was reported by (Bhiah *et al.,* 2010). Potassium helps in root development and enhances the growth of rice plants (Vijayan and Sreedharan, 1972).

Total biomass also did not vary significantly due to NK ratio (potassium levels). But the biomass yield showed an increasing trend with increase in K levels recording an improvement of 12-18%. The higher value (though non significant) obtained for grain and straw yield and other yield contributing characters might have resulted in expressing better biomass yield for the treatments. Increase in shoot weight with increase in K levels has been reported by (Muhammed Salim, 2002)

NK ratio did not cause significant variation in culm strength. But there are reports favouring K application for improvement of culm strength (Bhiah *et al.,* 2010).The lowest ratio of NK 1:1 (40 kg ha^{-1}) may be sufficient for Njavara rice and hence failed to produce any improvement in culm strength with higher dose of K.

NK ratio (potassium levels) caused significant variation in N,P and K uptake(Fig.28).The highest value was recorded by application of potassium at 120 kg ha^{-1}(NK: 1:3). Uptake is a function of nutrient content and dry matter production. Though total biomass yield did not vary significantly, the increasing trend with higher level of potassium along with high content of nutrients in plant parts might have resulted in higher nutrient uptake. Increased uptake of N, P and K at higher levels of nutrients is in corroboration with the findings of Thomas (2000), who noticed that uptake of nutrients was the highest at NPK level of 60:30:45 kg ha^{-1}.

Increase in N uptake of rice by K application was reported by (Koch and Mengel, 1977). Several workers have reported that P uptake was noticed at higher levels of N and K (Muthuswamy *et al.,* 1974, Mengel *et al.,*1976 and Reddy *et al.,*1986). Muthuswamy *et al. (*1974) reported that higher levels of K application increased the uptake of K by rice. Niazi *et al.* (1992) found that K concentrations and its uptake in grain and straw were increased significantly with increasing application. K application @ 50 kg ha^{-1} increased the K uptake in rice (Kale and Chavan 1996).

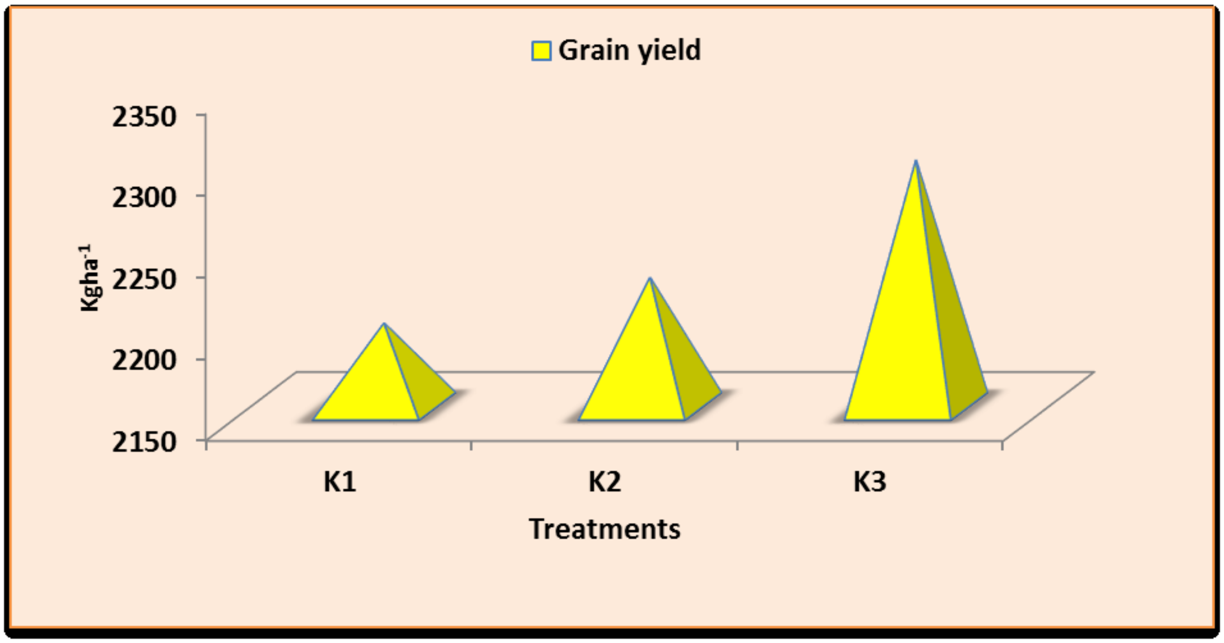

Fig 23. Effect of potassium (NK ratio) on grain yield of Njavara rice

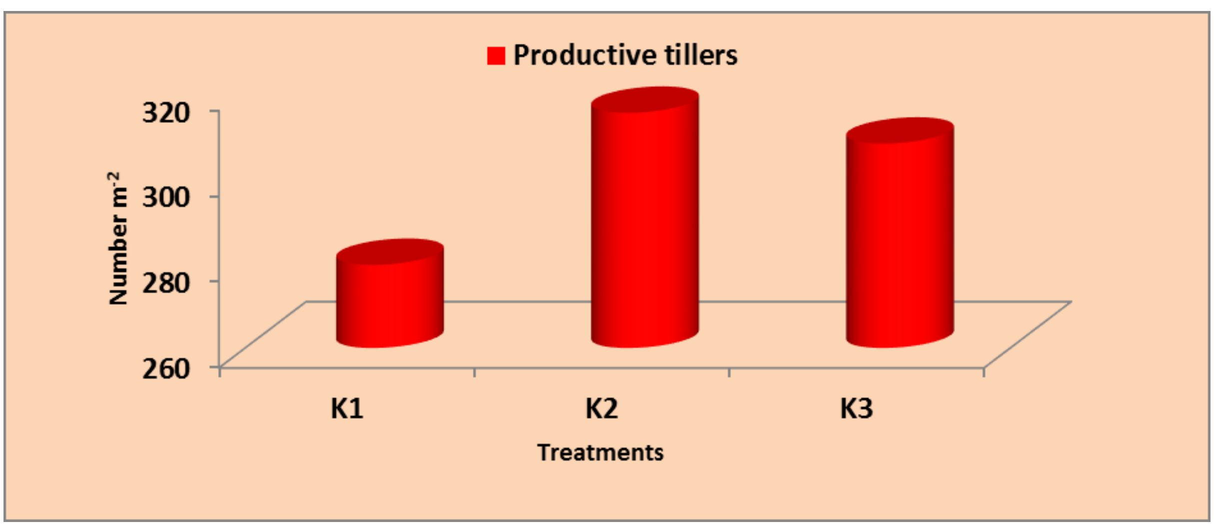

Fig 24. Effect of potassium (NK ratio) on productive tillers m^{-2} of Njavara rice

