ROCK DUST AS A NUTRIENT SOURCE FOR COLEUS
(*Solenostemon rotundifolius* (POIR) MORTON)

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DECLARATION

I hereby declare that this thesis entitled **"Rock dust as a Nutrient Source for Coleus (*Solenostemon rotundifolius* (poir) Morton)"**is a bonafide record of research work 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, associateship, fellowship or other similar title of any other university or society

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CERTIFICATE

Certified that this thesis entitled **"Rock dust as a Nutrient Source for Coleus (*Solenostemon rotundifolius* (poir) Morton)"**is a record of research work done independently by **Ms. Divya.S.S.Rose (2005-11-124)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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DIVYA.S.S.ROSE

CONTENTS

List of Abbreviations

@	At the rate of
B	Boron
B: C	Benefit: Cost
Ca	Calcium
CEC	Cation Exchange Capacity
cm	Centimeter
CD	Critical Difference
Cu	Copper
CTCRI	Central Tuber Crop Research Institute
$dS\ m^{-1}$	Deci Siemens per meter
DTPA	Diethylene Tri amine Penta Acetic Acid
EC	Electrical Conductivity
et al	And others
Fe	Iron
Fig.	Figure
FYM	Farm Yard Manure
g	Gram
ha	Hectare
K	Potassium
KAU	Kerala Agricultural University
$Kg\ ha^{-1}$	kilo gram per hectare
LAI	Leaf Area Index
m^2	Square meter
mm	Millimeter
mg	Milligram
$Mg\ m^{-1}$	Mega gram per meter cube
Mg	Magnesium
Mn	Manganese
MOP	Muriate of Potash
MSL	Mean Sea Level
N	Nitrogen
P	Phosphorus
$Plants\ ha^{-1}$	Plants per hectare
POP	Package of Practices
ppm	Parts per million
%	percent
t	tones
$t\ ha^{-1}$	tones per hectare
Zn	Zinc
°C	Degree Celsius

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INTRODUCTION

1. INTRODUCTION

Our soils are being subjected to rapid degradation day by day. Over exploitatation of natural resources, unscientific cultivation, deforestation and over use of chemicals and pesticides are depleting the soil nutrients and cause severe environmental problems.

The soils of the entire world have become severely demineralized by erosion over thousands of years. Plants require a continuous intake of minerals, just as we do, and for very similar reasons calcium to build structural support, iron to carry oxygen, and so on. Plants growing on mineral-depleted soil do not get enough nourishment and become smaller, less abundant and less hardy and more vulnerable to the insects, worms and fungi.

With the exception of nitrogen, all plant nutrient sources for farming systems are of geological provenance. In natural systems, nitrogen is 'harvested' from the air by legumes or through N-fixing organisms and recycled in the soil. Other nutrients critical for plant growth, like P, K, Ca, Mg, S and micronutrients are supplied by geological resources – rocks. Weathering of these rocks, as well as organic inputs, atmospheric deposition, and re-sedimentation of soil materials eroded from upper slopes, supplies most of the nutrients essential for plant growth. To sustain crop production, soils need replenishment of nutrients through inputs such as manures, water-soluble fertilizers or some other alternative inputs. Some agro minerals occur naturally in concentrations and forms that can be used as alternative fertilizers or soil amendments. 'Reactive' sedimentary phosphate rock (PR), gypsum, dolomite, limestone, and various other minerals fall in this category. In other cases, mineral resources do not occur in a form that is directly available to crops and must be modified physically, chemically and biologically to become effective nutrient sources for soils and crops. For other agro mineral resources, such as ground silicate rocks, large quantities of rock material are needed to be agronomically effective (Roschnik et al., 1967 and Gillman, 1980).

It has been noted that the use of rock dust can reduce or even replace fertilizers, pesticides or fungicides (SEER Centre, 1998). Rock dust has the potential for rebuilding dry soil, if it is used in combination with compost. Tropical soils that are low in humus could be rebuilt from a base of rock dust, which is the basis of agro geology. Agro geology is broadly defined as 'geology in the service of agriculture,' a study of geological processes that influence the distribution and formation of soils, and the application of geological materials in farming and forestry systems as means of maintaining and enhancing soil productivity for increased social, economical and environmental benefits (Chesworth et al., 1983).

Rock dust is a generic term applied to fine material produced as by products of quarrying and mineral processing. Agricultural research with finely ground and chemically unprocessed rocks and minerals based on the concept of 'bread from stone' started in the 19^{th} century. Application of rock dust changes the physical and chemical properties of soil that are reflected on changes in plant growth. It contains most of the nutrients required for plant growth except N. Finely ground rock powder is a fast food for microbes, and there is a population explosion of bacteria in soil after its application.

Rocks and minerals are used in crop productive systems for the purpose like improving soil fertility, correcting soil pH and conserving nutrients and water. The benefits of rock dust application are enhanced long term sustainable soil fertility, diverse soil biology, multi season effect, enhanced flavour aroma and shelf life of produce and good quality produces (Hamaker and Weaver, 1982)

Rocks, particularly igneous (primary) material are typically rich in minerals, and use of quarry wastes in crop production either direct to soil or in combinations with chemical fertilizers and farmyard manure is recommended. It can also be added to the potting media for raising seedlings or used as a feedstock for compost.

The use of rock dust as a low cost, locally available geological resource for agricultural development is not new. Use of rock dust either alone, or in combination with organic material plus inorganic fertilizers has increased crop yields in Europe and other countries. In Australia, rock dust has (granite, basalt, diorite etc) been used since 1980's for various crops as substitute to chemical fertilizers. The results of several studies showed that fertilizer applications could be reduced by 80 per cent and yield could be increased by 25 per cent by using rock dust. Such studies are lacking in Kerala. In this context, the present study was taken up with the following objectives

- To monitor the nutrient release pattern from rock dust applied in soil, under laboratory conditions.
- To study the effect of application of FYM on the release of nutrients from rock dust.
- To study the possibility for either full or partial substitution. of chemical fertilizers with rock dust without affecting the yield of coleus (*Solenostemon rotundifolius* (poir) Morton).
- To compare the effect of chemical fertilizers and naturally available material like rock dust on growth and yield of coleus (*Solenostemon rotundifolius* (poir) Morton).
- To reduce the cost of production of tuber crops like coleus

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Rock dust is a by - product of quarry industry, 90 per cent of which pass through 200 mesh screen. In the 18 th century James Hutan, Father of Modern Geology used rocks like marl to increase soil fertility of his farm in Scotland. Soil is made from rock; in fact, it is decayed rock – weathered by wind and water, micro and macro organisms. The use of rock dust as a part of soil improvement and fertility is referred to as remineralization because application of quarry fines restores the minerals lost through weathering and intensive crop production.

Soil remineralization is a concept that treats the soil as a live organism. Finely ground rock dust is added to the soil, which is broken down by microbiological activity. This is said to create food for the plants, which take up the processed minerals from the microorganisms. The plants grown on mineralized soils are healthier. The rock dust also helps to bind up excess atmospheric CO_2 in both plant biomass and by chemical reaction (Leonardos et al., 1982). The research results relating to the use, nutrient supplying ability and its influence on crop growth and yield are being reviewed in this chapter.

2.1 TYPES OF ROCKS USED

Earlier experiments revealed that common rock forming minerals such as feldspars and micas were early shown experimentally as efficient sources of potassium, calcium and micronutrients for a variety of plants (Aitken, 1887; Cushman, 1907; Turk, 1919; Haley, 1923; Graham, 1941 and Lyon, 1955).

One of the most comprehensive field trials using powdered rock fertilizer was carried out for sugar cane in Mauritius. The long - term trials successfully recorded that basalt flour could be used profitably to rejuvenate laterite soils (D'Hotman, 1947, 1949, 1961).

In Brazil, independent work has advocated the use of potassium rich (zeolitized) phonolite(Frayha,1950 and Ilchenko and Guimaraes 1953,1954), ultramafic tuffs (Ilchenko,1955),mica schist(Lima,1969.and Horowitz , et al.,1978), basalt (Paccola et al., 1974 and Leonardos et al.,1982) and other rock types as alternative fertilizers for laterite soils.

Igneous rock spectrum such as dunites and serpentines (Chittenden et al., 1969), granite and gneisses (Geering, 1952) have also been successfully employed as source of magnesium and potassium.

Hamaker and Weaver (1982) reported that a heterogeneous combination of various rocks or minerals is preferred. They also reported that other metamorphic or igneous rocks such as basalt, rhyolites are ideal for remineralization.

Igneous rocks are ideal for re mineralization process. In this, basalt rock types are the best, because they are rich in essential mineral elements such as Fe, Mg, Ca, and Mn and they weather quickly. Suitable basalt rock type includes Bentronite, Feldspar, Serpentine and greensand (Collins, 1985 and Oldfield, 1999).

Walters (1991) reported that ideal rock for remineralization is glacial moraine material because these rocks are formed deep within the earth from a large variety of rock types and particle size.

In an experiment conducted at Farming System Research Station, Kottarakara, Kerala during 1999-2000, khondalite (rock powder) collected from nearby quarry was used as of nutrient source for cassava either alone or in combination with chemical fertilizers and farmyard manures. (Shehana et al., 2006).

2.2 RATE OF APPLICATION

Hamaker and Weaver (1982) recommended an application rate of three, ten and twenty t acre $^{-1}$ for minimum, long term and for poor soils, respectively.

Fragstein et al. (1988) stated that application of silicate rock dust at the rate of one t ha^{-1} per year is sufficient to provide the nutrients required for sustainable growth of crops and trees.

Yarrow (1991) reported that the minimum application rate of rock dust to soil is seven t ha^{-1} and maximum application is 24 t ha^{-1}.

2.3 PARTICLE SIZE OF ROCK DUST

Hamaker and Weaver (1982) observed that rock dust means 90 per cent of which pass through 200 mesh screen. He also stated that the ideal particle size is 20 per cent pass through 200 mesh screen and 50 per cent pass through 100 mesh screen.

2.4 PHYSICAL PROPERTIES OF SOIL

Fragstein and Vougtmann (1987) observed on improvement in water holding capacity and cation exchange capacity of soil, by the application of rock dust.

In an incubation study conducted in the laterite soils of Kottarakara during 2001-2003, the lowest bulk density of 1.10 Mg m^{-3}, highest water holding capacity of 57.33 per cent and maximum pore space of 54.67 per cent were observed when rock dust was applied @ 1 t ha^{-1} along with lime (Shehana, 2006).

2.5 NUTRIENT SUPPLYING CAPACITY

Rocks have fast solubility rate both in water and weak organic acids, promptly releasing nutrients within minutes and increasing the pH of solution until the system is saturated (Keller, 1948, 1950).

Hamaker and Weaver (1982) reported that application of rock dust for corn crop resulted in an increase of 57 per cent P, 90 per cent K, 47 per cent Ca and 60 per cent Mg than chemically grown crop from the same seed.

Leonardos et al. (1985) designed a balanced diet using the following rock type , Alternative A :- basic rock (basalt, amphibole, chlorite , schist etc) to supply Ca, Mg, Na, micronutrients and variable amounts of S and P, alkaline or acidic rock in minor amounts to complement micronutrients and K, P and S and rock phosphate if not enough P. In Alternative B:- alkaline or acidic rocks to supply Na, K, Li, F, micronutrients and variable amount of Mg, Ca, S and P , dolomite , magnetite or serpentine to complement Mg, micronutrients and some times S. Alternative C: -

included any igneous, metamorphic or sedimentary rock with enough crystal or mantle geochemistry, dolomite, gypsum and sulphides depending on composition.

Fragstein and Vogtmann (1987) reported that rock dust contains most of the nutrients essential for plant growth except nitrogen and phosphorus.

Collins (1985) stated that the release of nutrients is directly related to weathering; consequently, their beneficial effect could last for many years. The problem of nutrient leaching could be minimized as the plants absorb the nutrients at the same rate of release and there was minimal problem with toxicity from over supply of nutrients.

Kramer (1996) reported that application of rock dust was best for total soil management.

Korcak (1996) stated that sixteen elements were considered to be essential for the growth of higher plants .These included those required in relatively large amount i.e. H, O, N, C, K, Mg, P, S and Ca and those required in relatively small amounts (ppm) i.e. Mn, Zn, Cu, Fe, B and Mo and most of these are provided by rock dust and from the environmental healthy soil systems.

2.5.1 Supply of major nutrients

Baerug (1991) studied the potassium release pattern from powdered (0 to 4 mm) granite, gneiss, syenite and amphibole in a five-year pot experiment with successively grown oats, timothy, red clover, meadow fescue and ryegrass. The growth media used were rock powder and fine sand low in K, and the percentages of rock powder were 0, 0.1, 5 and 100. A small amount of sphagnum (4 per cent) was added to all pots in order to improve the physical condition of the growth media. An admixture of 0.5 per cent powdered gneiss and amphibole increased the yields in the first two years but not in the subsequent three years. With 5 per cent rock powder in the growth medium, there was a substantial increase in dry matter, yield and K accumulated throughout the five-year experimental period. The responses were significantly lower for syenite than for gneiss and amphibole. The highest yields and uptake of K were obtained with media containing 100 per cent rock powder. The yield increases were considerable over the five years for all rock types, but the amounts of K accumulated were significantly lower for syenite than for gneiss and amphibole.

The magnesium release from powdered (0 to 4 mm) granite, gneiss, syenite and amphibole was investigated in a four-year pot experiment by Baerug (1991) with successively grown oats, timothy, red clover and meadow fescue. The growth media used were rock powder and fine sand, low in magnesium. The percentages of rock powder were 0, 0.1, 5 and 100. A small amount of sphagnum (4 per cent) was added to all pots to improve the physical condition of the growth media. An admixture of 0.5 per cent rock powder had no effect on the growth or uptake of magnesium by the crops. With 5 per cent rock powder in the growth medium, a moderate effect was found over one, two or three years for gneiss, syenite and amphibole, respectively. When rock powder constituted 100 per cent of the inorganic material a very clear effect on dry matter and Mg uptake was registered throughout the four year experimental period. Amphibole and syenite were more effective than gneiss as a source of Mg.

From the experiments with scrap grade phlogopite from a Sri Lankan mica processing centre, Hisinger et al. (1996) reported that up to 65 per cent of the K and Mg contained in the phlogopite could be recovered.

Scott (1995) found that the application of sedimentary rocks increased the uptake of Ca and Mg in natural forest of North Carolina, USA.

An incubation study was conducted in the laterite soils of Kottarakara, Kerala during 1999-2000 for studying the nutrient release pattern from the rock dust for a period of ten months. Here rock dust was applied @ 0.5, 1, 2 and 3 t ha^{-1} alone and in combination with FYM. N and P from rock dust were found to increase over time, where as K release was maximum during the first month (Shehana et al., 2006).

2.5.2 Supply of Micronutrients

Silicate minerals and rocks contain most of the nutrients required for growth and development of the plants. The application of ground silicate rocks to highly weathered, low fertile, acid soils has been proposed as alternative to conventional fertilization with water-soluble fertilizers (Leonardos et al., 1982; Fragstein et al., 1988. and Coroneos 1996). The effects of applying large tons of ground silicate rocks as byproducts of the quarrying industry are part of an alternative sustainable strategy to 'remineralize' or 'recapitalize' degraded soils (Fragstein et al., 1988. and Leonardos et al., 1982).

The incubation study conducted in the laterite soils of Kottarakara, Kerala during 1999-2000, revealed that the release of available Zn and Mn were maximum immediately after application (Shehana, 2006).

2.6 SOIL REACTION

In an experiment conducted by Fragstein et al. (1988) analyzing 32 different ground rock samples for their water and HCl extractable cations, micronutrients and pH, the highest cation release rates were observed from phonolitic rocks followed by basaltic rock types and granite powder regardless of extraction method. In water extracts, the pH of all samples was alkaline with ground phonolitic rocks reaching a pH of $>$ 10, basalts pH 8 to 10, and granites pH 7 to 10.

An experiment was conducted by Mersi et al. (1992) to study the effect of low dosage of rock powder on nitrification, basal respiration, microbial bio mass, xylanase, phosphatases and protinase activities, the amount of nitrate nitrogen and pH in forest loam soils. They observed that low dosage of rock powder increased protinase, nitrate nitrogen content and pH.

Campe et al. (1996) reported that rock dust neutralize the soil to a great degree in forest soil where lime stone is not recommended, which destroy the humus building complex.

2.7 CATION EXCHANGE CAPACITY

Five rock powders with different chemical and mineralogical characteristics were investigated for their suitability as soil conditioners by Blum et al. (1989). The highest cation exchange capacity (CEC) was determined for the powder of smectite-rich volcanic ash. Carbonate rock powders showed highest values for acid neutralization capacity (ANC). Silicate rock powders (granite, basalt) recorded the lowest values for both parameters.

2.8 SOIL BIOLOGY

Hamaker and Weaver (1982) reported that if the rock is finely ground, the microorganisms will access to the minerals more readily.

Fragstein (1983) carried out experiments in Germany to study the potential of silicate rocks as natural fertilizers, examining their weathering properties and the qualitative and quantitative aspects of their use. Their main conclusions were that rock dust has potential when used in conjunction with natural biologically oriented agriculture.