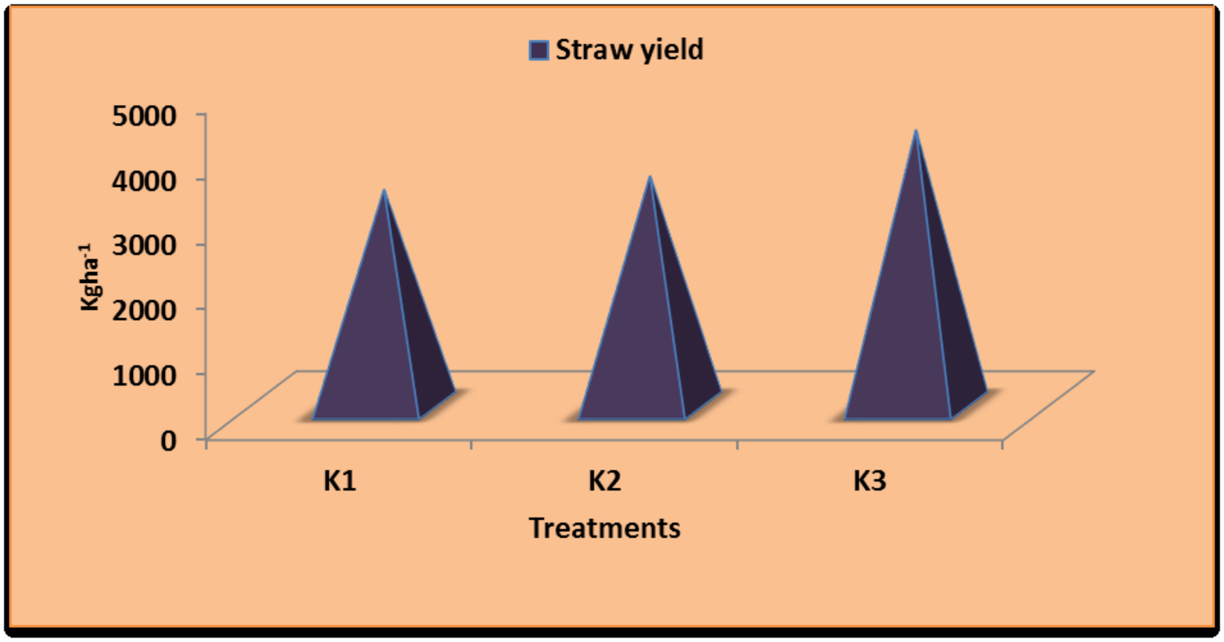

Fig 25. Effect of potassium (NK ratio) on straw yield of Njavara rice

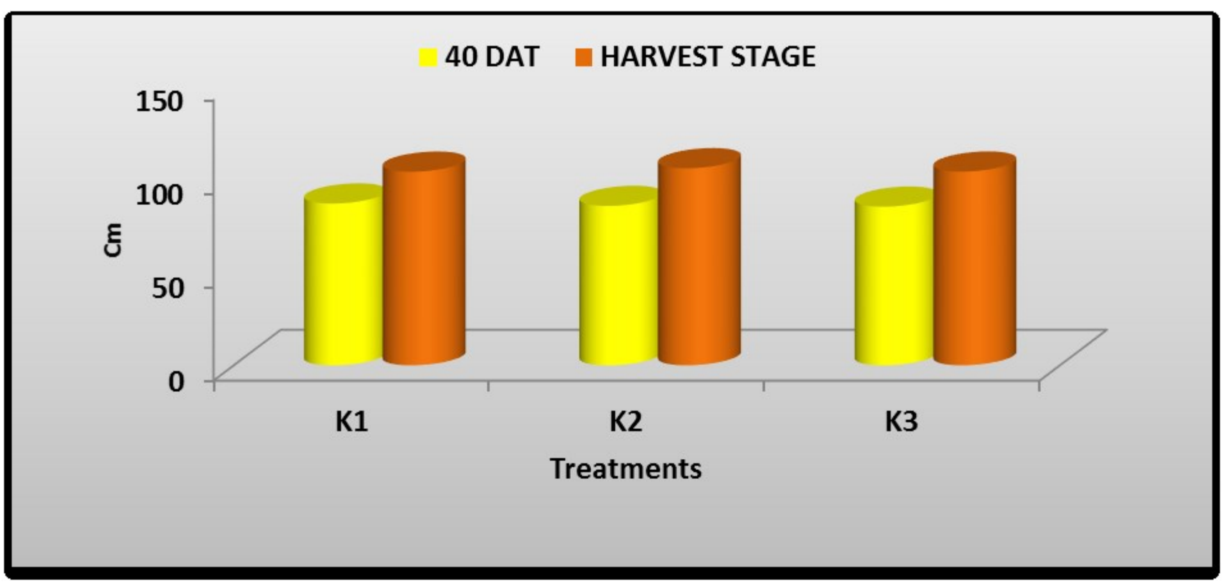

Fig 26. Effect of potassium (NK ratio) on plant height of Njavara rice at 40 DAS and harvest

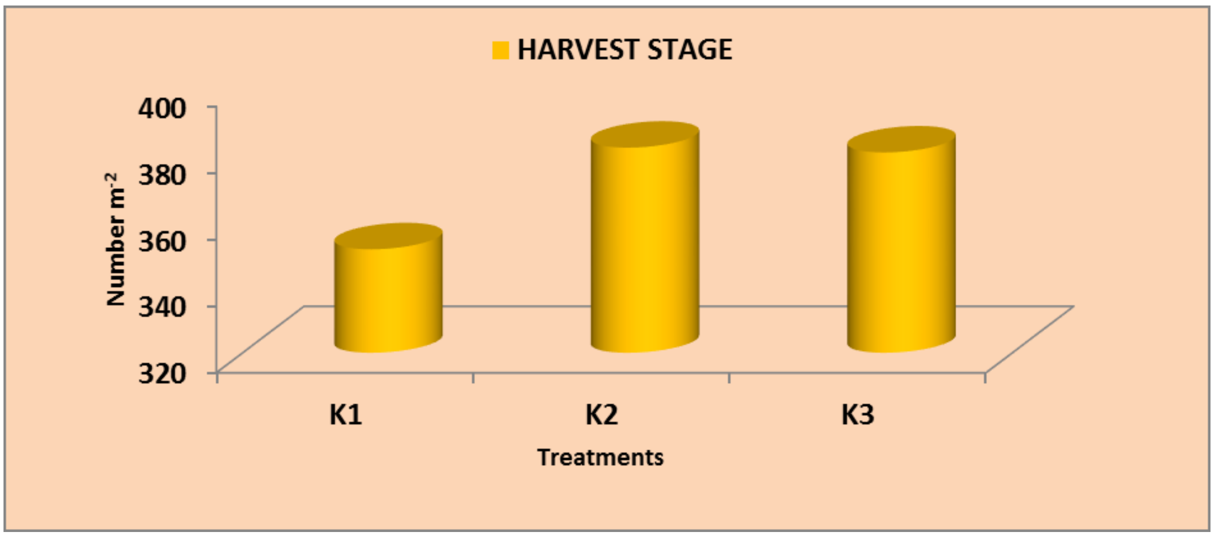

Fig 27. Effect of potassium (NK ratio) on tillers m^{-2} of Njavara rice at harvest stage

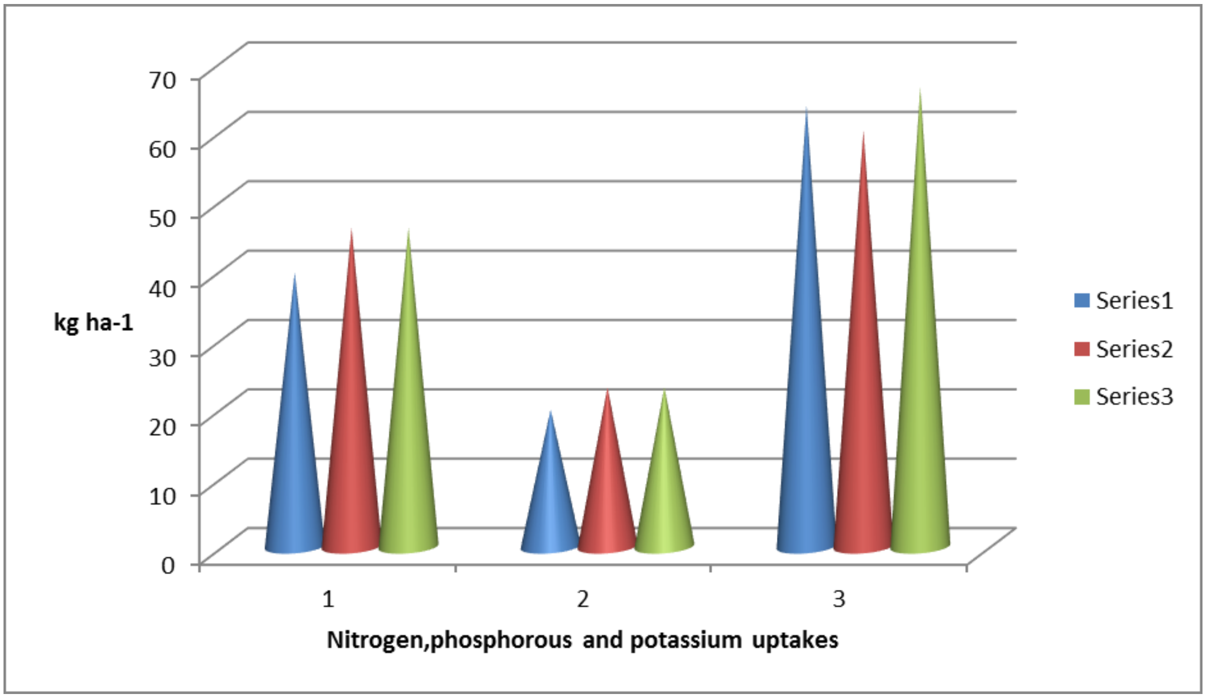

Fig 28. Effect of potassium (NK ratio) on nitrogen, phosphorous and potassium uptake of Njavara rice

5.4 EFFECT OF INTERACTION ON GROWTH, YIELD ATTRIBUTES, YIELD AND NUTRIENT UPTAKE OF NJAVARA

The treatments used in this experiment were varying levels of silicon namely (0, 50 and 100 kg ha^{-1}) ,varying levels of seed rates (50,75 and 100 kg ha^{-1}) and varying levels of K (NK ratio) at 40(1:1),80 (1:2) and 120 (1:3) kg $K_2O ha^{-1}$. In the foregoing discussion a critical analysis has been made on the main effects of these factors on the growth and yield of Njavara rice. As these factors were imposed on the crop as combination, naturally they may interact each other and their effect on crop may vary. Hence an analysis on their interaction on the growth and yield of medicinal rice Njavara is discussed here.

5.4.1 Silicon-Seed Rate Interaction (SxR)

Interaction effect of silicon and seed rate (SxR)was significant on tillers m^{-2} at both the stages ,LAI at PI stage ,total biomass, culm strength, number of productive tillers m^{-2} ,filled grains $panicle^{-1}$,thousand grain weight ,grain yield ,straw yield ,harvest index and uptakes. Other parameters did not show any significance due to SxR interaction.

SxR caused significant variation in grain yield ha^{-1}. The highest grain yield of 2513kg ha^{-1} was recorded by s_2 r_3 (silicon @50 kg ha^{-1} and seed rate @ 100 kg ha^{-1}.).Grain yield was not significant due to silicon application. But the effect of seed rate on grain yield was significant and hence this may be the reason for the significance of SxR interaction.

Number of filled grains $panicle^{-1}$, thousand grain weight and productive tillers m^{-2}, were also significantly influenced by SxR interaction. Though main effect silicon at 50 kg ha^{-1} and seed rate 75 kg ha^{-1} registered highest value for number of filled grains $panicle^{1}$, when the treatments were combined most of the interaction treatments performed similarly except s_1r_1 (silicon 0 kg ha^{-1} and seed rate 50 kg ha^{-1}) and s_3r_3 (silicon 100 kg ha^{-1} and seed rate 100 kg ha^{-1}) which were significantly lower. In SxR interaction the highest number of productive tillers m^{-2} of 340.25 and highest thousand grain weight of 16.35 g was recorded by s_2r_3 (silicon @50 kg ha^{-1} and seed rate @ 100 kg ha^{-1}) .Though S_3 recorded the highest number of productive tillers m^{-2} and thousand grain weight, when combined with different levels of seed rates S_2 level (75 kg seed ha^{1}) out performed indicating the positive interaction of seed rate with silicon.

Similarly in straw yield also SxR interaction showed significance due to the significant effect of seed rate even though silicon alone was not significant. SxR interaction exerted significant variation in HI. The highest harvest index of 0.21 was recorded by s_1r_3 (silicon @ 0 kg ha^{-1} and seed rate @ 100 kg ha^{-1}). Main effect of silicon and seed rate caused significant variation in harvest index in this experiment and hence combined effect was also significant.

Coming to growth attributes SxR interaction was found significant for LAI at panicle initiation stage only. Highest and lowest LAI values were recorded by s_1r_2 (silicon @ 0 kg ha^{-1} and seed rate @ 75 kg ha^{-1}) and s_2r_1(silicon @ 50 kg ha^{-1} and seed rate @ 50 kg ha^{-1}). Here both the main effects of silicon and seed rate was found to be significant.

Total biomass production was significantly influenced by SxR. The highest total biomass of 7260 kg $ha^{-1}$was recorded by s_1r_1 (silicon @ 0 kg ha^{-1} and seed rate @ 50 kg ha^{-1}). Though main effect of silicon was not significant, the influence of seed rate might have resulted in producing significantly higher biomass production for this treatment. The significant effect of seed rate nullified the non significance of silicon.

The interaction of silicon-seed rate was significant for culm strength also and this was because of the increased culm strength produced by main effect of silicon. The highest culm strength of 33.54 mg cm^{-1} was recorded by s_3r_1 (silicon @ 100 kg ha^{-1} and seed rate @ 50 kg ha^{-1}). The N, P and K uptake were significant which were similar to the main effect of silicon and seed rate

5.4.2 Silicon-Potassium Interaction (SxK)

SxK interaction effect was significant on plant height at both the stages, tillers m^{-2}, number of productive tillers m^{-2} and P and K uptakes. None of the other growth parameters and yield contributing characters was affected by SxK interaction.

Grain yield and straw yield was not affected by SxK interaction. In grain yield main effect of silicon and potassium was not significant and this may be the reason for non significance of grain yield due to SxK interaction. But the interaction was significant for number of productive tillers. Highest number of productive tillers m^{-2} was recorded by s_3k_3(silicon @ 100 kg ha^{-1} and K_2O 120 kg ha^{-1}). The significant influence of individual effect of silicon and potassium has contributed for this performance. It is observed that when silicon was interacted with potassium the response to potassium was increased to the highest level of 120 kg ha^{-1} (NK 1:3) as against 80 kg K_20 ha^{-1} (NK 1:2) when considered individually.