Lertola (1991) stated that compost and rock dust had a symbiotic combination. The compost provides an excellent medium for the "micro organism population explosion", incorporation of rock dust increased the microbial activity of soil.

Hisinger et. al. (1996) conducted electron microscopic and x- ray studies which proved that the roots of rape *(Brassica rapus)* and rye grass can transform phlogopite in to vermiculite, releasing K and Mg to plants. Roots and rhizospheres of plants are active biological weathering agents that transform micas and release K and other cations.

Garcia et al. (2002) found that application of rock dust increased the microbial activity in the initial period of composting, the mesophylic phase resulting in increased temperature.

2.9 MULTI SEASON EFFECT

Mersi et al. (1992) found that application of rock dust increased carbon and nitrogen mineralization with long-term effect.

2.10 PLANT GROWTH AND DEVELOPMENT

Leonardos et al. (1985) carried out pot experiments and field trials in University of Brasilia on lateritic soil with the objective of testing local and inexpensive rock materials that were already available in ground form as the residual by product of the quarrying industry. Rock powders were of three-type a) pigeonitic basalt b) muscovite- biotite-chlorite- carbonates schist c) phonolite. The grain size was less than 80 mesh screen with about 50 per cent less than 200 mesh screen. N, P, K, rock phosphate, micronutrients and dolomitic limestone were used in the experiments for comparative purposes. In pot experiment conducted in green house condition on the growth of beans (*Phaseolus vulgaris*, L.), the highest values were recorded in the treatments where N, P and mica schist + N, P, K + micronutrients + basalt; N, P + mica schist + dolomitic limestone and N, P + phonolite with basalt were applied. The values were higher than single N, P, K treatment which also had considerable residual effects than the other treatments. Rocks and trace element addition had much larger nodulation of *Rhizobium* than other treatments. Basalt, among the other rocks types have the best results followed by mica schist. He also carried out field experiments with *Eucalyptus pellita* where the rock powders like lime stone and basalt were supplied with NPK, basalt powder alone and N, P, K + basalt. The results showed that application of basalt rocks increased plant height and standard diameter measured at 1.6 m height when compared with N, P, and K, alone.

Yarrow (1991) reported the results of nursery trials conducted by Men of the trees using granite dust from a nearest quarry. It was found that rock dust treated seedlings grew up to 50 per cent more. He also reported that application of rock dust to vegetables, herbs and flowers resulted in the extra vigour of plants, large quantities of fruits, number flowers and seeds.

From the experiments in various trees in Australia using granite and diorite at the rate of 12 t to 20 t ha^{-1}, Oldfield (1992, 1997) found that application of rock dust increased plant growth and nitrogen fixation capacity.

Becker (1995) found that application of granite, basalt, glacial silt along with compost increased the grain yield of maize

In Australia, Bolland (1995) observed that application of granite increased the plant growth in wheat.

Campe (1995) reported that the application of granite, basalt and sand silt increased 50per cent growth in maize.

In North Carolina, Scott (1995) observed that in natural forest, the application of sedimentary rock lowered plant mortality by 39 per cent.

Oldfield (1997) found that in acacia, the application of granite increased the survival of seedlings by 57.5 per cent compared to untreated plots.

Application of basalt and glacial dust in lettuce, apple and sweet corn increased soil fertility and plant growth in USA (Barkar et al., 1998).

Improved plant growth and establishment through the application of basalt was reported from an experiment conducted at Scotland in brassicas by Szmith (1998, 2004).

Yarrow (1998) reported that the application of azomite clay (rock dust) increased the plant height and earliness of flowering in tomatoes.

Bruck (1998) found that application of rock dust increased the plant height of mahogany by 33.60 per cent.

Madeley (1999) conducted pot experiments using rock dust in lettuce, cress and brassicas using perlite as medium. It was found that the initial growth rate of the rock dust applied lettuce plant were higher, when compared to control. He also reported that the shoot height, root length and plant weight were significantly higher in the rock dust applied plants. In the same study, it was also found that the application of rock dust increased plant growth and establishment in brassicas.

BBC (2004) reported the success story of two Scottish teachers, Moriya Thomson and Cameron, who had spent 20 years experimenting with remineralization. In 1997, they set up a charitable trust the SEER Centre (The Sustainable Ecological Earth Regeneration) in highland Perth Shire, Scotland for experimental research in organic gardens and small holdings.

Edinei et al. (2006) reported that the application of 3 and 4 t ha $^{-1}$ powdered basalt in green manure crops resulted in an increase of 69 and 65 per cent more biomass over control.

2.11 YIELD AND YIELD ATTRIBUTES

Hamaker and Weaver (1982) reported that application of gravel dust in an organic garden at the rate of 2 to 4 lbs per square foot resulted in an increased yield of 2 to 4 times.

The effect of dusting to chickpea [*Cicer arietinum*] cultivars, ICCX 79012 and Annigeri, with fine rock powder at flowering on the damage by the noctuid *Helicoverpa armigera* was studied in India by Pimbert and Srivastava (1989). No significant differences in damage were observed between dusted and non-dusted ICCX 79012. But yields were significantly higher in dusted than in non-dusted plots.

Edward (1993) found that application of volcanic dust increased the yield of banana by 80 per cent in Australia.

In USA, Angeles et al. (1997) reported that the application of glacial sand and gravel increased nitrogen fixation and yield in soybean.

Yarrow (1997) found that application of granite increased the yield of potato and sugar beet in USA.

The response of cassava to rock dust viz. khondalite was studied during 2001-2003 at Farming System Research Station, Kottarakara, Kerala by conducting field experiments. Rock dust @ 1, 2, 3 t ha^{-1} was applied to cassava alone and also in combination with different doses of chemical fertilizers. The results revealed that application of rock dust @ 1 t ha^{-1} along with 75 per cent of the recommended dose of chemical fertilizer registered the highest yield of 21.32 t ha^{-1} and it was on par with full and 50 per cent of recommended dose of chemical fertilizers along with 1 t ha^{-1} (Shehana et al., 2006).

2.12 HIGH DRY MATTER CONTENT AND NUTRITIONAL VALUE

Coroneos (1995) reported that application of granite increased the plant dry weight, K uptake and soil moisture in clover, rye grass and tomato in Western Australia.

2.13 COMPATIBILITY WITH ORGANIC FARMING PRACTICES

Leortola (1991) stated that rock dust not only creates organic matter, but also helps hold it in place, reduce odours and conserve it.

Campe et al. (1996) reported that compost and rock dust have a symbiotic combination. Compost provides excellent medium for the microorganism explosion. He also recommended the application rate of 2 to 20 lbs of rock dust per cubic yard of compost.

The United State Department of Agriculture (USDA, 1998) conducted experiments on by product utilization, by reclaiming materials such as quarry waste fines, gypsum and coal dust. Combined composting of these with municipal by product, reduced pathogens, toxins and other odours and created high quality natural fertilizers for the soil.

Experiments on co- utilization of rock dust and compost by SEER centre (1998) revealed that addition of rock dust to compost not only increased mineral content but also accelerated microbial activity, heat build up, and thus increased the rate of break down.

Graham (2001) reported that application of rock dust @ 20 kg m^{-3} decreased the production of ammonia from the poultry mortality compost.

From an experiment conducted by Garcia et al. (2002) it was found that rock dust, a mineral waste could accelerate the composting process.

2.14 ECONOMIC BENEFITS

Experiment conducted in radish revealed that application of rock dust could substitute 25 per cent of fertilizer (Anon, 1997).

Results of experiments in Queensland SEER centre (1998) reported that application of rock dust reduced the fertilizer application by 80 per cent.

Shehana (2006) reported that application of Khondalite (rock powder) @ 1 t ha^{-1} along with FYM @ 12.5 t ha^{-1} resulted in a saving of 25 to 50 per cent of chemical fertilizers in cassava.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The experiment was undertaken with the main objective of monitoring the nutrient release pattern of rock dust under laboratory conditions and to study the influence of rock dust application alone and in combination with FYM and chemical fertilizers on the growth and yield of coleus. The present study consists of two parts. a laboratory incubation study and a field study.

3.1 COLLECTION AND ANALYSIS OF ROCK DUST

Finely powdered rock dust, 90 per cent of which pass through 200# mesh screen was collected from the nearby quarry, Mookunnimala (Table.1). The applied rock dust was mixture of Khondalite – Charnockite rock type. Mineral composition and elemental analysis were carried out at CESS, Aakkulam.

3.2 LABORATORY INCUBATION STUDY

The incubation study was conducted under laboratory condition for a period of six months from 12-10-06 to 15-04-2007. Main objective of the study was to assess the nutrient release pattern from rock dust.

3.2.1 Collection and Preparation of Soil Sample for Incubation Study

The soil for the incubation study was collected from the main experimental site. Five kg of soil was taken in plastic pots of uniform size and incubated for six months maintaining moisture level at field capacity with and without FYM and rock dust. The moisture level in each treatment was maintained throughout the study period replenishing the moisture loss by evaporation. The details of experiment are presented below.

3.2.2 Design and Lay out of Experiment

Design	: CRD
Treatments	: 7
Replication	: 3

Table 1. Chemical constituents of rock dust

Sl. No	Constituent / Chemical property	Content Per cent
1	SiO_2	49.80
2	Al_2O_3	13.50
3	Fe_2O_3	12.80
4	CaO	6.72
5	MgO	9.18
6	Na_2O	2.72
7	MnO	0.18
8	ZnO	0.04
9	P_2O_5	0.70
10	K_2O	1.71
11	pH	7.7
12	EC ($\mu S\ m^{-1}$)	100.30
Mineral composition 1. Quartz 2. Feldspar 3. Plagioclase 4. Magnetite 5. Olivine 6. Orthoclase 7. Augite		

R1	R2	R3
T6	T2	T4
T7	T4	T5
T2	T6	T7
T5	T7	T2
T3	T1	T1
T1	T5	T3
T4	T3	T6

Fig.1 Lay out Plan of incubation study

3.2.3 Treatments

T1	: Soil alone, 5kg
T2	: Soil + rock dust @ 8 t ha^{-1}
T3	: Soil + rock dust @ 10 t ha^{-1}
T4	: Soil + rock dust @ 12 t ha^{-1}
T5	: Soil + rock dust @ 8 t ha^{-1}+ FYM @ 8 t ha^{-1}
T6	: Soil + rock dust @ 10 t ha^{-1}+ FYM @ 10 t ha^{-1}
T7	: Soil + rock dust @ 12 t ha^{-1}+ FYM @ 12 t ha^{-1}

The lay out of the experiment is presented in Fig.1

3.2.4 Soil Sampling

Samplings were done at an interval of 15 days for a period of six months.

3.2.5 Analysis of Soil Sample

The following properties were analyzed at 15 days intervals

i) Soil reaction (pH)

ii) Electrical conductivity (EC)

iii) Available Nitrogen

iv) Available Phosphorous

v) Available Potassium

vi) Available micronutrients *viz.* Fe, Mn and Zn

The analysis methods followed are presented in Table. 2

3.3 FIELD EXPERIMENT

A field experiment was carried out to study the effect of rock dust as a nutrient source for coleus (*Solanostemon rotundifolius)* from September 2006 to March 2007 at the Instructional Farm attached to College of Agriculture, Vellayani, Thiruvananthapuram.

Table. 2 Physical and chemical properties of the soil of the experimental site

Sl. No	Parameters	Methods	Concentration	unit	Reference
I	Physical Properties				
1	Mechanical composition of soil Sand Silt Clay	International pipette method	 67.54 20.20 10.42	Per cent	Piper, (1966)
2	Texture	Sandy loam			
3	Bulk density	Core sampling method	1.40	Mg m^{-3}	Guptha and Dakshinamoortl (1980)
5	Particle density	Pycno meter method	2.30	Mg m^{-3}	Guptha and Dakshinamoortl (1980)
6	Field capacity	Core sampling	22.70	Per cent	Black *et al.* (1965
7	Water holding capacity	Core sampling	17.60	Per cent	Black *et al.*(1965
II	Chemical properties				
1	pH	PH meter (soil: water 1:2.5)	4.7		Jackson (1973)
2	EC	Conductivity meter	70.20	(µS m^{-1})	Jackson (1973)
3	CEC	Neutral Normal Ammonium Acetate extraction	5.72	c mol kg^{-1}	Jackson (1973)
4	Organic carbon	Chromic acid wet digestion method	1.16	Per cent	Jackson (1973)

5	Available Nitrogen	Alkaline potassium per manganate methods	329.28	kg ha $^{-1}$	Subbiah and Asija (1956)
6	Available Phosphorus	Bray No 1 extraction	20.30	kg ha $^{-1}$	Jackson (1973)
7	Available Potassium	Neutral normal ammonium acetate extraction and flame photometry	156.80	kg ha $^{-1}$	Jackson (1973)
8	Available Calcium	Titrimetry	1.65	c mol kg $^{-1}$	Jackson (1973)
9	Available Magnesium	Titrimetry	0.62	c mol kg $^{-1}$	Jackson (1973)
10	Available Fe	DTPA extraction and Atomic Absorption Spectro Photometry	62.93	mg kg $^{-1}$	Lindsay and Norvell (1975)
11	Available Mn	DTPA extraction and Atomic Absorption Spectro Photometry	12.56	mg kg $^{-1}$	Lindsay and Norvell (1975)
12	Available Zn	DTPA extraction and Atomic Absorption Spectro Photometry	1.32	mg kg $^{-1}$	Lindsay and Norvell (1975)