Plant height at 40 DAS and harvest was significantly varied due to the interaction of silicon and potassium (NK ratio) . For the main effect also same trend was observed and hence the interaction also produced significant variation in plant height. SxK interaction had significant effect on number of tillers m^{-2} at PI stage registering the highest value for s_2k_3.

SxK interaction caused significant variation in the uptake values of P and K. But N uptake was not significant. The highest phosphorous uptake of 31.31was recorded by s_3k_3 (silicon @ 100 kg ha^{-1} and NK ratio 1:3).The individual effect of silicon and potassium (NK ratio) has resulted in causing significant variation in P uptake due to SxK interaction .Similarly SxK interaction had significant effect on potassium uptake also. The highest potassium uptake of 68.95 was recorded by s_1k_2(silicon @ 0 kg ha^{-1} and NK ratio 1:2).

5.4.3 Seed Rate-Potassium Interaction (RxK)

Interaction effect of RxK was significant on tillers m^{-2} at both the stages, LAI, number of productive tillers m^{-2}, and uptake N,P and K. Other growth parameters and yield contributing characters were not significant.

Grain yield and straw yield was not found to be significant due to RxK interaction even though seed rate was significant in both these parameters.

But for productive tillers m^{-2} RxK interaction caused significant variation and highest number of productive tillers m^{-2} was recorded by r_3k_3(seed @ 100 kg ha^{-1} and NK ratio 1:3) . When individually considered, seed rate @ 100 kg ha^{-1} and potassium at 80 kg ha^{-1} produced highest number, the combined effect of RxK suggested that at highest seed rate at highest level of potassium is beneficial in expressing maximum productive tillers m^{-2} .

RxK interaction was significant on tillers m^{-2} at both the stages and highest number of tillers m^{-2} was recorded by r_3k_2 at harvest (Seed @ 100 kg ha^{-1} and potassium 80 kg ha^{-1}). The main effect of seed rate on tiller production was significant only at harvest stage while NK ratio was significant at both the stages.

In the case of LAI, RxK interactions were significant only at PI stage and the highest value of 2.12 was recorded by r_3k_1(seed @ 100 kg ha^{-1} and NK ratio 1:1).Significant influence of seed rate alone caused variation in LAI though NK ratio was non significant.

N, P and K uptakes were found to be significant due to RxK interaction. The highest N, P and K uptake was for r_3k_2. (seed rate @ 100 kg ha^{-1} and NK ratio 1:2).

5.4.4 Silicon- Seed Rate and Potassium Interaction (SxRxK)

SxRxK interactions was significant on plant height at harvest stage, tillers m^{-2} at PI and harvest stages, number of productive tillers m^{-2},grain yield and uptake of N,P and K .

SxRxK interaction caused significant variation in grain yield. The highest grain yield of 2678 kg ha^{-1} was recorded by $s_2r_3k_2$(silicon @ 50 kg ha^{-1} ,seed rate @ 100 kg ha^{-1} and NK ratio 1:2 with K_2O 80 $kgha^1$). Though the main effect silicon and NK ratio (potassium levels) were non significant, the influence of seed rate along with the added positive influence of silicon and potassium had resulted in getting significantly superior yield for this treatment. About 22 percentage increase over the lowest level of this factors were obtained for this treatment.

SxRxK interaction was significant on maximum number of productive tillers m^{-2} and maximum number of productive tillers $m^{-2}$of 356.6 was recorded by $s_3r_1k_3$(silicon @ 50 kg ha^{-1} ,seed @ 50 kg ha^{-1} and NK ratio 1:3). Significant variation of silicon, seed rate and potassium has resulted in causing significance due to SxRxK interaction.

Similarly due to the significant effect of three main effects, SxRxK interaction also caused appreciable variation on plant height at harvest stage. SxRxK interaction was also significant at both the stage for tillers m^{-2} . The highest number of tillers m^{-2} was recorded by $s_1r_1k_1$(silicon @ 0 kg ha^{-1} , seed rate @ 50 kg ha^{-1} and NK ratio 1:1).

N, P and K uptakes were found to be significantly varied with SxRxK interaction and the influence of three main effects viz, silicon, seed rate and potassium contributed for such result.

5.5 Economics of Njavara Production

The economic analysis based on the net income received, clearly indicated that the Njavara rice production using the various levels of silicon, seed rate and potassium is profitable.

Net income varied significantly due to silicon and potassium levels (Fig.29). Net income was highest for treatment without silicon application and this was on par with silicon at 50 kg ha^{-1}. The reduction in net income due to silicon application may be due to the high cost of sodium silicate (Rs 250/kg).

Potassium (NK ratio) significantly influenced net income and highest net income of Rs 72,102/- was obtained for potassium at 120 kg ha^{-1} (NK: 1:3). Even though NK ratio (potassium levels) could not exert any significant influence on grain yield, the income received from additional yield with the use of higher level of K was sufficient to meet the extra cost spent for this.

Silicon-seed rate – potassium (NK ratio) interaction was also significant with regard to net income obtained. Highest net income of Rs 93120/- was recorded by $s_1r_2k_1$(S-0, R-75 , NK 1:1 -40 kg ha^{-1}) followed by s_2 r_1 k_3 (S-50 kg ha^{-1}, R-50 kg ha^{-1},NK 1:3 -120 kg ha^{-1}).Though the interaction effect of the factors under study contributed in expressing highest yield at silicon 50 kg, seed rate 100 kg and potassium 80 kg ha^{-1} , these levels failed to reach the highest monetary benefit mainly because of the high cost of these inputs, especially the seed and silicon. The positive effect of silicon was not reflected in the net income largely and the main reason is the very high cost of silicon. As cheaper and indigenous sources of silicon like rice husk and rice straw are available, the use of these materials can increase the profit of the Njavara. Rice hull, a major by-product of rice milling, contains about 8% Si that can be recycled for use in a sustainable rice cultivation system.

The data on B:C ratio revealed that the cultivation of Njavara rice by imposing the present treatments are economically viable. All the treatments registered B:C value more than 1. The main effects of silicon and seed rate significantly influenced the B: C ratio (Fig.30).

The highest B:C ratio of 1.79 was obtained for the treatment without silicon. Silicon at 50 kg ha^{-1} produced a B: C ratio of 1.69, which indicated that the use of this level was also beneficial for Njavara. Seed rate caused significant variation registering highest value of 1.79 for the treatment receiving 100 kg seed ha^{-1}. Potassium could not exert any significant variation on B:C ratio.

While considering SxRxK interaction it is observed that $s_1r_2k_1$. (S-0, R-75 , NK 1:1 -40 kg ha^{-1}) registered highest B:C ratio which was closely followed by $s_1r_1k_1$. (S-0, R-50, NK 1:1 -40 kg ha^{-1}).

The results thus revealed that for the profitable production of Njavara rice, application silicon and potassium along with use of higher seed rate is economically feasible. Considering the general performance of the crop with regard to all the growth and yield parameters, the treatment receiving silicon @ 50 kg $ha^{-1,}$ seed @ 100 kg ha^{-1} and potassium @ 80 kg K_2O ha^{-1}(NK ratio 1:2) was found beneficial for Njavara rice.

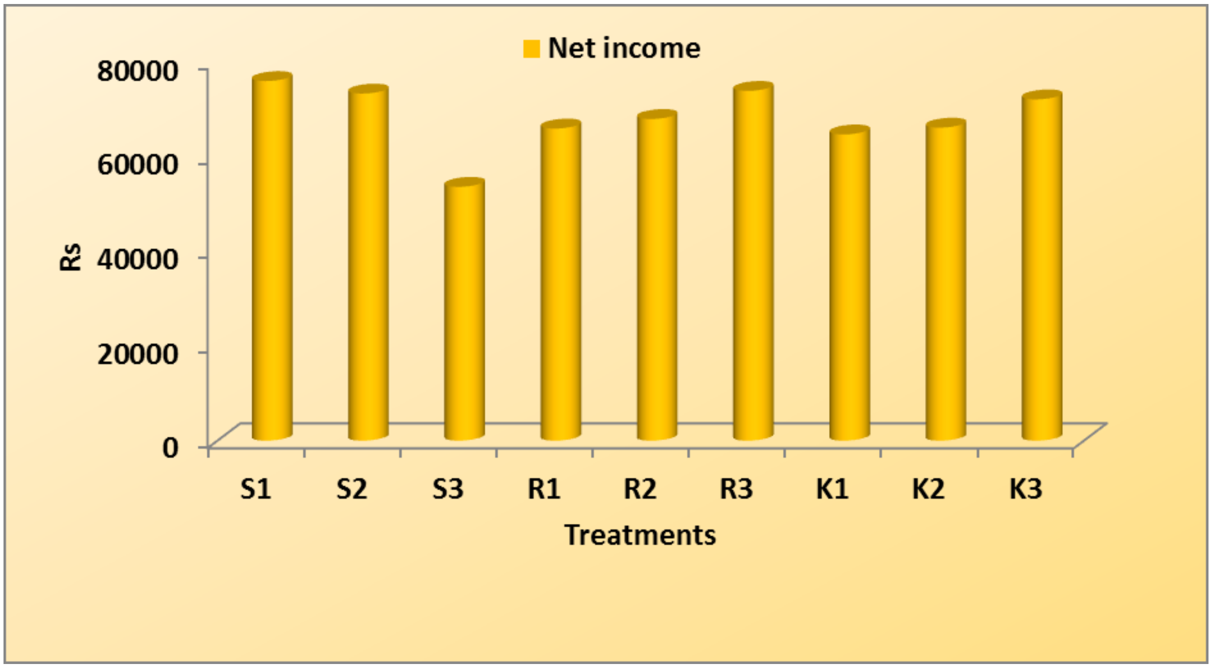

Fig 29. Effect of silicon, seed rate and potassium (NK ratio) on net income

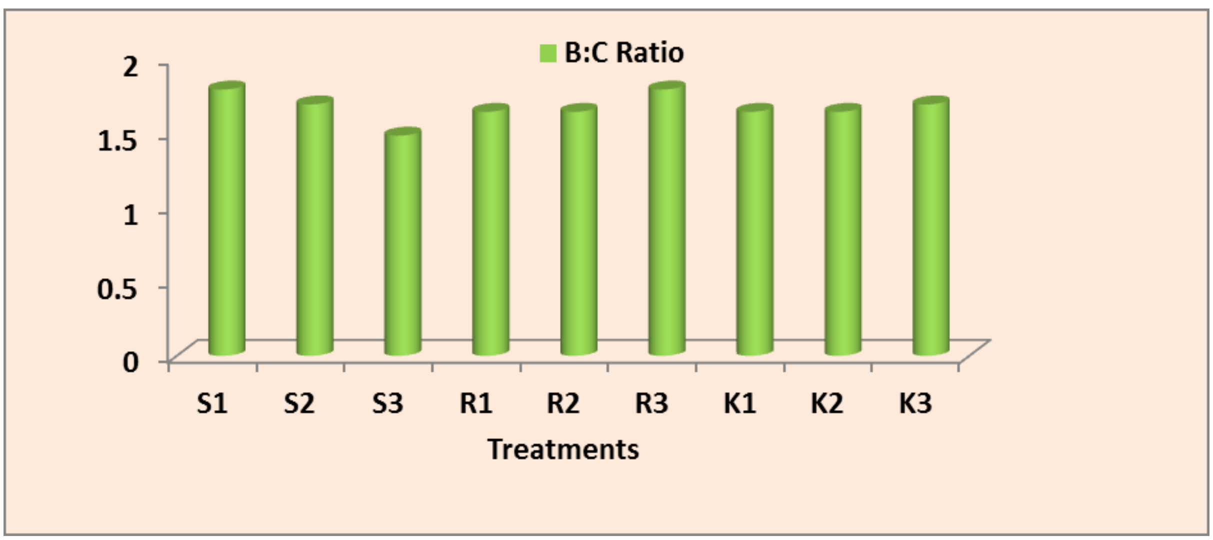

Fig 30. Effect of silicon, seed rate and potassium (NK ratio) on B:C ratio

Summary and Conclusion

6. SUMMARY

An experiment entitled "Productivity enhancement in medicinal rice (*Oryza sativa* L.) cv. Njavara" was undertaken at the Instructional Farm, College of Agriculture,Vellayani, Thiruvananthapuram, during the third crop season of 2012.The major objective of the study was to assess the impact of silicon, modified NK ratios and reduced seed rate on the growth, lodging and yield and the economics of production of Njavara rice.

The experiment was laid out in split plot design with three replications. It includes 9 main plot treatments as combinations of silicon and seed rate (SR) and 3 sub plot treatments as the levels of K (modified N: K ratios). The treatments consisted of three rates of silicon, *viz*, (S_1)-0 kg, (S_2)-50 kg and (S_3) -100 kg $Si0_2$ ha^{-1}.,three seed rates as (R_1)-50 kg, (R_2)-75 kg and R_3- 100 kg ha^{-1} and three levels of K(modified N:K ratios) as K_1- 40 kg(1:1),K_2- 80 kg(1:2) and K_3-120 kg(1:3) K_20 ha^{-1}.The variety used for the experiment was Njavara (black glumed variety).

Silicon caused significant variation on plant height, LAI at panicle initiation stage, culm strength, number of productive tillers m^{-2}, spikelets $panicle^{-1}$, thousand grain weight, net income, B:C ratio and uptake of major nutrients.

Height of the plant varied significantly due to silicon application only at 40 DAS and at harvest. At 40 DAS tallest plants of 86.70 cm was observed when silicon was applied at 100 kg ha^{-1}.Total no of tillers m^{-2} varied significantly due to silicon application at harvest stage, while the effect was non significant at PI stage. Leaf area index was significantly varied due to silicon application only at panicle initiation stage. The highest leaf area index of 1.94 was recorded by S_3 (silicon -100 kg ha^{-1}). No significant difference in rooting depth and total biomass was observed due to silicon application. Culm strength was found to be significant due to silicon application. The highest culm strength of 31.99 mg cm^{-1} was obtained for S_3 (silicon -100kg ha^{-1}).