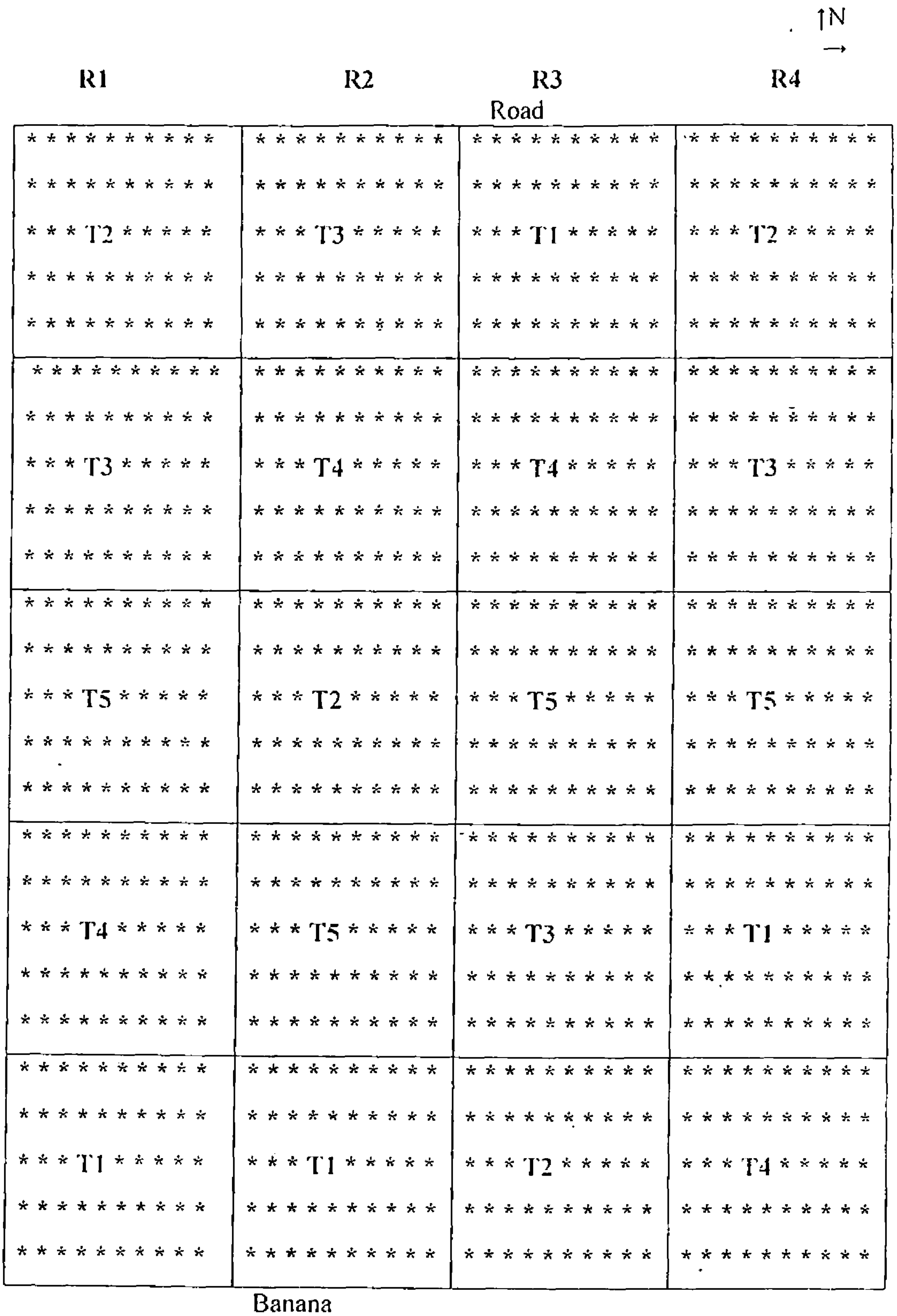

Fig.3 Lay out Plan of Field Experiment

Plate 1. Overall view of Laboratory Incubation Study

Plate 2. Overall view of Field Experiment

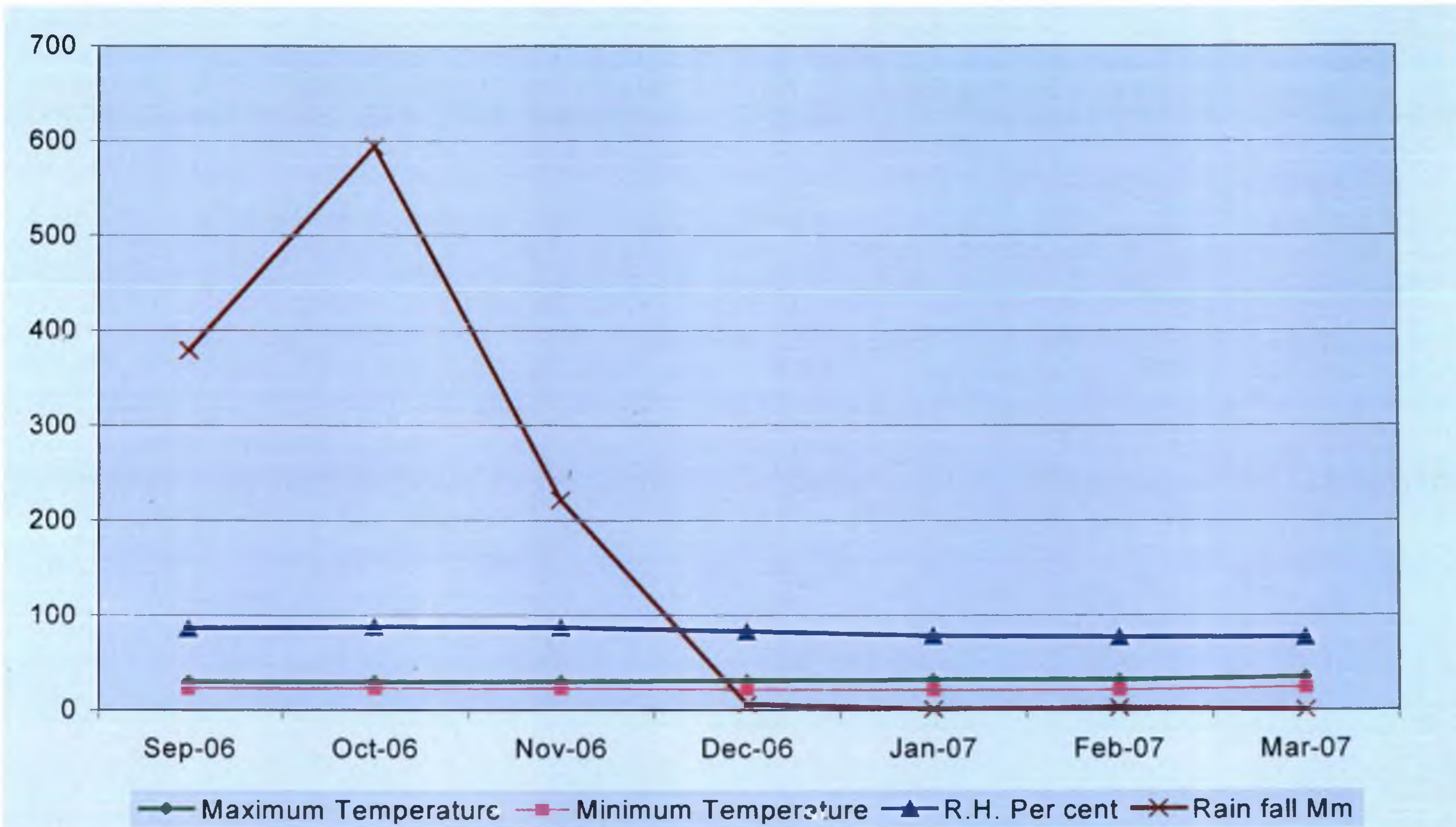

Fig. 2. Weather Data during the Experimental Period (September-2006 to March-2007)

3.3.1 Experimental Site

The experiment was undertaken at Instructional Farm Vellayani located at $8^0$30, N latitude and $76^0$54'E longitude and at an altitude of 29 m above mean sea level.

3.3.2 Soil

The soil of the experimental site was Loamy skeletal Kaolinitic Isohyper thermic Rhodic Haplustult belonging to Vellayani series, which comes under the order Ultisol. The initial data on mechanical and chemical properties of soil and the method adopted for analysis are presented in Table. 2.

3.3.3 Weather Conditions

A humid tropical climate prevailed in the experimental site. Data on maximum and minimum temperature, relative humidity and rainfall during the entire cropping period were collected and depicted in Fig - 2.

3.3.4 Crop history of Experimental Site

The experimental site was lying fallow for one year prior to the experiment.

3.3.5 Season

The nursery was laid out on 23-08-2006. The crop was planted on 16-10-2006 and harvested on 15-03 -2007.

3.3.6 Design and Lay out of Experiment

Design	: RBD
Treatments	: 5
Replication	: 4

3.3.7 Treatments

T1: KAU POP (100 per cent) NPK @ 60: 60: 100 kg ha^{-1}+ FYM @10 t ha^{-1}

T2: KAU POP (75 per cent) NPK @ 45: 45:75 kg ha^{-1}+ FYM @10 t ha^{-1}+Rock dust @ 10 t ha^{-1}

T3: KAU POP (50 per cent) NPK @ 30:30:50 kg ha^{-1}+ FYM @10 t ha^{-1} + Rock dust @ 10 t ha^{-1}

T4: Rock dust @10 t ha^{-1} +FYM @ 10 t ha^{-1}

T5: Rock dust @ 10 t ha^{-1} and FYM @ 10 t ha^{-1} mixed and kept for 15 days at 60 per cent Field capacity.

The lay out of the experiment is presented in Fig - 3 and an over view of the experimental site is presented in Plate - 2.

3.4 PLANTING MATERIALS AND METHODS

The planting materials of coleus variety Sreedhara were obtained from the Instructional farm, Vellayani. Sreedhara, the high yielding variety of coleus released from CTCRI, Sreekariyam, was used for the experiment.

3.4.1 Nursery

A 3.78 m^2 area near the experimental site was cleared and dug well, stubbles were removed, clods were broken and raised beds were prepared. FYM @1 kg per m^2 was mixed with soil and coleus cuttings were planted at a spacing of 30 x 15 cm.

3.4.2 Planting

Healthy and vigorous cuttings of length of 10 to 15 cm from apical portions were taken for planting in the main field.

3.4.3 Manures and Fertilizers

According to the treatment schedule, N, P, K was applied in the form of Urea (46 per cent N), Raj phos (20 per cent P_2O_5), and Muriate of potash (60 per cent K_2O) respectively in appropriate quantities. Full dose of P, rock dust and half dose of N and K were applied as basal dose. Half of N and K was applied at 45 DAP. FYM was applied as per the latest package of practices, Kerala Agricultural University (2007).

3.4.4 Aftercultivation Practices

Irrigation, earthing up, pant protection measures and weeding were done at scheduled intervals as per package of practices, Kerala Agricultural University.

3.4.5 Harvesting

The crop was ready for harvest five months after planting. Harvesting was done by digging out the tubers carefully and tubers were separated from the shoot portion. The border plants and observation plants were harvested separately from each plot.

3.5 BIOMETRIC OBSERVATIONS

Growth Attributes

3.5.1 Number of Branches per Plant

The total number of branches produced by the selected plants was counted at 30 days interval.

3.5.2 Number of Functional Leaves

Total number of functional leaves in the selected plants was counted at 30 days interval

3.5.3 Plant Spread

Plant spread was measured by taking the diameter of the spread of the selected plants and expressed in cm.

3.6 PHYSIOLOGICAL OBSERVATIONS

3.6.1 Leaf Area Index

Leaf area index was calculated as described by Watson (1952)

LAI =leaf area/land area

3.6.2 Chlorophyll Content

Chlorophyll content was estimated in samples from recently matured leaves of selected plants from each plot, using colorimetric method suggested by Arnon (1949)

3.7 YIELD COMPONENTS

3.7.1 Number of Tubers per Plant

Number of tubers of selected plants in each plot was taken.

3.7.2 Weight of Tubers per Plant

Weight of tubers of selected plants in each plot was taken and expressed in kg.

3.7. 3 Tuber Yield

Weight of tubers were recorded from each plot and expressed as t ha^{-1}.

3.7.4 Tuber Index.

It is the ratio of tuber yield to the top yield on fresh weight basis. This was worked out for each plot.

3.8 QUALITY ATTRIBUTES

3.8.1 Cooking Quality

Taste panel assessed the cooking quality of tuber and scores were given as per the procedure described by Prema et al. (1975).

3.8.2 Starch Content

Starch content of the tubers from each plot was estimated as per the procedure described by Chopra and Kanwar (1976).

3. 9 ECONOMIC ANALYSIS

The economics of cultivation was worked out considering the cost of cultivation and income derived from the plants. It was calculated as per the norms and rates fixed by the Instructional farm, Vellayani.

B.C ratio = Gross income/ Cost of cultivation

3.10 SOIL ANALYSIS

Soil samples from the experimental area were collected before planting, at the time of tuberization and at the time of harvest.

3.11 PLANT ANALYSIS

After harvest, the leaf, stem, tuber and roots were analyzed for the content of N, P, K, Ca, Mg, Fe, Mn, Cu, and Zn.

Nitrogen was estimated by modified kjeldahl method after digestion with concentrated sulfuric acid (Jackson, 1973). Determination of P, K, Ca, Mg and micronutrients were done after digestion with nitric- perchloric acid mixture in the ratio 9:4 (Jackson, 1973). P was estimated by Vanado molybdic yellow colour method in spectrophotometer (Systronics model 69) (Jackson, 1973). Estimation of K was done by using the flame photometer (Elico model CL22D). Ca and Mg were estimated by Versenate method (Jackson, 1973).

3.12 STATISTICAL ANALYSIS

Statistical methods of analysis such as analysis of variance were carried out to find out the relationship between variables and definite conclusions were drawn. (Panse and Sukhatme, 1978)

RESULTS

4. RESULTS

An experiment entitled "Rock dust as a Nutrient Source for Coleus (*Solenostemon rotundifolius*) was carried out at the College of Agriculture, Vellayani during 2006-2007 with Coleus variety, Sreedhara. The objective of the experiment was to study the effect of rock dust application either alone and or in combination with FYM and chemical fertilizers on the growth and yield of Coleus. An incubation study was also carried out to assess the nutrient release pattern of rock dust under laboratory conditions. Results based on statistically analyzed data pertaining to the experiment conducted during the course of investigation are presented in this chapter.

4.1 LABORATORY INCUBATION STUDY

The incubation experiment was done to study the nutrient release pattern of rock dust under laboratory conditions. Some important properties of soil viz. pH, EC, available nitrogen, available phosphorus, available potassium and micronutrients were estimated and recorded at an interval of 15 days and presented in Table 3 to 10.

4.1.1 pH

Mean values of pH of the soil incubated for different period is given in Table.3. There was significant difference in pH between treatments on 45th, 90th, 105th 135th and 180 th day after the application of treatments. On the 45 th day the highest value of 5.3 was observed in T_6 which was on par with T_7, T_5 and T_4. On 90th day, the highest pH value of 4.9 was recorded in T_3. This was significantly superior to T_1, T_2 and T_4 and on par with T_7, T_5 and. T_6. On 105th day the highest pH value of 4.7 was observed T_6, T_5 and T_7. This was significantly superior to T_2 but on par with T_1, T_3 and T_4. The highest pH value of 4.8 was recorded on 135th day in T_7 and it was significantly superior to T_1, T_3 and T_2 and on par with T_4, T_5 and T_6. There was significant difference between treatments on 180th day. The highest value of 5.3 was recorded in T_6 and it was significantly superior to T_1, T_2 and T_3 but on par with T_4, T_5, and T_7.

Table 3. Changes in soil pH during the incubation period

Treatments	15 DAI	30 DAI	45 DAI	60 DAI	75 DAI	90 DAI	105 DAI	120 DAI	135 DAI	150 DAI	165 DAI	180 DAI	Mean
T_1	4.7	4.7	4.6	4.5	4.5	4.2	4.4	4.1	4.0	4.7	4.7	4.6	4.4
T_2	4.4	4.7	4.7	4.5	4.6	4.3	4.3	4.3	4.3	4.4	4.7	4.7	4.5
T_3	4.6	4.6	4.6	4.5	4.6	4.9	4.3	4.3	4.3	4.6	4.6	4.6	4.5
T_4	4.5	4.6	5.0	4.5	4.5	4.5	4.4	4.4	4.6	4.5	4.6	5.0	4.6
T_5	4.4	4.7	5.0	4.7	4.5	4.7	4.6	4.3	4.4	4.4	4.7	5.0	4.6
T_6	4.4	4.6	5.3	4.7	4.7	4.8	4.7	4.6	4.5	4.4	4.6	5.3	4.7
T_7	4.6	4.8	5.0	4.8	5.1	4.7	4.7	4.5	4.8	4.6	4.8	5.0	4.7
Mean	4.5	4.6	4.8	4.6	4.6	4.5	4.7	4.3	4.4	4.5	4.6	4.8	
CD (0.05 level)	NS	NS	0.41	NS	NS	0.27	0.26	NS	0.29	NS	NS	0.41	

*** DAI – Days After Incubation**

There was an increase in pH from the start of the experiment reaching a value of 4.9 during the 45th day and a more or less uniform pH was maintained throughout the incubation period.

4.1.2 Electrical Conductivity (μ S m^{-1})

The EC values are presented in Table. 4. There was significant difference in EC between treatments on 60th, 75th, 90th, 105th, 135th, 150th, and 165th day of incubation. The lowest value of 277.06 was recorded in T_3 on 60th day. On 90th day the lowest value of 323.43 was recorded in T_2. T_1 recorded the lowest EC values during the rest of the period. The highest EC values were recorded in T_7 on 75th, 105th, 120th, and 165th day of incubation

The EC of the soil increased from an initial value of 132.82 to value of 463.22 on the 120th day of incubation, as evident from the mean value presented in the Table. 4.

4.1.3 Available Nitrogen (kg ha^{-1})

Available nitrogen content of the incubation study is presented in Table.5. There was significant difference in available nitrogen between treatments on 45th, 60th, 75th, 150th and 165th day of incubation of soil. On 45th day, T_5 recorded the highest mean value of 355.41 kg ha^{-1} and it was significantly superior to T_1 and T_3 and was on par with T_7, T_6, T_4 and T_2. T_7 showed the highest mean value of 418.13 on 60th day of incubation. T_7 was significantly superior to T_3, T_2 and T_1 and was on par with T_4, T_5 and T_6. During 75th day, T_7 recorded the highest value of 412.90, which was on par with T_5, T_6 T_4, and T_3. T_7 was significantly superior to T_2 and T_1. On 150th day of incubation, T_5 showed the highest value of 410.76, which was on par with T_7, T_6 and T_4. T_5 was significantly superior to T_3, T_2 and T_1.

Table 4. Changes in soil EC (µ S m^{-1}) during the incubation period

Treatments	15 DAI	30 DAI	45 DAI	60 DAI	75 DAI	90 DAI	105 DAI	120 DAI	135 DAI	150 DAI	165 DAI	180 DAI	Mean
T_1	156.66	137.80	142.76	287.46	267.16	358.43	318.00	336.50	341.40	328.60	332.00	294.66	275.11
T_2	125.03	127.11	203.33	313.77	313.33	323.43	327.70	344.36	337.46	342.80	356.16	357.60	289.34
T_3	129.80	136.36	245.76	277.06	310.10	327.60	366.56	355.63	351.00	351.43	367.03	389.46	300.64
T_4	124.56	135.86	253.43	329.28	354.26	330.73	416.56	377.60	395.36	412.43	438.03	449.23	334.77
T_5	138.23	145.90	234.50	355.41	364.06	442.60	435.20	396.10	442.63	438.00	454.80	460.63	359.00
T_6	127.80	161.06	260.60	365.86	351.83	433.93	459.20	453.30	458.43	444.76	456.22	466.03	369.91
T_7	124.60	150.20	312.83	371.09	377.06	438.16	472.43	463.86	466.46	471.80	473.80	476.76	383.25
Mean	132.38	142.04	236.17	328.56	333.97	379.26	399.37	389.62	398.96	398.54	411.14	413.48	
CD (0.05 level)	NS	NS	NS	57.51	64.93	30.71	13.50	68.83	57.51	51.64	NS	35.82	

*** DAI – Days After Incubation**

T_7 showed the highest mean value of 402.53 on 165th day of incubation. It was on par with T_6, T_5, T_4 and T_3 but was significantly superior to T_2 and T_1.