Among the yield contributing characters, number of productive tillers panicle^{-1}, spikelets panicle^{-1} and thousand grain weight were significantly influenced by silicon application. The highest number of spikelets panicle $^{-1}$ of 66.14 was obtained for S_2 (silicon – 50 kg ha^{-1}). The highest thousand grain weight of 15.86 g was obtained for S_3 (silicon – 100 kg ha^{-1}). Grain weight panicle^{-1}, filled grains panicle^{-1} and sterility percentage were not significant due to silicon application.

Grain yield, straw yield and harvest index did not vary significantly due to silicon application. Net income was significantly varied due to silicon application. Highest net income was obtained for treatment without silicon (S_1) and was on par with 50 kg SiO_2 ha^{-1} (S_2) but significantly superior to 100 kg SiO_2 ha^{-1} (S_3).B: C ratio significantly varied due to silicon. Highest B: C ratio was for treatment without silicon (S_1).

Significant difference in nitrogen, phosphorus and potassium uptakes was found due to silicon.

Seed rate caused significant variation on plant height at 40 DAS and at harvest stage, tillers m^{-2} at harvest stage, LAI at panicle initiation stage, rooting depth, total biomass, number of productive tillers m^{-2}, thousand grain weight, grain yield, straw yield, harvest index ,B:C ratio and uptake of major nutrients.

There was significant difference in plant height only at 40 DAS and at harvest due to the effect of seed rate. In early stage R_3 (Seed rate @100 kg ha^{-1}) reported tallest plant. But at harvest R_1 (Seed rate @ 50 kg ha^{-1}) produced taller plants of 105 cm. Seed rate could not exert any significant influence on number of tillers m^{-2} at panicle initiation stage, but at harvest stage seed rate produced significant variation. Seed rates at 50 kg ha^{-1} (R_1) recorded highest tillers m^{-2} at harvest stage. Effect of seed rate on the leaf area index was also significant at panicle initiation stage. Rooting depth was significant and the highest rooting depth of 11.56 cm was recorded by R_1 (seed rate-50 kg ha^{-1}). Total biomass varied significantly and R_1 (seed @ 50 kg ha^{-1}) recorded the maximum value of 6317 kg ha^{-1}. Culm strength was not influenced by varying seed rates.

Among the yield contributing characters, seed rate caused significant variation in productive tillers m^{-2} and thousand grain weight. The highest number of productive tillers $m^{-2}$of 312.2 was recorded by R_3 (seed rate-100 kg ha^{-1}) and highest thousand grain weight by R_1 (seed rate-50 kg ha^{-1}) .Grain weight $panicle^{-1}$, spikelets $panicle^{-1}$, filled grains $panicle^{-1}$ and sterility percentage were not significantly influenced by seed rate.

The effect of seed rate on grain yield was significant and R_3 (seed @100 kg ha^{-1}) recorded the maximum yield of 2356 kg ha^{-1}. Seed rate on straw yield was also significant and R_1 (seed @50 kg ha^{-1}) recorded the maximum value of 4163 kg ha^{-1}. Highest harvest index of 0.21 was recorded by R_3 (seed @100 kg ha^{-1}).

Seed rate did not cause any significant influence on net income. Seed rate influenced the B: C ratio significantly and highest B: C ratio was for R_3 (seed @100 kg ha^{-1}) .

Significant difference in nitrogen, phosphorus and potassium uptakes was found due to seed rate .

Potassium levels (NK ratio) exerted significant influence on plant height at 40 DAS and at harvest stage, tillers m^{-2}, number of productive tillers m^{-2}, net income and uptake of N, P and K. The other parameters did not vary significantly due to K application.

K exerted significant influence on plant height at 40 DAS and at harvest stage. Potassium at 40 kg ha^{-1} (N: K 1:1) recorded higher plant height at 40 DAS. Potassium at 80 kg ha^{-1} NK: 1:2 recorded significantly superior plant height of 105.3 cm. Potassium (NK ratios) levels produced significant effect on number of tillers at both stages and the highest number of tillers m^{-2} of 400.82 was recorded by potassium at 80 kg ha^{-1} (NK ratio 1:2) at PI stage and at harvest stage.

Potassium levels (NK ratio) produced significant effect on productive tillers m^{-2} and potassium at 80 kg ha^{-1} (NK ratio 1:2) recorded the highest number of productive tillers m^{-2}.

NK ratio significantly influenced net income and highest net income was obtained for potassium at 120 kg ha^{-1}(NK: 1:3). Potassium levels could not exert influence on B: C ratio.

Uptake of N, P and K varied significantly due to potassium.

Interaction effect of SxR was significant on tillers m^{-2}, LAI at PI stage, total biomass, culm strength, number of productive tillers m^{-2}, filled grains $panicle^{-1}$, thousand grain weight, grain yield, straw yield, harvest index and uptakes. Other parameters did not show any significance due to SxR interaction.

SxK interaction effect was significant on plant height at both the stages, tillers m^{-2}, number of productive tillers m^{-2} and P and K uptakes. None of the other growth parameters and yield contributing characters was affected by SxK interaction. Grain yield and straw yield was not effected by SxK interaction.

Interaction effect of RxK was significant on tillers m^{-2} at both the stages, LAI, number of productive tillers m^{-2}, and uptakes. Other growth parameters and yield contributing characters did not significantly varies due to RxK interaction. Grain yield and straw yield was not found to be significant due to RxK interaction.

SxRxK interactions was found to be significant on plant height only at harvest stage, tillers m^{-2} at both stages, number of productive tillers m^{-2},grain yield and uptakes. The highest grain yield of 2678 kg ha^{-1} was recorded by $s_2r_3k_2$(silicon @ 50 kg ha^{-1} ,seed rate @ 100 kg ha^{-1} and NK ratio 1:2).

Net income and B: C ratio varied significantly by interaction of treatments. The highest net income and the highest B: C ratio of Rs 93120/- and 1.97

respectively was for $s_1r_2k_1$. (silicon @ 0 kg ha^{-1}, seed @ 75 kg ha^{-1} and potassium @ 40 kg ha^{-1}-NK ratio 1:1) .

The results thus revealed that for the profitable production of Njavara rice, application silicon and potassium along with use of higher seed rate is economically feasible. Considering the general performance of the crop with regard to all the growth and yield parameters, the treatment receiving silicon @ 50 kg ha^{-1}, seed @ 100 kg ha^{-1} and potassium @ 80 kg K_2O ha^{-1}(NK ratio 1:2) was found beneficial for Njavara rice.