The mean values of available N content increased from the initial value of 374.82 kg ha $^{-1}$ to a maximum value of 386.23 kg ha $^{-1}$ on the 30th day of incubation and there after there was a slow pace of decline reaching a value of 313.59 kg ha $^{-1}$ during the 180th day of incubation.

4.1.4 Available Phosphorus (kg ha^{-1})

Different treatments significantly influenced the available P content in soil (Table. 6). There was significant difference in P content between treatments on 30th ,45th ,60th ,75th, 90th ,105th , 135th , 150th , 165th and 180th day after the application of treatments.

On the 30th day, the highest mean value of 33.96 was observed in T_6, which was on par with T_7 and T_5. T_6 was significantly superior to T_4, T3, T_2 and T_1.On 45th day of incubation, the highest mean value of 36.25 was recorded for T_7 and it was significantly superior to all other treatments. During 60th day of incubation, the highest mean value of 36.88 was recorded for T_7, which was on par with the treatment T6, and T_5 and it was significantly superior to T_4, T_3, T_2 and T_1. T_7 showed the highest mean value of 34.88 on 75th day of incubation. This treatment was significantly superior to T_4, T_3, T_2 and T_1 and it was on par with T_6 and T_5. During 90th day of incubation, T_7 showed the highest value of 46.02, which was significantly superior to T2, T3, and T1 and it, was on par with T_6, T_5 and T_4. On 105th day of incubation, T_7 showed the highest mean of 46.25. T_7 was on par with T_6, T_5, T_4 and T_3 and was significantly superior to T_2 and T_1. Same trend was noticed during the 135th day of incubation, T_7 recorded the highest mean value of 57.04. It was on par with T_6, T_5, T_4, T_3 and T_2 and was significantly superior to T_1.

Table 5. Changes in available N (kg ha^{-1}) content of soil during the incubation period

Treatments	15 DAI	30 DAI	45 DAI	60 DAI	75 DAI	90 DAI	105 DAI	120 DAI	135 DAI	150 DAI	165 DAI	180 DAI	Mean
T_1	350.18	360.64	287.47	297.92	292.69	313.60	287.46	344.97	287.46	292.69	292.69	285.78	307.79
T_2	355.41	345.14	313.77	318.82	324.05	308.37	313.77	252.21	313.77	329.27	308.37	313.77	316.39
T_3	371.09	397.21	277.00	329.27	376.48	308.28	277.68	345.30	277.01	334.50	355.40	292.70	328.49
T_4	392.00	351.46	329.28	391.97	381.60	386.74	329.28	351.46	329.28	371.17	355.41	339.73	359.11
T_5	355.41	407.68	355.41	386.74	407.68	381.62	344.96	345.14	355.41	410.76	381.54	329.28	371.80
T_6	402.45	407.68	355.38	381.62	402.45	376.32	318.82	433.80	365.86	392.08	402.50	329.20	380.68
T_7	397.20	433.8	355.41	418.13	412.90	355.38	355.33	412.97	324.04	407.68	402.53	339.73	384.59
Mean	374.82	386.23	324.81	360.63	371.12	347.18	318.18	355.12	321.83	362.59	356.92	318.59	
CD (0.05 level)	N.S	N.S	57.51	46.48	35.40	71.01	N.S	N.S	N.S	71.00	65.13	N.S	

*** DAI – Days After Incubation**

Table 6. Changes in available P (kg ha^{-1}) content of soil during the incubation period

Treatments	15 DAI	30 DAI	45 DAI	60 DAI	75 DAI	90 DAI	105 DAI	120 DAI	135 DAI	150 DAI	165 DAI	180 DAI	Mean
T_1	27.80	22.19	18.68	21.30	22.60	31.94	26.16	32.04	22.49	24.67	30.15	27.21	25.60
T_2	30.66	23.77	25.76	25.90	23.42	35.94	31.74	39.37	39.73	35.70	34.91	29.64	31.37
T_3	24.48	25.83	26.67	27.44	23.86	35.49	34.31	35.50	44.97	39.39	36.74	36.18	32.57
T_4	30.25	26.41	25.22	29.52	27.99	38.43	36.00	41.04	48.49	36.48	41.15	37.06	34.83
T_5	34.06	29.20	30.00	32.07	32.55	39.20	39.57	46.79	41.48	39.91	42.30	42.86	37.49
T_6	32.92	33.96	30.40	33.35	34.18	42.75	45.62	54.51	45.14	49.80	49.33	53.21	42.09
T_7	38.05	32.90	36.25	36.88	34.88	46.02	46.25	53.72	57.04	50.63	53.03	53.82	44.95
Mean	31.17	27.75	27.56	29.49	28.49	38.53	37.09	43.28	42.76	39.51	41.08	39.99	
CD (0.05 level)	N.S	5.39	5.04	4.90	5.21	7.69	12.47	N.S	17.51	11.93	6.02	5.46	

*** DAI – Days After Incubation**

During 150[th] day of incubation, T_7 showed the highest mean value of 50.63, which was significantly superior to T4, T2 and T1 and it was on par with T_6, T_5 and T_3. T_7 recorded the highest mean of 53.03 on 165[th] day of incubation study. This was significantly superior to T_5, T_4, T_3, T_2 and T_1 and it was on par with T_6. On 180[th] day of incubation, there was significant difference between treatments. T_7 was significantly superior to T_5, T_4, T_3, T_2 and T_1 and it was on par with T_6.

A careful scrutiny of the data presented in Table. 6 reveal that the maximum solubilisation of available P in the soil occurred during the 135[th] day of incubation when rock dust was applied alone. The value of available P ranged from 39.73 to 48.49 kg ha $^{-1}$. The same dose of rock dust i.e. 8, 10 and 12 t ha^{-1} when applied with equal quantities of FYM resulted in significantly higher values of available P ranging from 41.48 to 57.04 kg ha $^{-1}$ during the 135[th] day of application.

4.1.5 Available Potassium (kg ha^{-1})

Table.7 indicates the available K content due to the treatments. There was significant difference in K content between treatments at different intervals of observations.

On the 15[th] day, the highest mean value of 373.33 was observed in T_7 and it was significantly superior to all other treatments. On 45[th] day of incubation, the highest mean value of 612.33 was recorded for T_7 and it was on par with T_5. T_7 was significantly superior to T_6, T_4, T_3, T_2 and T_1. During 60[th] day of incubation also, the highest mean value of 649.66 was recorded for T_7 that was on par with T_6 and T_5 and it was significantly superior to T_4, T_3, T_2 and T_1. T_7 showed the highest mean of 612.33 on 75[th] day of incubation and this treatment was significantly superior to the T_5, T_4, T_3, T_2 and T_1 and it was on par with T_6. During 90[th] day of incubation, also T_7 showed the highest value of 843.76, which was significantly superior to all the other treatments. On 105[th] day of incubation, treatment T_7 showed the highest mean value of 798.93, which was significantly superior to all other treatments.

Table 7. Changes in available Potassium (kg ha^{-1}) content of soil during the incubation period of 180 days

Treatments	15 DAI	30 DAI	45 DAI	60 DAI	75 DAI	90 DAI	105 DAI	120 DAI	135 DAI	150 DAI	165 DAI	180 DAI	Mean
T_1	141.90	268.66	345.03	287.20	345.03	336.00	313.62	352.00	336.00	398.53	346.93	318.12	315.75
T_2	230.10	380.41	374.40	403.00	374.40	440.53	455.46	381.86	448.00	398.53	455.46	470.60	401.06
T_3	244.07	387.66	404.26	455.46	404.26	496.53	488.80	430.40	465.60	548.66	466.66	560.00	446.03
T_4	179.20	251.86	433.06	515.20	433.06	500.26	474.13	459.20	492.80	474.13	537.60	556.93	442.28
T_5	238.10	366.33	507.66	578.66	507.66	549.46	545.06	530.06	507.73	537.33	604.80	641.93	509.56
T_6	253.86	436.26	470.40	649.60	470.40	619.63	601.06	500.26	574.93	671.80	649.60	683.20	548.41
T_7	373.33	406.66	612.33	649.66	612.33	843.76	798.93	649.53	582.40	671.90	769.00	746.56	643.03
Mean	237.22	356.83	449.59	505.54	449.59	540.88	525.29	471.90	486.78	528.69	547.15	568.19	
CD (0.05 level)	88.42	158.49	105.18	116.63	105.18	148.37	117.01	144.61	99.92	176.87	109.59	202.80	

*** DAI – Days After Incubation**

T_7 showed the highest mean of 649.53 on 120th day of incubation also. This was significantly superior to T_6, T_4, T_3, T_2 and T_1 and it was on par with T_5.

During 135th day of incubation, T_7 recorded the highest mean value of 582.40. This was on par with T_6, T_5 and T_4 and it was significantly superior to the T_3, T_2, and T_1. During 150th day of incubation, T_7 showed the highest mean value of 671.90, which was significantly superior to T4, T2 and T1 and it was on par with T_6, T_5 and T_3. T_7 recorded the highest mean of 769.00 on 165th day of incubation study and it was significantly superior to T_6, T_5, T_4, T_3, T_2 and T_1. The highest mean value of 746.56 was recorded for T_7 on 180th day of the incubation. There was significant difference between treatments. T_7 was significantly superior to T_2 and T_1 and it was on par with T_6, T_5, T_4 and T_3.

A perusal of the data shows that the treatment receiving FYM along with rock dust resulted in increased values of available K ranging from 547.15 to 843.76 kg ha $^{-1}$ when compared to treatments with rock dust with out FYM with available K ranging from 455.46 to 548.6 kg ha $^{-1}$.

There was an increase in the available K content from the start of the experiment with the mean values starting from 237.22 and reaching a highest value of 568.19 at the end of the incubation period.

4.1.6 Available Fe (mg kg $^{-1}$)

Fe content of the incubation study is presented in Table.8. The different treatments significantly influenced the available Fe content of soil. There was significant difference in Fe content between treatments on all observations except at 15 days after application of treatments.

Table 8. Changes in available Fe (mg kg $^{-1}$) content of soil during the incubation period

Treatments	15 DAI	30 DAI	45 DAI	60 DAI	75 DAI	90 DAI	105 DAI	120 DAI	135 DAI	150 DAI	165 DAI	180 DAI	Mean
T_1	63.59	63.68	62.81	62.81	69.03	77.39	70.93	85.71	81.09	79.23	110.65	112.93	78.32
T_2	63.59	79.48	64.99	64.99	69.33	84.19	69.15	87.33	86.69	85.99	87.66	104.27	78.97
T_3	78.63	64.81	63.70	70.79	79.67	85.48	85.15	86.51	86.77	87.37	72.23	106.33	80.62
T_4	65.19	72.21	70.63	73.18	79.60	93.00	83.17	92.65	92.69	82.79	105.11	105.37	84.63
T_5	72.87	69.79	77.58	93.59	91.39	93.06	84.33	93.15	79.19	99.61	104.67	109.91	89.09
T_6	76.85	77.41	75.93	92.99	95.00	95.00	93.15	93.15	86.72	101.89	109.77	106.49	92.02
T_7	77.31	72.58	78.77	96.99	93.00	99.59	93.95	109.23	100.59	86.59	108.03	105.28	93.49
Mean	71.14	71.42	70.63	79.33	82.43	89.67	82.83	92.53	87.67	89.06	99.73	107.22	
CD (0.05 level)	NS	3.13	2.99	3.33	3.52	3.75	3.50	3.85	3.71	3.76	4.15	4.40	

*** DAI – Days After Incubation**

On the 30[th] day, the highest mean value of 79.48 was observed in T_2. T_2 was significantly superior to T_7, T_5, T_4, T_3 and T_1 and was on par with T_6.On 45[th] day of incubation, the highest mean value of 78.77 was recorded for T_7 and it was on par with T_5 and T_6. During 60[th] day of incubation also, the highest mean value of 96.99 was recorded for T_7 and it was significantly superior to T_6, T_5, T_4, T_3, T_2 and T_1. T_6 showed the highest mean value of 95.00 on 75[th] day of incubation. T_6 was significantly superior to T_5, T_4, T_3, T_2 and it was on par with T_7. During 90[th] day of incubation, T_7 showed the highest value of 99.59, which, was significantly superior to all the other treatments. On 105[th] day of incubation, T_7 showed the highest mean of 93.15, which was significantly superior to T3, T5, T4, T1and T2 and it was on par with T_6. T_7 showed the highest mean of 109.23 on 120[th] day of incubation and it was significantly superior to all other treatments.

During 135[th] day of incubation, T_7 recorded the highest mean value of 100.59 and it was significantly superior to all other treatments. During 150[th] day of incubation, T_6 showed the highest mean value of 101.89. This treatment was significantly superior to T_3, T_7, T_2, T_4 and T_1 and it was on par with T_5. T_1 recorded the highest mean value of 110.65 on 165[th] day of incubation study. This treatment was significantly superior to T_4, T_5, T_2 and T_3 and it was on par with T_6 and T_7.The highest mean value of 112.93 was recorded for T_1 on180[th] day of incubation. T_1 was significantly superior to T_6, T_3, T_4, T_7 and T_2 and it was on par with T_5.

In general, there was an increase in the release of available Fe content from the initial stage of the experiment and the highest mean value of 107.22 was recorded on the 180[th] day of incubation.

4.1.7 Available Mn (mg kg $^{-1}$)

Different treatments significantly influenced the available Mn content of soil as shown in Table.9. There was significant difference in Mn content between treatments on different intervals after the application of treatments.

On the 15th day, the highest mean value of 22.36 was observed in T_7 and it was significantly superior to T_5, T_4, T_2, T_3, and T_1 but on par with T_6. On 30th day of incubation highest mean value of 29.07 was recorded for T_7 and it was significantly superior to all other treatments. On 45th day of incubation, the highest mean value of 29.21 was recorded for T_7 and it was significantly superior to all other treatments. During 60th day of incubation, the highest mean value of 28.99 was recorded for T_5 and it was significantly superior to all other treatments. T_7 showed the highest mean value of 26.29 on 75th day of incubation and it was significantly superior to all other treatments. During 90th day of incubation T_7 showed the highest value of 31.37. It was significantly superior to all the other treatments.

On 105th day of incubation, T_2 recorded the highest mean value of 25.51. T_2 was significantly superior to T_3, T_7, T_6, T_4 and T_5 and it was on par with T_1. T_6 showed the highest mean of 22.18 on 120th day of incubation. T_6 was significantly superior to T_4, T_3, T_1 and T_2 and it was on par with T_7 and T_5. During 135th day of incubation, T_6 recorded the highest mean value of 21.85 and it was significantly superior to T_4, T_3, T_1 and T_2 and on par with T_5 and T_7. During 150th day of incubation, T_6 recorded the highest mean value of 27.00 and it was significantly superior to all other treatments. T_7 recorded the highest mean of 22.25 on 165th day of incubation study. This treatment was significantly superior to T_5, T_2, T_3 and T_1 and it was on par with T_4 and T_6. The highest mean value of 25.71 was recorded for T5 on 180th day of incubation. T_5 was significantly superior to T_1 and it was on par with T_7, T_6, T_3, T_4 and T_2.

Table 9. Changes in available Mn (mg kg $^{-1}$) content of soil during the incubation period

Treatments	15 DAI	30 DAI	45 DAI	60 DAI	75 DAI	90 DAI	105 DAI	120 DAI	135 DAI	150 DAI	165 DAI	180 DAI	Mean
T_1	13.40	13.40	13.54	15.77	12.69	12.91	25.32	17.99	18.12	13.51	11.79	15.86	15.35
T_2	13.64	13.59	17.60	18.70	21.44	16.82	25.51	15.49	15.66	19.01	16.49	21.84	17.98
T_3	13.49	13.19	17.89	18.59	22.39	23.40	22.01	21.26	20.29	22.53	16.14	23.49	19.55
T_4	14.26	13.39	22.59	19.83	23.22	20.14	12.35	21.42	20.43	22.28	22.19	22.26	19.53
T_5	20.32	20.19	23.20	28.99	23.69	25.01	11.92	21.50	21.50	23.61	20.00	25.71	22.13
T_6	21.88	22.39	24.49	23.69	24.89	26.89	13.22	22.18	21.85	24.60	21.59	24.08	22.64
T_7	22.36	29.07	29.21	25.19	26.29	31.37	15.16	22.08	20.89	27.00	22.25	25.31	24.68
Mean	17.05	17.88	21.21	21.53	22.08	22.36	17.92	20.27	19.82	21.79	18.63	22.65	
CD (0.05 level)	1.04	0.75	0.93	2.80	0.92	0.78	0.63	0.85	0.99	0.93	0.80	4.20	

*** DAI – Days After Incubation**

4.1.8 Available Zn (mg kg $^{-1}$)

Zn content of the incubation study is presented in Table.10. The different treatments significantly influenced the available Zn content of soil. There was significant difference in Zn content between treatments on 15th, 30th, 45th, 60th, 75th, 90th, 105th, 120th, 135th, 150th, 165th and 180th day after the application of treatments.

On the 15th day, the highest mean value of 5.58 was observed in T_7 and it was significantly superior to T_2, T_6, T_4, T_3 and T_1 and it was on par with T_5. On 30th day of incubation, the highest mean value of 4.43 was recorded for T_3 and it was significantly superior to all other treatments. On 45th day of incubation, the highest mean value of 5.72 was recorded for T_5 and it was significantly superior to T1 and it was on par with T_3, T_7, T_2, T_6 and T_4. During 60th day of incubation, the highest mean value of 5.48 was recorded for T_4 and it was significantly superior to T_5, T_1, T_2, T_3 and T_6 and on par with T_7. T_6 showed the highest mean of 6.57 on 75th day of incubation. T_6 was significantly superior to all other treatments. During 90th day of incubation, T_5 showed the highest value of 7.13. It was significantly superior to all the other treatments.

On 105th day of incubation, T_5 recorded the highest mean value of 5.59. T_5 was significantly superior to T_2, T_4 and T_6 but it was on par with T_7, T_3 and T_1. T_7 showed the highest mean value of 5.10 on 120th day of incubation. It was significantly superior to T_2 and T_3 and it was on par with T_4, T_6, T_1 and T_5. During 135th day of incubation, T_3 showed the highest mean value of 6.50 and it was significantly superior to T_4, T_7, T_6, T_2 and T_1. It was on par with T_5. During 150th day of incubation, T_4 recorded the highest mean value of 6.30. This treatment T_4 was significantly superior to T_7, T_2, T_3 and T_1 and it was on par with T_6 and T_5. T_5 recorded the highest mean value of 7.23 on 165th day of incubation and it was significantly superior to all other treatments.

Highest mean value of 6.37 was recorded for T_2 on 180th day of incubation. T_2 was on par with T_6, T_1, T_3 and T_7 and it was significantly superior to T_5 and T_4.

Table 10. Changes in available Zn (mg kg $^{-1}$) content of soil during the incubation period

Treatments	15 DAI	30 DAI	45 DAI	60 DAI	75 DAI	90 DAI	105 DAI	120 DAI	135 DAI	150 DAI	165 DAI	180 DAI	Mean
T_1	4.26	3.38	3.75	4.91	5.04	5.14	5.32	4.90	4.68	5.03	5.32	6.32	4.83
T_2	4.53	3.60	5.23	4.79	5.91	5.54	4.82	4.75	5.12	5.74	5.13	6.37	5.12
T_3	4.36	4.43	5.52	4.38	4.23	4.61	5.32	4.56	6.50	5.67	5.40	6.18	5.09
T_4	4.38	2.28	4.96	5.48	4.20	5.71	4.81	5.00	5.98	6.30	5.68	5.02	4.98
T_5	5.44	2.48	5.72	5.04	4.65	7.13	5.59	4.88	6.36	6.13	7.23	6.04	5.55
T_6	4.48	1.48	4.98	4.03	6.57	5.90	4.66	4.95	5.90	6.27	6.47	6.33	5.16
T_7	5.58	2.25	5.51	5.13	5.98	5.68	5.59	5.10	5.96	5.99	6.11	6.13	5.41
Mean	4.71	2.84	5.09	4.82	5.22	5.67	5.15	4.87	5.78	5.87	5.90	6.05	
CD (0.05 level)	0.19	0.45	0.74	0.40	0.21	0.75	0.43	0.23	0.24	0.25	0.33	0.25	

*** DAI – Days After Incubation**

4.2 FIELD EXPERIMENT

4.2.1 Effect of Application of Rock Dust on Biometric Observations

4.2.1.1 Number of Branches per Plant

The number of branches per plant were taken at 30, 60, 90, 120 and 150 DAP and the mean values are given in Table. 11. There was no significant difference between treatments at 30 DAP, 60 DAP and 150 DAP, but the treatments differed significantly on 90 DAP. The highest mean value of 102.65 was recorded for T_3 and it was significantly superior to T_2, T_4 and T_5. It was on par with T_1.

4.2.1.2 Number of Functional Leaves

Number of functional leaves were taken on 30, 60, 90, 120 and 150 DAP and the mean values are presented in Table. 11. There was no significant difference between treatments at 30 DAP, 60 DAP, 90 DAP, 120 DAP and 150 DAP.

4.2.1.3 Plant Spread (cm)

Plant spread was measured on 30, 60, 90, 120 and 150 DAP and it is given in Table. 11. There was no significant difference between treatments at 30 DAP, 90 DAP, 120 DAP and 150 DAP. There was significant difference between treatments at 60DAP. The highest mean value of 22.97 was recorded for T_5, which was significantly superior to T3, and it was on par with T_4, T_1 and T_2.

4.2.2 Effect of Application of Rock Dust on Physiological Characters

Table.12 present the data on the physiological characters as influenced by the application of rock dust.

4.2.2.1 Leaf Area Index

The mean values showed no significant differences at 60 DAP and 120 DAP.

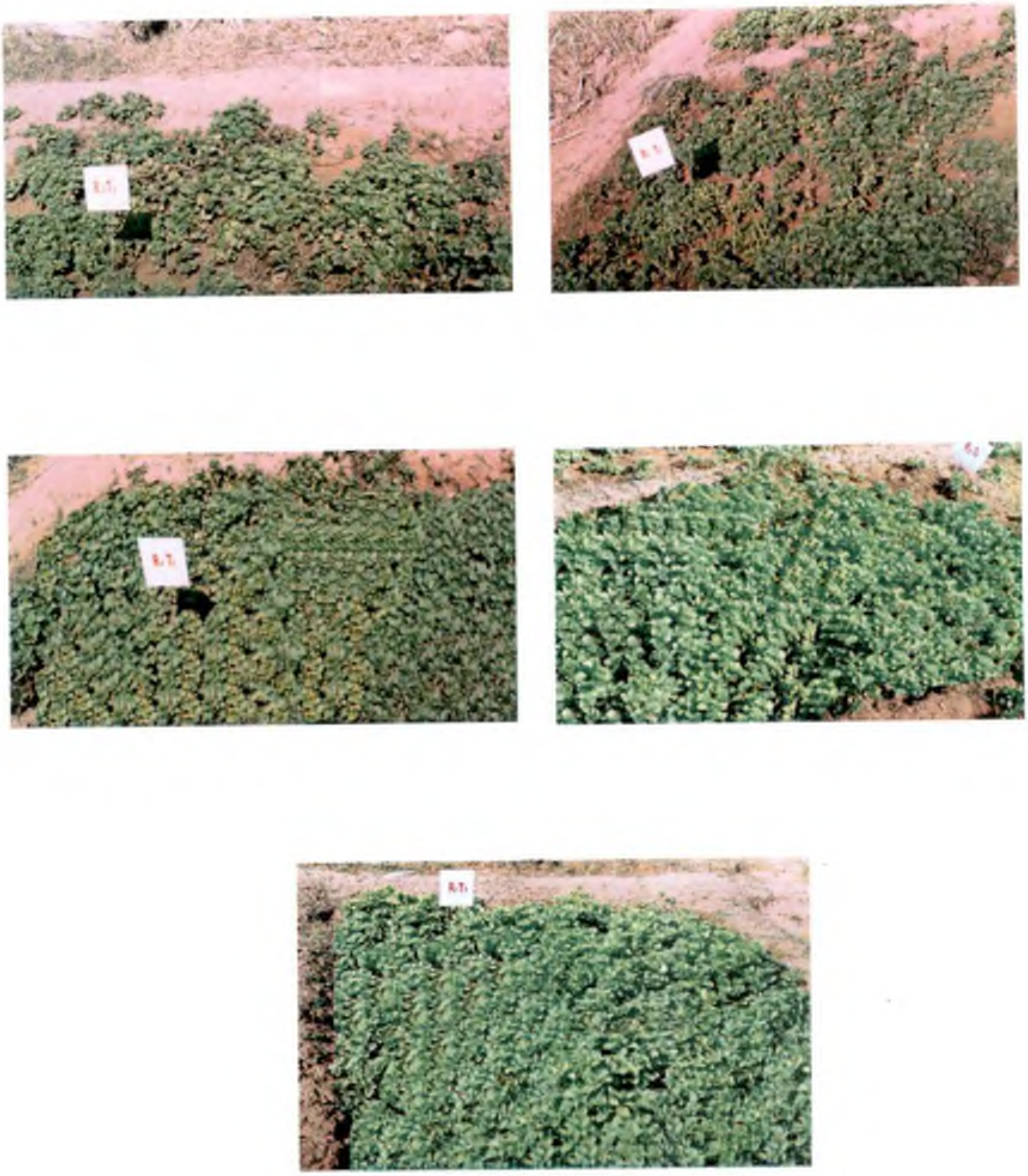

Plate 3. Effect of Treatments T_1, T_2, T_3, T_4 and T_5 on the growth of coleus

Table 11. Biometric observation as affected by the treatments

Treatments	Number of branches per plant					Number of functional leaves					Plant spread (cm)				
	30 DAP	60 DAP	90 DAP	120 DAP	150 DAP	30 DAP	60 DAP	90 DAP	120 DAP	150 DAP	30 DAP	60 DAP	90 DAP	120 DAP	150 DAP
T_1	11.70	39.20	81.90	91.45	179.55	100.15	191.10	243.15	465.75	583.10	9.17	20.55	24.40	28.45	33.66
T_2	15.35	46.05	41.35	81.55	165.95	93.50	182.70	171.22	405.25	739.85	7.53	18.22	24.40	27.72	32.46
T_3	14.50	54.95	102.65	184.75	195.75	87.85	221.20	164.65	469.60	825.10	9.17	8.66	20.40	30.35	34.52
T_4	16.75	53.00	31.95	89.70	186.95	107.54	222.20	92.10	326.90	716.70	9.16	22.28	24.16	27.08	32.41
T_5	13.75	42.60	31.05	89.25	194.00	112.95	207.75	217.75	432.90	839.50	8.66	22.97	23.27	28.59	32.46
CD (0.05 level)	NS	NS	53.93	NS	NS	NS	NS	NS	NS	NS	NS	7.58	NS	NS	NS

*** DAP: Days After Planting**

Plate 4. Effect of Treatments T_1, T_2, T_3, T_4 and T_5 on the yield of coleus

4.2.2.2 Chlorophyll Content

There was significant difference between treatments in the leaf chlorophyll content at 60 DAP. The highest value of 0.56 was recorded for T_5. The lowest mean value of 0.37 was recorded for T_1. T5 was significantly superior to all other treatments

At 120 DAP also, there was significant difference between treatments in the leaf chlorophyll content and the highest value of 0.51 was recorded for T_5 and it was on par with T_4. Lowest value of 0.38 was recorded for T_1. T_5 was significantly superior to all other treatments

4.2.3 Effect of Application of Rock Dust on Yield Attributes

Yield attributes were recorded at harvest and presented in Table.12. There was significant difference in yield and yield attributes due to the application of the treatments.

4.2.3.1 Number of Tubers per Plant

. There was significant difference in number of tubers between treatments. The highest number of tubers (21.25) was recorded for T_3 and it was significantly superior to all other treatments. The lowest mean value of 13.50 was recorded for T_1.

4.2.3.2 Weight of Tubers per Plant (g)

There was no significant difference between treatments on this character

4.2.3.3 Top Yield (t ha^{-1})

The weight of top portion was recorded at the time of harvest and presented in Table.13. There was no significant difference between treatments

4. 2.3.4 Tuber Yield (t ha^{-1})

The mean tuber yield was recorded at the time of harvest and presented in Table.13. Significant difference in yield was observed in various treatments. The highest value of 19.55 t ha^{-1} was recorded in T_1 which was on par with T_3 (17.26 t ha^{-1}) and T_4 (16.58 t ha^{-1}) T_1 was significantly superior to T_5 and T_2

4.2.3.5 Tuber Index

The data presented in Table.12 revealed that there was no significant difference between treatments; the highest value of 1.94 was recorded in T_2 followed by T_4.

Table 12. Physiological observations and Yield Attributes

Treatments	Physiological observations				Yield attributes		
	LAI		Chlorophyll content (mg g^{-1})				
	60 DAP	120 DAP	60 DAP	120 DAP	No. of tubers $plant^{-1}$	Weight of tuber $plant^{-1}$ (g)	Tuber index
T_1	1.79	1.81	0.37	0.38	13.50	255.25	1.43
T_2	2.43	2.49	0.42	0.40	15.75	298.75	1.94
T_3	2.24	2.38	0.42	0.40	21.25	330.00	1.17
T_4	2.66	2.32	0.46	0.45	14.50	256.25	1.54
T_5	2.02	2.49	0.56	0.51	15.50	251.25	1.34
CD (0.05 level)	NS	NS	0.06	0.07	2.29	NS	NS

*** DAP: Days After Planting**

4.3 EFFECT OF APPLICATION OF ROCK DUST ON THE QUALITY OF TUBERS

4.3.1 Cooking quality

Organoleptic tests were conducted and it is presented in Table.13. There was no significant difference between treatments. However the tubers from T5 registered higher score than other treatments.

4.3.2 Starch content (per cent)

The starch content of the tuber in Table.13 revealed significant difference among treatments. The highest mean value of 24.71 was recorded for T_5. T_5 was significantly superior to T_2 and T_1. It was on par with T_4 and T_3.

4.3.3 Dry Matter production of Tuber (kg ha $^{-1}$)

Dry matter production of tuber was calculated after the harvest and the data are presented in Table.13. The treatments showed significant difference. The highest mean value of 1939.52 was recorded for T_3. T_3 was significantly superior to T_5 and T_4 and it was on par with T_1 and T_2

4.3.4 Dry Matter production of Aerial Portion (kg ha $^{-1}$)

Dry matter production of aerial portion calculated after the harvest showed no was significant difference among treatments. Highest mean value of 3901.50 was recorded for T_1 and it was significantly superior to T_5 and T_2 but on par with T_3 and T_4

4.3.5 Total Dry matter production (kg ha $^{-1}$)

Total dry matter production of tuber was calculated after the harvest and the data are presented in Table.13. There was significant difference between the treatments. The highest mean value of 5771.19 was recorded for T_5 and it was on par with T_3.

4.4 PLANT ANALYSIS

4.4.1 Plant Nutrient Content

The nutrients content in the various plant parts are presented in Table.14.

4.4.1.1 Nitrogen Content of Plant (per cent)

Nitrogen content in plant portion was estimated at the time of harvest and there was no significant difference among treatments. Highest mean value of 0.18 was recorded for T_3 and the lowest value of 0.13 was recorded for T_2

Table 13. Yield, Dry matter production, Economic analysis and Quality attributes in coleus

Treatments	Yield		Dry matter production			Quality attributes		Economic analysis	
							Cooking quality		
	Top yield (t ha^{-1})	Tuber yield (t ha^{-1})	Aerial portion (kg ha^{-1})	Tuber (kg ha^{-1})	Total dry matter production (kg ha^{-1})	Starch content (Per cent)	Score based on over all acceptability	Net income (Rs ha^{-1})	B.C ratio
T_1	13.72	19.55	3910.50	1783.34	5771.19	18.30	3.40	87090	2.63
T_2	13.70	12.24	2446.75	1781.25	4241.25	20.98	3.40	39441	1.97
T_3	14.93	17.26	3452.20	1939.52	5337.98	27.07	3.70	80587	2.39
T_4	10.74	16.58	3316.00	1396.60	4716.50	24.08	3.70	86890	2.89
T_5	11.94	16.12	2446.75	1552.85	4828.20	24.71	3.90	83210	2.81
CD (0.05 level)	NS	3.31	NS	239.53	679.89	1.87	0.48	26524	0.52

4.4.1.2 Nitrogen Content of Tuber (per cent)

There was no significant difference between treatments. Highest mean value of 0.14 was recorded for T_4 and the lowest value of 0.11 was recorded for T_1.

4.4.1.3 Phosphorus Content of Plant **(per cent)**

No significant difference was noticed between treatments. Highest mean value of 0.06 was recorded for T_2 and the lowest value of 0.03 was recorded for T_5.

4.4.1.4 Phosphorus Content of Tuber **(per cent)**

Though no significant difference was observed among the treatments, highest mean value of 0.07 was recorded for T_3 and the lowest value of 0.03 was recorded for T_2.

4.4.1.5 Potassium Content of Plant **(per cent)**

There was no significant difference between treatments. Highest mean value of 0.65 was recorded for T_2 and the lowest value of 0.33was recorded for T_1.

4.4.1.6 Potassium Content of Tuber **(per cent)**

Potassium content of tuber (Table.14) showed no significant difference between treatments. Highest mean value of 0.70 was recorded for T_2 and the lowest value of 0.32 was recorded for T_3.

4.4.2 MICRONUTRIENT CONTENT IN PLANTS

4.4.2.1 Fe Content of Plant **(mg kg $^{-1}$)**

There was no significant difference between treatments. Highest mean value of 68.88 was recorded for T_3 and the lowest value of 36.12 was recorded for T_1.