FUTURE LINE OF WORK:

- Indigenous and cheaper source of silicon may be tested.
- Organic package has to worked out
- Performance of Njavara under upland situation
- Available types of Njavara rice may be evaluated for their performance and medicinal value.
- Shade response of Njavara rice o be investigated
- Clinical studies for assessing the medicinal property
- Popularization of Njavara cultivation among farmers

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Appendices

APPENDIX-1

Data on weather parameters during cropping period

(December 2012-March 2013)

Standard weeks	Maximum temperature (^0C)	Minimum temperature (^0C)	Maximum relative humidity (%)	Minimum relative humidity (%)	Sunshine hours	Rainfall (mm)
49	30.5	22.6	99.0	66.3	8.7	0.5
50	30.6	22.1	99.0	62.4	8.9	0.0
51	31.1	22.8	91.4	60.3	8.2	0.0
52	30.5	23.5	99.0	71.9	7.9	40.0
1	32.3	23.7	91.4	75.4	9.8	17.5
2	30.0	22.6	96.4	74.6	8.5	24.0
3	30.1	20.8	96.0	75.1	9.4	0.0
4	30.5	21.3	96.1	73.6	9.4	0.0
5	30.4	20.8	94.3	75.4	9.3	0.0
6	31.2	22.9	93.3	74.3	9.2	5.0
7	32.0	23.0	92.4	75.7	9.3	33.0
8	31.4	21.8	89.9	74.9	9.3	0.0
9	32	21.4	91.3	67.4	9.5	0.0
10	32.1	24.3	94.7	80.6	9.3	21.0

Abstract

Productivity Enhancement in Medicinal Rice

(*Oryza sativa* L.) cv. Njavara

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ABSTRACT

The present investigation on "Productivity enhancement in medicinal rice (*Oryza sativa* L.) cv. Njavara" was conducted at College of Agriculture, Vellayani for assessing the impact of silicon, modified NK ratios and reduced seed rate on the growth, lodging and yield and the economics of production of Njavara rice. The treatments consisted of three rates of silicon, *viz*, (S_1)-0 kg, (S_2)-50 kg and (S_3) -100 kg $Si0_2$ ha^{-1}.,three seed rates as (R_1)-50 kg, (R_2)-75 kg and R_3- 100 kg ha^{-1} and three levels of K(modified N:K ratios) as K_1- 40 kg(1:1),K_2- 80 kg(1:2) and K_3- 120 kg(1:3) K_20 ha^{-1}.The experiment was laid out in split plot design with three replications. It includes 9 main plot treatments as combinations of silicon and seed rate (SR) and 3 sub plot treatments as the levels of K (modified N: K ratios). The results of the investigation are summarised below.

Application of silicon influenced the growth attributes like plant height at 40DAS and at harvest, LAI at panicle initiation stage and culm strength at harvest stage. The other growth attributes like rooting depth, tillers m^{-2} and total biomass were not significantly influenced by silicon. Yield contributing characters like productive tillers m^{-2}; spikelets $panicle^{-1}$ and thousand grain weight were significantly influenced by silicon application. While silicon @100 kg ha^{-1} recorded significantly higher number of productive tillers m^{-2} and thousand grain weight, silicon @50 kg ha^{-1}registered the highest number of spikelets $panicle^{-1}$. The other yield contributing characters like grain weight $panicle^{-1}$, filled grains $panicle^{-1}$, sterility percentage, straw yield, grain yield and harvest index were not significantly influenced by silicon.

Seed rate produced significant influence on growth attributes like plant height, LAI, total biomass and rooting depth. Seed @ 50 kg ha^{-1} produced the highest rooting depth and total biomass and seed @75 kg ha^{-1} produced highest plant height. Tillers m^{-2} and culm strength were not significantly influenced by seed rate. Yield attributes like number of productive tillers m^{-2}, thousand grain

weight, grain yield, straw yield and harvest index were significantly influenced by seed rate. While seed @100 kg ha^{-1}produced significantly highest number of productive tillers m^{-2}, thousand grain weight, grain yield, straw yield and harvest index were highest at seed @ 50 kg ha^{-1}.

Potassium (NK ratio) could not exert any significant influence on growth characters except plant height and number of tillers m^{-2}, registering the superiority at K_2 (N:K: 1:2). Number of productive tillers m^{-2} was the only yield contributing parameter significantly influenced by NK ratio (K levels) and the highest value was recorded by K_3 (N:K: 1:3).

Yield attributes like number of productive tillers m^{-2}, grain yield, net income and B: C ratio varied significantly by interaction of treatments and s_2 r_3 k_2 (S-50 kg ha^{-1}, R-100 kg ha^{-1}, NK 1:2 -80 kg ha^{-1}) registered the highest grain yield. The highest net income and the highest B: C ratio of Rs 93120/- and 1.97 respectively were for $s_1r_2k_1$. (S-0, R-75 , K-40 kg ha^{-1}).

Considering the general performance of the crop with regard to all the growth and yield parameters, the treatment receiving silicon @ 50 kg ha^{-1}, seed @ 100 kg ha^{-1} and potassium @ 80 kg K_2O ha^{-1}(NK ratio 1:2) was found beneficial for Njavara rice.

സംഗ്രഹം

ഔഷധനെല്ലിനമായ ഞവരയുടെ വിളവർദ്ധനവിനായി ഒരു പഠനം ഡിസംബർ 2012 മുതൽ മാർച്ച് 2013 വരെയുള്ള കാലയളവിൽ വെള്ളായണി കാർഷികകോളേജിലെ ഇൻസ്ട്രക്ഷണൽ ഫാമിൽ നടത്തുകയുണ്ടായി. ഞവരകൃഷിയിൽ സിലിക്കണിനുള്ള പ്രാധാന്യം എത്രത്തോളം ഉണ്ട് എന്ന് അറിയുന്നതിനും നൈട്രജന്റെയും പൊട്ടാഷിന്റെയും ശരിയായ അനുപാതം ഏത് എന്ന് അറിയുന്നതിനും വേണ്ടിയായിരുന്നു ഈ പരീക്ഷണം. ഞവര വിത്തിന്റെ കൂടിയ വില പരിഗണിച്ച് ശുപാർശയിലും കുറഞ്ഞ അളവിൽ വിത്ത് ഉപയോഗിക്കുന്നത് വിളവിനെ എങ്ങനെ ബാധിക്കും എന്നത് ഈ പരീക്ഷണത്തിൽ പഠന വിധേയമാക്കുകയുണ്ടായി.

പ്രസ്തുത പരീക്ഷണത്തിന് സപ്ലിറ്റ് പ്ലോട്ട് ഡിസൈൻ എന്ന പരീക്ഷണരീതി യാണ് അവലംബിച്ചത്. ഈ പഠനത്തിൽ സിലിക്കണിന്റെ മൂന്ന് തോത് (0,50,100 കിലോഗ്രാം/ ഹെക്ടർ), വിത്തിന്റെ മൂന്ന് അളവ് (50,75,100 കിലോഗ്രാം/ ഹെക്ടർ) പൊട്ടാഷ് മൂന്ന് തോത് (40,80,120 കിലോഗ്രാം/ ഹെക്ടർ അതായത് എൻ.കെ. അനുപാതം 1:1, 1:2, 1:3) എന്നിവയായിരുന്നു പരീക്ഷണവിധേയമാക്കിയത്.

സിലിക്കൺ ഉപയോഗിച്ചപ്പോൾ നെൽച്ചെടിയുടെ പൊക്കം, ഇലയുടെ എണ്ണം, തണ്ടിന്റെ ബലം എന്നീ വളർച്ചാമാനദണ്ഡങ്ങൾ കൂടിയതായി കണ്ടു. അതോടൊപ്പം തന്നെ കതിരുകളുടെ എണ്ണം നെൻമണികളുടെ എണ്ണം, നെൽവിത്തിന്റെ വലിപ്പം എന്നിവയും മെച്ചപ്പെട്ടതായി മനസ്സിലായി. സിലിക്കണിന്റെ ഉപയോഗം മൂലം മറ്റ് മൂലകങ്ങൾ വലിച്ചെടുക്കുന്നതിനുള്ള ശേഷി വർദ്ധിക്കുകയും അറ്റാദായം കൂടുകയും ചെയ്തു.