Table 14. Nutrient content of different plant parts in coleus

Treatments	N content (per cent)		P Content (per cent)		K (per cent)		Fe (mg kg $^{-1}$)		Mn (mg kg $^{-1}$)		Zn (mg kg $^{-1}$)	
	Aerial portion	Tuber	Aerial portion	Tuber	Aerial portion	Tuber	Aerial portion	Tuber	Aerial portion	Tuber	Aerial portion	Tuber
T_1	0.14	0.11	0.06	0.07	0.33	0.45	36.12	47.48	10.95	11.80	2.70	2.98
T_2	0.13	0.12	0.06	0.03	0.65	0.70	46.21	59.64	11.39	13.87	3.08	3.05
T_3	0.18	0.12	0.04	0.07	0.37	0.32	68.88	62.92	12.19	12.11	3.21	3.25
T_4	0.15	0.11	0.05	0.03	0.64	0.52	51.42	51.45	11.89	13.60	3.28	3.19
T_5	0.18	0.14	0.03	0.05	0.52	0.42	51.73	46.07	12.71	14.77	3.01	3.06
CD (0.05 level)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

4.4.2.2 Fe Content of Tuber **(mg kg $^{-1}$)**

The results did not show any variation due to treatments. Highest mean value of 62.92 was recorded for T_3 and the lowest value of 46.07 was recorded for T_5.

4.4.2.3 Mn Content of Plant **(mg kg $^{-1}$)**

There was no significant difference between treatments. Highest mean value of 12.71 was recorded for T_5 and the lowest value of 10.95 was recorded for T_1.

4.4.2.4 Mn Content of Tuber **(mg kg $^{-1}$)**

There was no significant variation due to treatments. Highest mean value of 14.77 was recorded for T_5 and the lowest value of 11.80 was recorded for T_1.

4.4.2.5 Zn Content of Plant **(mg kg $^{-1}$)**

There was no significant difference between treatments. Highest mean value of 3.28 was recorded for T_4 and the lowest value of 2.70 was recorded for T_1.

4.4.2.6 Zn Content of Tuber **(mg kg $^{-1}$)**

Though the treatments did not cause any variation, the highest mean value of 3.25 was recorded for T_3 and the lowest value of 2.81 was recorded for T_1.

4.5 NUTRIENT UP TAKE BY PLANT PARTS

The nutrient uptake by different plant parts are presented in Table.15.

4.5.1 Nitrogen Uptake by Aerial Portion **(kg ha^{-1})**

The treatments significantly differed in N uptake. Highest mean value of 356.97 was recorded for T_3 and it was significantly superior to T_1, T_2 and T_4 and it was on par with T_5.

4.5.2 Nitrogen Uptake by Tuber **(kg ha^{-1})**

There was no significant difference between treatments. Highest mean value of 745.80 was recorded for T_2 and the lowest value of 389.10 was recorded for T_4.

Table 15. Nutrient uptake by different plant parts as affected by the treatments

Treatments	N (kg ha^{-1})		P (kg ha^{-1})		K (kg ha^{-1})		Fe (kg ha^{-1})		Mn (kg ha^{-1})		Zn (kg ha^{-1})	
	Aerial portion	Tuber	Aerial portion	Tuber	Aerial portion	Tuber	Aerial portion	Tuber	Aerial portion	Tuber	Aerial portion	Tuber
T_1	258.12	436.38	107.35	145.06	612.46	1722.80	6.30	18.65	1.97	4.64	0.52	0.52
T_2	236.63	745.80	115.45	80.08	1173.94	1741.82	8.23	13.69	2.03	3.47	0.53	0.53
T_3	356.97	435.82	83.76	267.10	746.27	1124.94	13.65	21.65	2.39	4.20	0.60	0.62
T_4	215.02	389.10	133.21	113.65	877.91	1679.70	7.26	17.26	1.63	4.55	0.45	0.44
T_5	281.88	471.18	132.22	182.83	801.98	1378.10	8.95	14.88	1.96	4.75	0.42	0.47
CD (0.05 level)	72.54	NS	NS	NS	NS	NS	4.75	NS	NS	1.47	NS	0.10

4.5.3 Phosphorus Uptake by Aerial Portion (kg ha^{-1})

The treatments did not register any significant variation in uptake. Highest mean value of 133.21 was recorded T_4 and lowest mean value of 83.76 was recorded for T_3.

4.5.4 Phosphorus Uptake by Tuber (kg ha^{-1})

There was no significant difference between treatments. Highest mean value of 263.10 was recorded for T_3 and the lowest value of 80.08 was recorded for the treatment T_2.

4.5.5 Potassium Uptake by Aerial Portion (kg ha^{-1})

There was no significant difference among treatments. Highest mean value of 1173.94 was recorded for T_2 and lowest mean value of 612.46 was recorded for T_1.

4.5.6 Potassium Uptake by Tuber (kg ha^{-1})

Though no significant difference was noticed among treatments, the highest mean value of 1722.8 was recorded for T2 and the lowest value of 1124.94 was recorded for T_3.

4.5.7 Fe Uptake by Aerial Portion (kg ha^{-1})

The treatments differed significantly. Highest mean value of 13.65 was recorded for T_3. T_3 was significantly superior to T_2, T_4 and T_1 and it was on par with T_5.

4.5.8 Fe Uptake by Tuber (kg ha^{-1})

There was no significant difference between treatments. Highest mean value of 21.65 was recorded for $T_3$and the lowest value of 13.69 was recorded for T_2.

4.5.9 Mn Uptake by Aerial Portion (kg ha^{-1})

The variation due to treatment was found insignificant. Highest mean value of 2.39 was recorded for T_3 and the lowest value of 1.63 was recorded for T_4.

Table 16. pH, EC and available major nutrients as affected by the treatments

Treatments	pH		EC (μS m^{-1})		Available N (kg ha^{-1})		Available P (kg ha^{-1})		Available K (kg ha^{-1})	
	At tuberization	At harvest	At tuberization	At harvest	At tuberization	At harvest	At tuberization	At harvest	At tuberization	At harvest
T_1	4.8	4.8	214.35	205.28	266.56	270.48	24.57	24.21	349.65	339.26
T_2	4.8	5.0	121.65	124.28	308.08	310.62	25.55	26.96	408.80	410.20
T_3	5.1	5.2	144.28	139.25	274.40	256.76	27.85	27.83	472.57	461.91
T_4	5.3	5.3	97.15	103.09	258.72	264.60	32.48	32.93	482.00	479.30
T_5	5.4	5.4	123.72	129.50	306.76	298.63	33.06	32.42	515.60	537.70
CD (0.05level)	0.1	0.1	49.86	NS	NS	NS	4.43	3.03	79.66	71.86

4.5.10 Mn Uptake by Tuber **(kg ha^{-1})**

There was significant variation due treatments. Highest mean value of 4.75 was recorded for T_5. T_5 was significantly superior to T_2 and it was on par with T_1, T_4 and T_3.

4.5.11 Zn Uptake by Aerial Portion **(kg ha^{-1})**

No significant difference was noticed among treatments. Highest mean value of 0.60 was recorded for T_3 and the lowest value of 0.42 was recorded for T_5.

4.5.12 Zn Uptake by Tuber **(kg ha^{-1})**

There was significant difference between treatments. Highest mean value of 0.62 was recorded for T_3. T_3 was significantly superior to T_5 and T_4. It was on par with T_2, and T_1.

4.6 SOIL ANALYSIS

The data on soil analysis is presented in Table. 16 and 17

4.6.1 pH at Tuberization

There was significant difference between treatments in pH of the soil at the time of tuberization. The highest pH value of 5.4 was recorded for T_5. It was significantly superior to T_3, T_2 but was on par with T_4.

4.6.2 pH at Harvest

There was significant difference between treatments at the time of harvest. The highest pH value of 5.5 was recorded for the treatment T_5. This was significantly superior to T_3, T_2 and T_1 but on par with the treatment T_4.

4.6.3 EC at Tuberization **(µS m^{-1})**

There was significant difference between treatments at the time of tuberization. The highest value of 214.35 µS m^{-1} was recorded for T_1 and it was significantly superior to all the other treatments.

4.6.4 EC at Harvest **(µS m^{-1})**

There was no significant difference among treatments. The highest value of 205.28 µS m^{-1} was recorded in T_1 and the lowest value of 103.09 µS m^{-1} was recorded for T_4.

Table 17. Exchangeable Ca, Mg, and available micronutrient content as affected by the treatments

Treatments	Exchangeable Ca (c mol kg^{-1})		Exchangeable Mg (c mol kg^{-1})		Available Fe (mg kg^{-1})		Available Mn (mg kg^{-1})		Available Zn (mg kg^{-1})	
	At tuberization	At harvest	At tuberization	At harvest	At tuberization	At harvest	At tuberization	At harvest	At tuberization	At harvest
T_1	1.65	1.61	9.21	9.79	48.73	49.66	12.27	12.32	4.99	5.01
T_2	1.82	1.70	7.23	7.08	64.10	64.27	13.80	13.88	5.05	5.05
T_3	2.40	2.62	12.98	13.51	79.36	78.16	15.92	15.99	5.17	5.16
T_4	2.57	2.54	9.98	10.31	79.29	78.39	18.55	19.10	5.47	5.46
T_5	2.67	2.44	14.02	14.36	87.06	86.66	21.80	21.46	5.97	6.01
CD (0.05level)	NS	NS	3.83	NS	9.44	7.58	2.86	2.05	0.21	NS

4.6.5 Available Nitrogen at Tuberization **(kg ha^{-1})**

The results revealed no significant variation due to treatments. T_2 showed the highest mean value of 308.08 kg ha^{-1}. The lowest value of 258.72 kg ha^{-1} was recorded for the treatment T_4.

4.6.6 Available N at Harvest **(kg ha^{-1})**

At harvest also no significant difference was noticed for the different treatments. T_4 showed the highest mean value of 409.50 kg ha^{-1} followed by T_5. The lowest mean value of 343.54 kg ha^{-1} was recorded for T_1.

4.6.7 Available P at Tuberization **(kg ha^{-1})**

The treatments differed significantly. T_5 showed the highest mean value of 33.06 kg ha^{-1} and was on par with T_4. T_5 was significantly superior to T_3, T_2 and T_1.

4.6.8 Available P at Harvest **(kg ha^{-1})**

Available P at harvest showed significant difference due to treatments. T_5 showed the highest mean value of 34.65 kg ha^{-1} and was on par with T_4, T_5 was significantly superior to T_3, T_2 and T_1.

4.6. 9 Available K at Tuberization **(kg ha^{-1})**

The treatments differed significantly. T_5 showed the highest mean value of 515.60 kg ha^{-1} and on par with T_4 and T_3. T_5 was significantly superior to T_2 and T_1.

4.6.10 Available K at Harvest **(kg ha^{-1})**

Available K at harvest presented in Table.16 revealed significant among between treatments. T_5 showed the highest mean value of 607.10 kg ha^{-1} and on par with T_4. T_5 was significantly superior to T_3, T_2 and T_1.

*4.6.11 Exchangeable Ca at Tuberization***(c mol kg $^{-1}$)**

No significant difference was observed between treatments. Highest mean value of 2.67 was recorded for T_5 and the lowest value of 1.65 was recorded for T_1.

4.6.12 Exchangeable Ca at Harvest **(c mol kg $^{-1}$)**

The treatments failed to impart any variation on exchangeable Ca. However, highest mean value of 2.62 was recorded for T_3 and the lowest value of 1.65 was recorded for T_2.

4.6.13 Exchangeable Mg at Tuberization **(c mol kg $^{-1}$)**

The exchangeable Mg at tuberization presented in Table.17 revealed significant difference due to treatments. Highest mean value of 14.02 was recorded for T_5. This was significantly superior to T_4, T_1 and T_2 and it was on par with the treatment T_3.

4.6.14 ***Exchangeable Mg at Harvest*** **(c mol kg $^{-1}$)**

Exchangeable Mg at harvest presented in Table.17 did not show any variation due to treatments. Highest mean value of 17.5 was recorded for the treatment T_3 and the lowest value of 13.74 was recorded for the treatment T_2.

4.6.15 ***Available Fe at Tuberization*** **(mg kg $^{-1}$)**

There was significant difference among treatments. Highest mean value of 83.06 was recorded for T_5. T_5 was significantly superior to T_2 and T_1 and it was on par with T_3 and T_4.

4.6.16 Available Fe at Harvest **(mg kg $^{-1}$)**

There was significant difference among treatments. Highest mean value of 104.12 was recorded for T_4 and it was significantly superior to T_3, T_2 and T_1 and it was on par with T_5.

4.6.17 Available Mn at Tuberization **(mg kg $^{-1}$)**

The treatments differed significantly and the highest mean value of 21.80 was recorded for T_5 and it was significantly superior to all other treatments.

4.6.18Available Mn at Harvest **(mg kg $^{-1}$)**

Available Mn content at harvest revealed significant difference between treatments. Highest mean value of 29.61 was recorded for T_5 and it was significantly superior to T_3, T_2 and T_1 and it was on par with T_4.

4.6.19 Available Zn at Tuberization **(mg kg $^{-1}$)**

There was significant difference between treatments. Highest mean value of 5.97 was recorded for T_5 and it was significantly superior to all other treatments.

4.6.20 Available Zn at Harvest **(mg kg $^{-1}$)**

The results showed no significant difference due to treatments. Highest mean value of 6.36 was recorded for T_5 and the lowest value of 5.67 was recorded for T_1.

4.7 ECONOMIC ANALYSIS

Economic analysis of the study was worked out. The net income and B: C ratio is presented in Table. 15. The different treatments significantly influenced the net income and the maximum net income was registered by T_1 (87090 Rs ha $^{-1}$), which was on par with T_3, T_4 and T_5. T_2 registered the lowest net income. Highest B.C ratio of 2.89 was recorded for the treatment T_4, which was on par with T_3, T_5 and T_1.

DISCUSSION

5. DISCUSSION

An investigation entitled "Rock dust as a nutrient source for coleus (*Solenostemon rotundifolius*)" was carried out at the College of Agriculture, Vellayani during 2006-2007.

The first part of the experiment consisted of a laboratory incubation study where the field samples were incubated with rock dust and FYM under optimum moisture level to monitor the nutrient release pattern as measured by the level of available nutrients in the soil. The second part was a field experiment with coleus, where the different treatments were designed to bring out the specific effect of rock dust application on the growth and yield of coleus and in maintaining adequate level of available major and micro nutrients in the soil throughout the growth period.

5.1 INCUBATION STUDY

The effect of incubation of soil with different rates of rock dust was assessed by periodical monitoring of changes in soil pH, available nutrients *viz.* N, P, K and micronutrients presented in Table. 3 to 10 are discussed.

There was an increase in pH of the soil during the initial period extending up to 45 days. A more or less uniform pH was maintained thereafter. Campe et al. (1996) found that rock dust neutralize the soil to a great degree. This is evident in the treatments where rock dust was applied in combination with FYM, which had a positive effect on soil reaction. The pH of incubated soils where rock dust @ 8, 10 and 12 t ha^{-1} was applied along with FYM @ 8, 10 and 12 t ha^{-1} respectively were higher when compared to the treatments with rock dust alone. This shows the beneficial influence of FYM in providing a favourable environment for the activity of soil microorganisms as well as for nutrient availability. The soil pH significantly affects the availability of most of the nutrients required for the plant growth. Almost all the nutrients *viz.* N, Ca, Mg, P, K, S, Mo, and B become available with in an intermediate pH. (Brady, 1990)

There was an increase in EC throughout the incubation period, but the values were lower than the critical limits, and hence in the present study, EC had no significant importance.

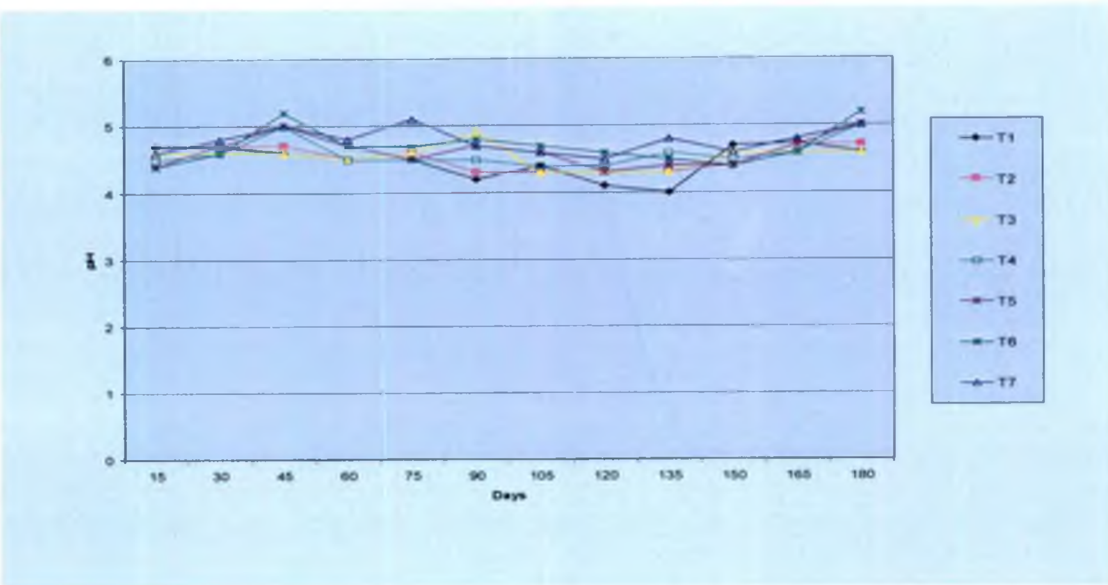

Fig. 4 Changes in soil pH during the incubation period

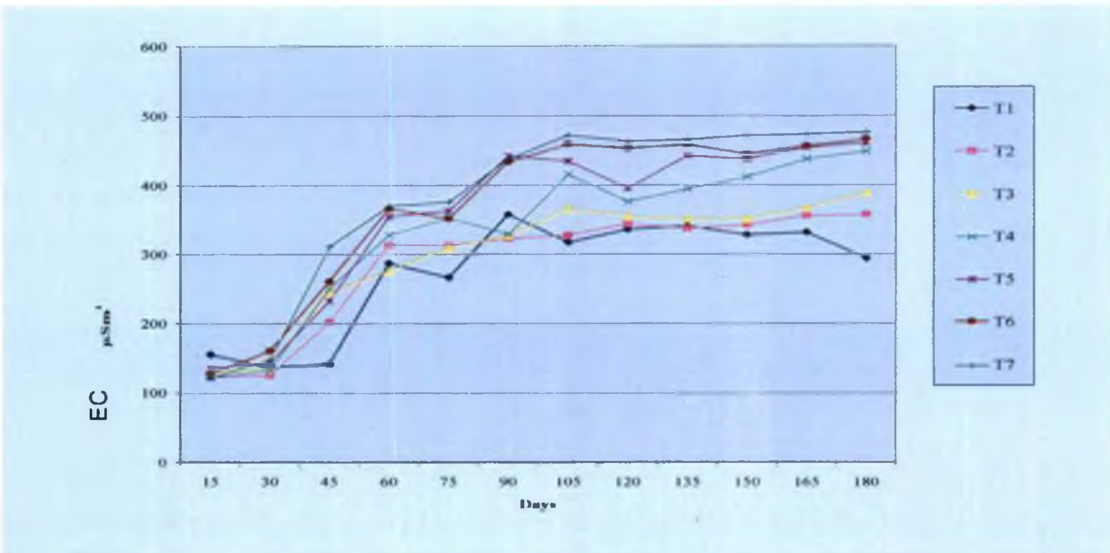

Fig.5 Changes in soil EC (μ S m^{-1}) during the incubation period

It can be seen from the data on available N present in Table. 5 that the treatments with rock dust and FYM applied at different rates resulted in an increased availability of N in soil. The percentage increase in N due to addition of FYM ranged from 7 – 17.50. the increase can be attributed to the contribution of N from the FYM itself as well as due to increased microbial activity in the soil due to the addition of FYM.

In the case of available P also, a higher dose of rock dust *i.e.* 12 t ha $^{-1}$ along with an equal quantity of FYM recorded the highest values of P in the soil. This is evident from the data presented in Table.8, which showed the highest values of P from 30th days onwards. It could be inferred that a higher quantity of rock dust is required to provide sufficient quantity of available P in soil. Fragstein et al. (1988) and Leonardos et al. (1985) reported that the application of large quantities of ground silicate rocks obtained as a by-product of quarry industry are part of an alternative sustainable strategy to remineralize the degraded soils. The average P content in the soil ranged from 18.68 to 53.82 kg ha^{-1}. Thus, it is evident that rock dust was able to raise the available P content from medium to higher levels. It is inferred from the data presented in the Table. 8 that increasing the rate of application of rock dust from 8 to 12 t ha $^{-1}$ resulted in corresponding increase in the available P content from 31.37 to 34.83 kg ha^{-1} in the soil. Beneficial effect of FYM on the release of nutrients from rock dust can be observed from the increase in available P content of soil, which ranged from 37.49 to 44.95 kg ha^{-1} when compared to the treatments where rock dust was applied with out FYM in treatments T2 to T4, which ranged from 31.37 to 34.83 kg ha^{-1}. Application of FYM along with rock dust resulted in an increase in available P, which ranged from 19.50 to 29.22 per cent. When rock dust was applied @ 8 t ha^{-1} along with FYM, the available P content increased by 19.59 per cent. But when higher dose of rock dust *i.e.* 10 and 12 t ha^{-1}, were applied along with equal quantities of organic manure, the percentage increase in available P was 29.22 and 29.09 respectively. The increase in P availability observed in the treatments receiving a combination of rock dust and FYM further emphasises the positive effect of FYM in P solubilisation. Further, the amendment of rock dust with FYM also registered early solubilisation of P when compared to the treatments without FYM as evidenced from the results. Solubilisation of P was found to decrease during the

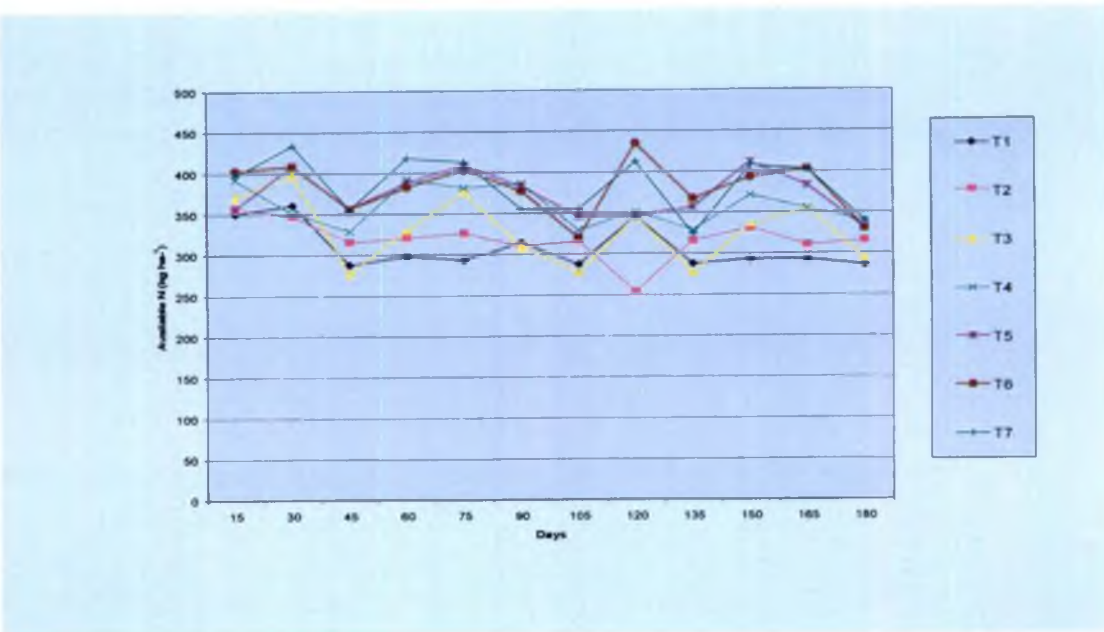

Fig.6 Changes in available N (kg ha^{-1}) content of soil during the incubation period

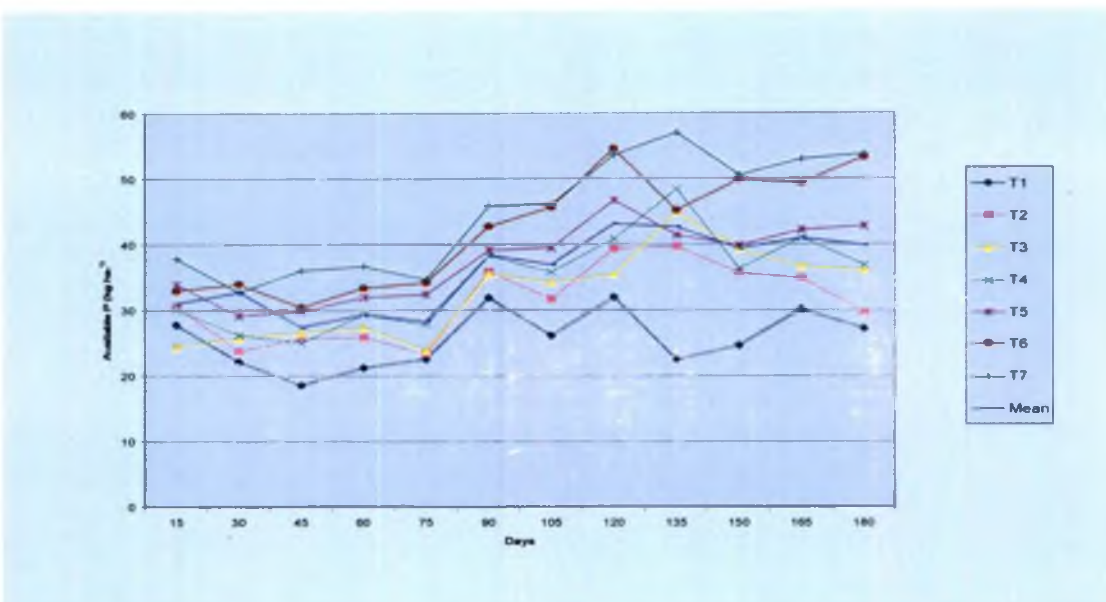

Fig.7 Changes in available P (kg ha^{-1}) content of soil during the incubation period

initial stages of incubation, which continued for a period of 75 days. But, the P availability was found to increase after the 75th day reaching the maximum value on 120th day and more or less the same level was maintained up to the end of the incubation period.

The beneficial effect of application of organic manure in the release of available P could be attributed to many ways as suggested by Datta et al. (1992) and Datta, and Banik (1994). They reported that FYM, which is a mixture of feed waste of animals and their dung and urine, has a high load of heterotrophic microorganisms, which continue to be active during storage also. Their continued action results in the decomposition of organic matter in FYM producing substantial amount of humus consisting of a mixture of humic and fulvic acids. The phosphate released as soluble P from rock dust, which is not immediately absorbed by the plants is not subjected to fixation in the presence of this humified organic matter. Reaction of humus with P, forming phospho humic complex which is more easily available to plants; replacement of the phosphate ions on the clay complex by humate anions and the coating of sesquioxides particles by humus, there by reducing P fixing capacity are some of the ways by which the P availability to crop is improved by the use of FYM.

The available K content in the soil ranged from 141.90 to 843.76 kg ha^{-1}. The treatment where rock dust was applied at the highest rate *i.e.* @ 12 t ha^{-1} along with an equal quantity of FYM recorded the highest available K content through out the period of incubation. This showed that a higher rate of rock dust is required to maintain the available K content of soil in appreciably good levels. This should be supplemented by the addition of FYM. The percentage increase in available K by the incorporation of FYM in the soil along with rock dust at different rates *viz.* 8, 10, and 12 t ha^{-1} is 27.05, 22.95 and 45.38 respectively. Monitoring of the potassium release pattern of the rock dust treated soil revealed that rock dust when applied in conjunction with FYM could render more available K in the soil. Studies conducted by Hisinger et al. (1996) using scrap grade phlogopite from a Sri Lankan mica processing centre revealed that up to 65 per cent of the K contained in the phlogopite could be released. The release of K was found to increase over time, reaching the maximum values during the later part of the study.

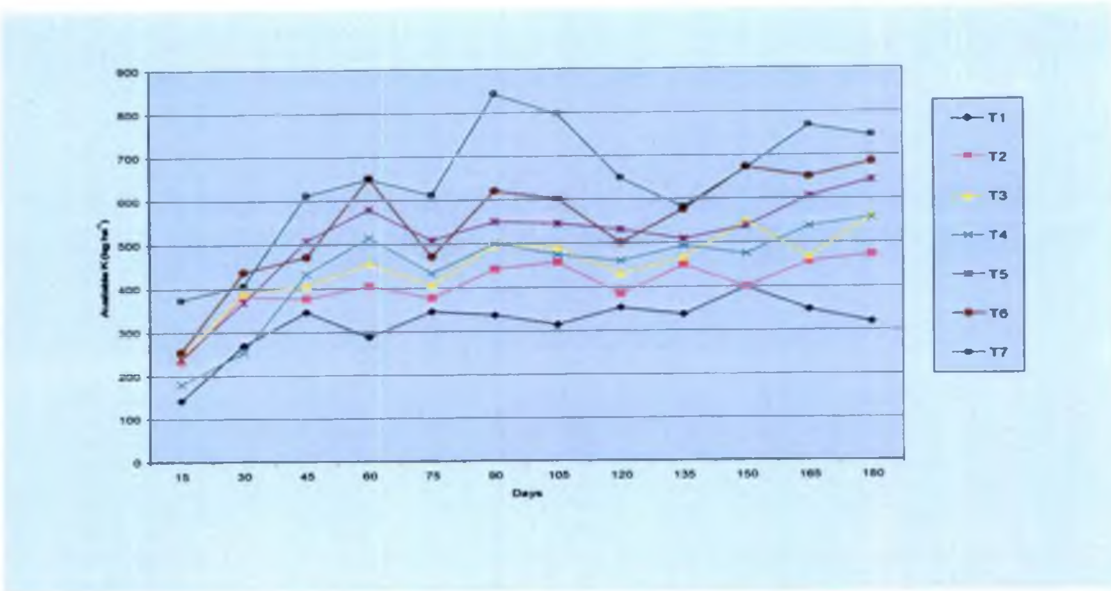

Fig.8 Changes in available K (kg ha^{-1}) content of soil during the incubation period

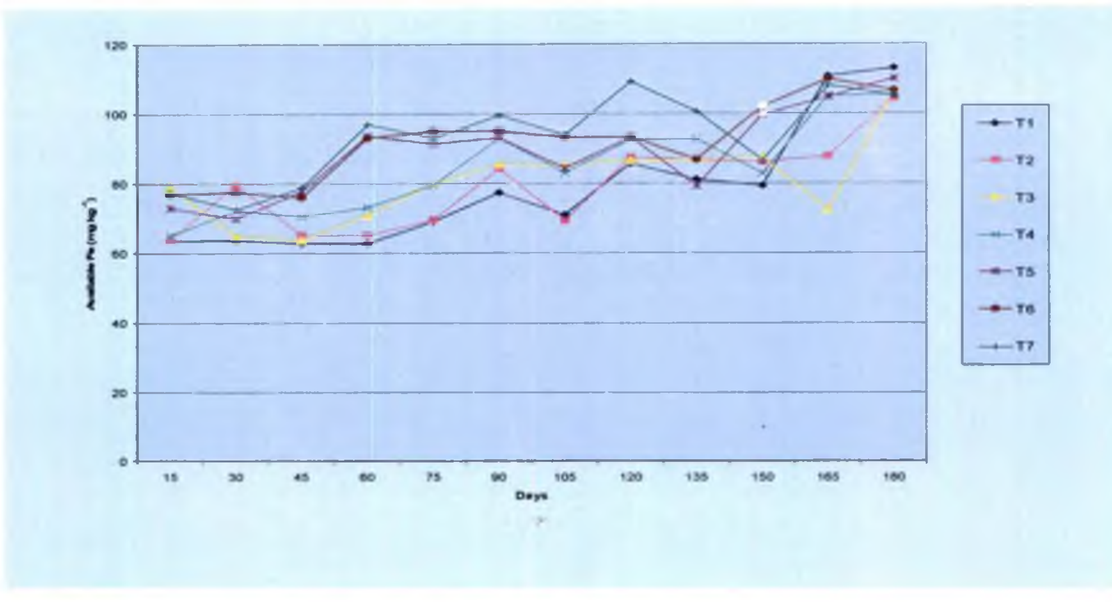

Fig.9 Changes in available Fe content (.ng kg^{-1}) of soil during the incubation period

Application of rock dust at higher rate *i.e.*@ 12 t ha $^{-1}$ along with an equal quantity of FYM released the maximum amount of available Fe, on 45th , 60th , 90th, 105th 120th and 135th day of incubation. Rock dust @ 10 t ha^{-1} with equal quantity of FYM released Fe during 75th and 150th day of incubation. Data on available Fe presented in Table. 10 revealed that the treatment where the highest doses of rock dust *i.e.* 12 t ha $^{-1}$along with an equal quantity FYM recorded the highest Fe availability. Application of rock dust along with FYM resulted in an increase in available Fe content, which ranged from 62.81 to112.93 mg kg $^{-1}$. When rock dust was applied along with equal quantities of FYM, the available Fe content was increased by 12.81 per cent where as for the treatments where 10 and 12 t ha $^{-1}$ rock dust was applied along with an equal quantity of organic manures, the percentage increase in available Fe was 14.14 and 10.47 per cent respectively. Maximum solubilisation of Fe occurred during the 180th day of incubation and there was a steady increase in the Fe content, which continued throughout the period of incubation.

The same trend was noticed in the case of available Mn also. The results revealed that increasing the rate of application of rock dust resulted in increased availability of the nutrients in the soil. Rock dust @ 12 t ha $^{-1}$ with equal quantity of FYM resulted in the highest available Mn calculated during 15th, 30th, , 45th , 60th ,90thand165th, day where as, rock dust @ 10 t ha $^{-1}$ and 8 t ha $^{-1}$ along with equal quantity of FYM released the highest Mn content during 120th ,135th, 150th and 180th day respectively. The percentage increase in available Mn by the incorporation of FYM in soil along with rock dust @ different rates *viz.* 8, 10 and 12 t ha $^{-1}$ was 23.08,15.80 and 26.36 per cent respectively. The availability of Mn content of the soil showed an increase throughout the period of incubation reaching the highest solubilisation during the later stage of experiment.