പൊട്ടാഷ് ഹെക്ടർ ഒന്നിന് 80 കി.ഗ്രാം എന്ന തോതിൽ ഉപയോഗിച്ചപ്പോൾ കതിരുകളുടെ എണ്ണം കൂടുകയും മൂലകങ്ങൾ വലിച്ചെടുക്കുന്നതിനുള്ള ശേഷി വർദ്ധിക്കുകയും അറ്റാദായം കൂടുകയും ചെയ്തു.

ശുപാർശയിലും കുറഞ്ഞ അളവിൽ വിത്ത് ഉപയോഗിച്ചപ്പോൾ ഞവരനെല്ലിന്റെ വളർച്ചയിലും വിളവിലും പ്രകടമായ കുറവ് കാണപ്പെട്ടു. ശുപാർശ ചെയ്തിട്ടുള്ള അളവിൽ അതായത് ഒരു ഹെക്ടറിന് 100 കി.ഗ്രാം എന്ന തോതിൽ വിത്ത് ഉപയോഗിക്കുന്നതുതന്നെയാണ് വിളവർദ്ധനയ്ക്കും മെച്ചപ്പെട്ട ആദായം ലഭിക്കുന്നതിനും നല്ലത് എന്ന് കാണപ്പെട്ടു.

ഞവരനെൽക്കൃഷിയിൽ മെച്ചപ്പെട്ട വിളവും കൂടുതൽ ആദായം ലഭിക്കുന്നതിനും ഒരു ഹെക്ടറിന് സിലിക്കൺ 50 കി.ഗ്രാം എന്ന അളവിലും, പൊട്ടാഷ് 80 കി.ഗ്രാം എന്ന തോതിലും (നൈട്രജൻ പൊട്ടാഷ് അനുപാതം 1:2), വിത്ത് 100 കി.ഗ്രാം എന്ന തോതിലും ഉപയോഗിക്കുന്നതാണ് ഏറ്റവും അഭികാമ്യം.

സംഗ്രഹം

ഔഷധനെല്ലിനമായ ഞവരയുടെ വിളവർദ്ധനവിനായി ഒരു പഠനം ഡിസംബർ 2012 മുതൽ മാർച്ച് 2013 വരെയുള്ള കാലയളവിൽ വെള്ളായണി കാർഷികകോളേജിലെ ഇൻസ്ട്രക്ഷണൽ ഫാമിൽ നടത്തുകയുണ്ടായി. ഞവരകൃഷിയിൽ സിലിക്കണിനുള്ള പ്രാധാന്യം എത്രത്തോളം ഉണ്ട് എന്ന് അറിയുന്നതിനും നൈട്രജന്റെയും പൊട്ടാഷിന്റെയും ശരിയായ അനുപാതം ഏത് എന്ന് അറിയുന്നതിനും വേണ്ടിയായിരുന്നു ഈ പരീക്ഷണം. ഞവര വിത്തിന്റെ കൂടിയ വില പരിഗണിച്ച് ശുപാർശയിലും കുറഞ്ഞ അളവിൽ വിത്ത് ഉപയോഗിക്കുന്നത് വിളവിനെ എങ്ങനെ ബാധിക്കും എന്നത് ഈ പരീക്ഷണത്തിൽ പഠന വിധേയമാക്കുകയുണ്ടായി.

പ്രസ്തുത പരീക്ഷണത്തിന് സ്പ്ലിറ്റ് പ്ലോട്ട് ഡിസൈൻ എന്ന പരീക്ഷണരീതിയാണ് അവലംബിച്ചത്. ഈ പഠനത്തിൽ സിലിക്കണിന്റെ മൂന്ന് തോത് (0,50,100 കിലോഗ്രാം/ ഹെക്ടർ), വിത്തിന്റെ മൂന്ന് അളവ് (50,75,100 കിലോഗ്രാം/ ഹെക്ടർ) പൊട്ടാഷ് മൂന്ന് തോത് (40,80,120 കിലോഗ്രാം/ ഹെക്ടർ അതായത് എൻ.കെ. അനുപാതം 1:1, 1:2, 1:3) എന്നിവയായിരുന്നു പരീക്ഷണവിധേയമാക്കിയത്.

സിലിക്കൺ ഉപയോഗിച്ചപ്പോൾ നെൽച്ചെടിയുടെ പൊക്കം, ഇലയുടെ എണ്ണം, തണ്ടിന്റെ ബലം എന്നീ വളർച്ചാമാനദണ്ഡങ്ങൾ കൂടിയതായി കണ്ടു. അതോടൊപ്പം തന്നെ കതിരുകളുടെ എണ്ണം നെൻമണികളുടെ എണ്ണം, നെൽവിത്തിന്റെ വലിപ്പം എന്നിവയും മെച്ചപ്പെട്ടതായി മനസ്സിലായി. സിലിക്കണിന്റെ ഉപയോഗം മൂലം മറ്റ് മൂലകങ്ങൾ വലിച്ചെടുക്കുന്നതിനുള്ള ശേഷി വർദ്ധിക്കുകയും അറ്റാദായം കൂടുകയും ചെയ്തു.

പൊട്ടാഷ് ഹെക്ടർ ഒന്നിന് 80 കി.ഗ്രാം എന്ന തോതിൽ ഉപയോഗിച്ചപ്പോൾ കതിരുകളുടെ എണ്ണം കൂടുകയും മൂലകങ്ങൾ വലിച്ചെടുക്കുന്നതിനുള്ള ശേഷി വർദ്ധിക്കുകയും അറ്റാദായം കൂടുകയും ചെയ്തു.

ശുപാർശയിലും കുറഞ്ഞ അളവിൽ വിത്ത് ഉപയോഗിച്ചപ്പോൾ ഞവരനെല്ലിന്റെ വളർച്ചയിലും വിളവിലും പ്രകടമായ കുറവ് കാണപ്പെട്ടു. ശുപാർശ ചെയ്തിട്ടുള്ള അളവിൽ അതായത് ഒരു ഹെക്ടറിന് 100 കി.ഗ്രാം എന്ന തോതിൽ വിത്ത് ഉപയോഗിക്കുന്നതുതന്നെയാണ് വിളവർദ്ധനയ്ക്കും മെച്ചപ്പെട്ട ആദായം ലഭിക്കുന്നതിനും നല്ലത് എന്ന് കാണപ്പെട്ടു.

ഞവരനെൽക്കൃഷിയിൽ മെച്ചപ്പെട്ട വിളവും കൂടുതൽ ആദായം ലഭിക്കുന്നതിനും ഒരു ഹെക്ടറിന് സിലിക്കൺ 50 കി.ഗ്രാം എന്ന അളവിലും, പൊട്ടാഷ് 80 കി.ഗ്രാം എന്ന തോതിലും (നൈട്രജൻ പൊട്ടാഷ് അനുപാതം 1:2), വിത്ത് 100 കി.ഗ്രാം എന്ന തോതിലും ഉപയോഗിക്കുന്നതാണ് ഏറ്റവും അഭികാമ്യം.