There was an increase in Zn content of soil throughout the incubation period. Maximum solubility occurred during the 180th day of incubation. Here also application of rock dust @ 12 t ha^{-1} along with an equal quantity of FYM resulted in an increase in available Zn content in soil. The percentage increase due to the application of FYM along with different rates of rock dust @ 8, 10 and 12 t ha $^{-1}$ are 1.3, 8.3 and 8.6 respectively.

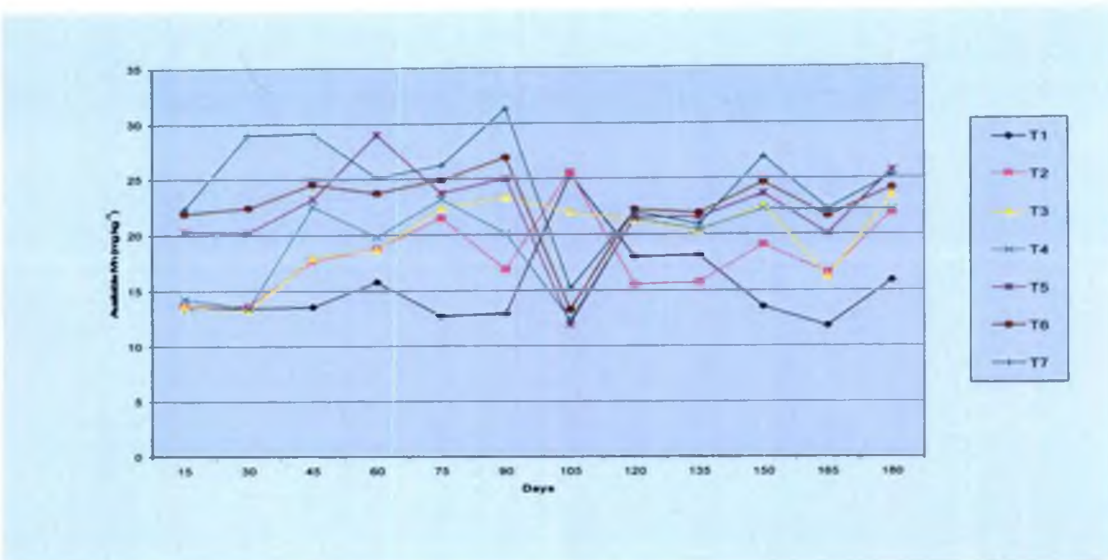

Fig.10 Changes in available Mn content (mg kg $^{-1}$) of soil during the incubation period

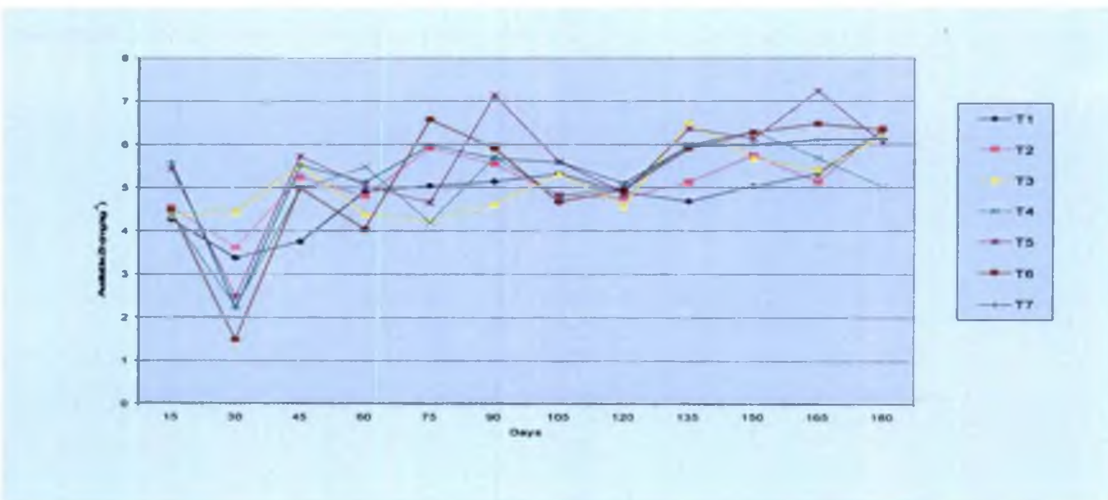

Fig.11 Changes in available Zn content (mg kg $^{-1}$) of soil during the incubation period

Thus the incubation study provided valuable information on possible status of the available nutrients that can be made available in soil solution for plant up take by the use of rock dust alone or in combination with FYM.

5.2 FIELD EXPERIMENT

5.2.1 Biometric Observations as Influenced by the Application of Rock Dust

The plant growth characters like number of branches per plant at 90 DAP and plant spread at 60 DAP showed significant variation due to treatments at different growth stages in coleus. The influence of organic manure and rock dust were pronounced through out the growth period. The highest number of branches per plant was recorded at 90 DAP for the treatment where the rock dust and FYM was applied @ of 10 t ha^{-1} along with 50 per cent of the recommended dose of fertilizer. The maximum plant spread was observed at 60 DAP in the treatment where rock dust @ 10 t ha^{-1} mixed and kept for 15 days with equal quantity of FYM and kept for 15 days was applied. Similar reports on the application of rock dust in lettuce, cress and brassicas were furnished by Madeley (using perlite as medium) where the growth rate of rock dust applied plants recorded significantly higher shoot length, root length and plant weight.

5.2.2 Physiological Characters as Influenced by the Application of Rock Dust

Concentration of chlorophyll in the leaves shows the photosynthetic efficiency of the plant. In the present study, the chlorophyll content showed significant variation during 60 DAP and 120 DAP. Rock dust treated plants recorded higher leaf chlorophyll content than chemically fertilized plants. It is evident from the data presented in Table.12 that all the treatments receiving rock dust produced comparatively higher chlorophyll concentration when compared to the treatments with inorganic fertilizers. Application of rock dust @ 10 t ha^{-1} mixed with equal quantity of FYM and kept for 15 days resulted in a higher concentration of chlorophyll at 60 and 120 DAP. This may be due to the higher supply of Mg from the rock dust, which is an important constituent of chlorophyll. Data presented in Table.17 revealed that the treatment which recorded higher concentration of chlorophyll recorded higher values of exchangeable Mg in soil. This is in confirmation with the results presented by Havlin et al. (2003) who stated that chlorophyll usually accounts for about 15 to 20 per cent of the total Mg^{2+} content of the plants.

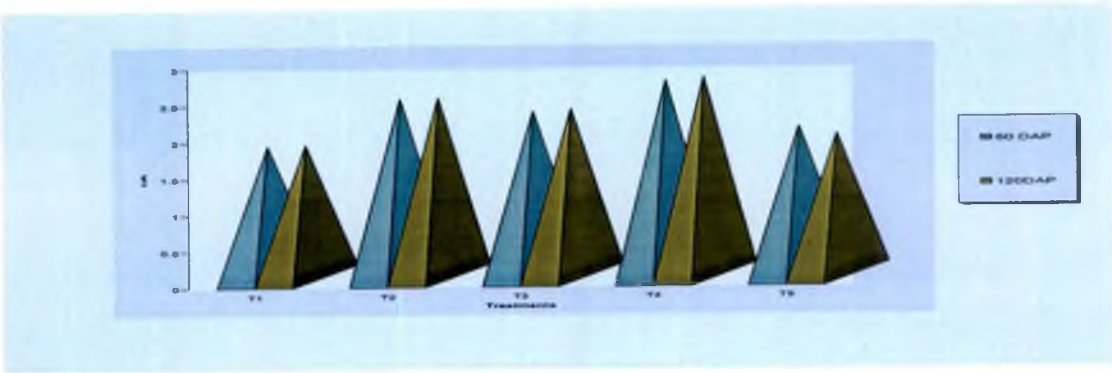

Fig. 15 Leaf Area Index as influenced by the treatments

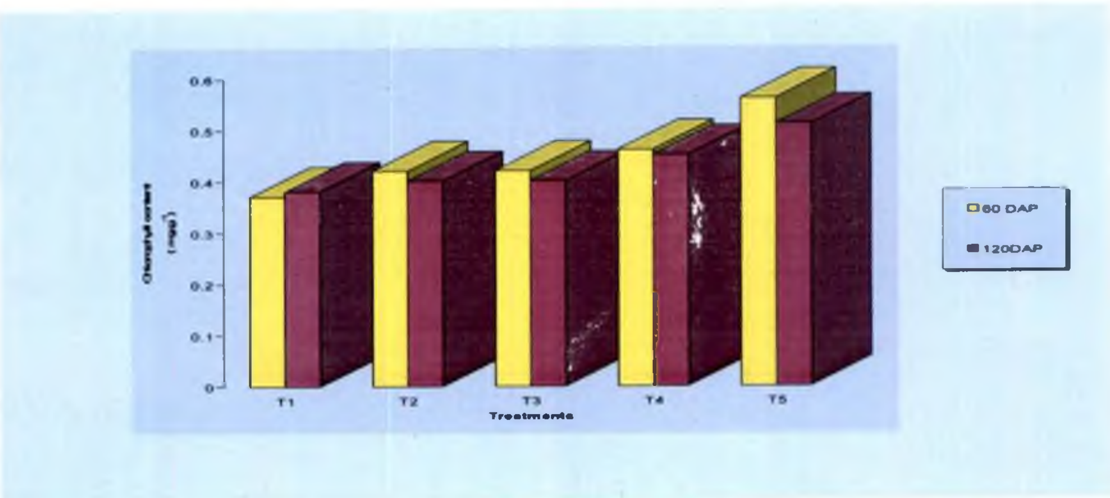

Fig. 16 Leaf chlorophyll content as influenced by the treatments

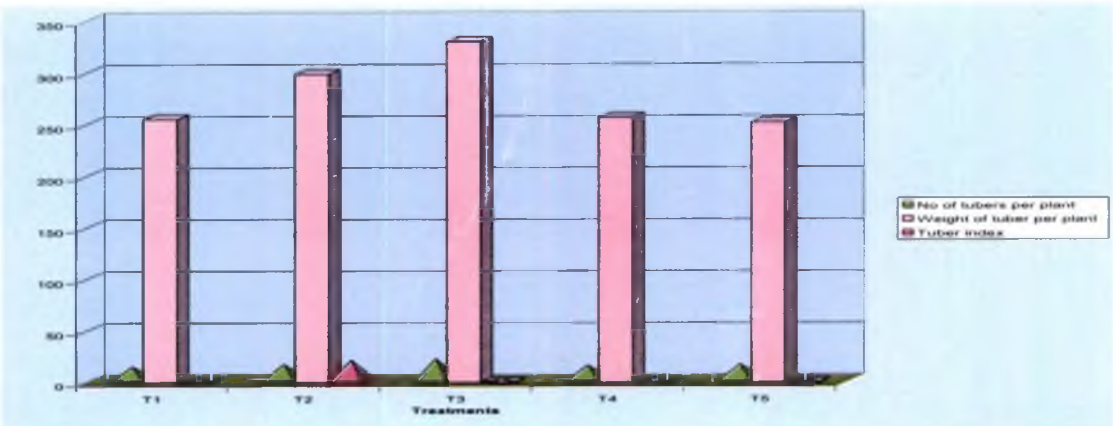

Fig. 17 Yield components as influenced by the treatments

5.2.3 Yield and Yield Attributes as Influenced by the Application of Rock Dust

Yield and yield attributes showed significant variation due to the treatments. In general, plants supplied with rock dust showed better performance in terms of yield and yield attributes.

The highest yield of 19.56 t ha $^{-1}$ was recorded for the treatment, where KAU POP recommendation (*i.e.* @ 60: 60:100 kg NPK ha^{-1} and FYM @ 10 t ha $^{-1}$) was applied (with B: C ratio of 2.63). But this was on par with the treatment where the KAU POP recommendation was reduced to half (50 per cent) *i.e.* 30: 30: 50 kg NPK ha $^{-1}$ along with rock dust @ 10 t ha $^{-1}$ (17.26 t ha $^{-1}$). The treatment supplying rock dust @ 10 t ha $^{-1}$ along with an equal quantity FYM also produced a similar yield of 16.58 t ha $^{-1}$ which was on par with the highest yield of 19.56 t ha $^{-1}$. It is evident that plants supplied with rock dust is efficient in producing yield similar to that of chemically fertilized plants, provided it is applied along with sufficient quantity of organic manure. In a five-year pot experiment conducted by Baerug (1991) using rock powder in the growth medium for crops like oats, timothy, red clover and rye grass, it was found that highest yield and K uptake were obtained with media containing 100 per cent rock powder. The increased yields were considerable over the five years for all the rock types used namely granite, syenite and amphibole.

The results also showed that even half the recommended level of NPK is sufficient to produce as much yield as that of full dose of NPK provided it is applied along with rock dust and FYM. Either rock dust can be partially substituted for chemical fertilizers up to 50 per cent or it can be recommended as such *i.e.* rock dust @ 10 t ha $^{-1}$along with an equal quantity of FYM, for coleus for the production of economic yield. Similar result on the rock dust application in cassava was reported by Shehana (2006), where application of rock dust *viz.* khondalite @ 1 t ha $^{-1}$ along with 75 per cent of the KAU POP recommendation i.e. 38:38:38 kg NPK ha $^{-1}$ and FYM @ 12.5 t ha $^{-1}$ produced the highest yield. The study also revealed that 25 to 50 per cent of the present POP recommended level of fertilizers for cassava *i.e.* @ 50: 50: 50 kg NPK ha $^{-1}$ can be substituted with khondalite with out affecting the yield.

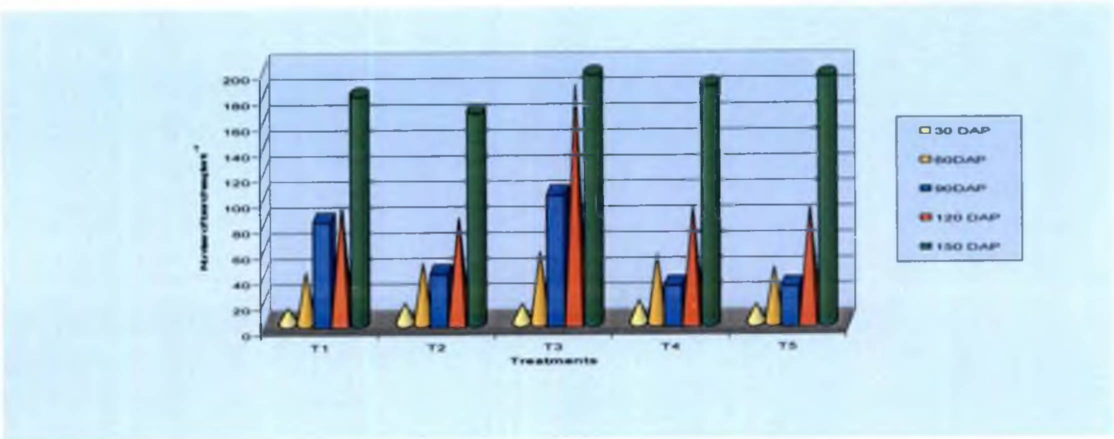

Fig. 12 Number of branches per plant as influenced by the treatments

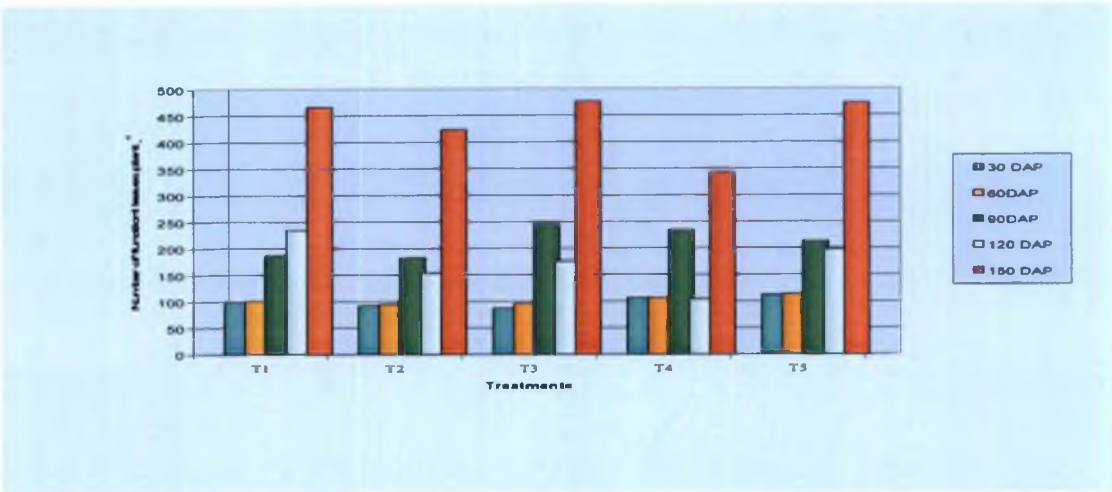

Fig 13 Number of Functional Leaves per plant as influenced by treatments

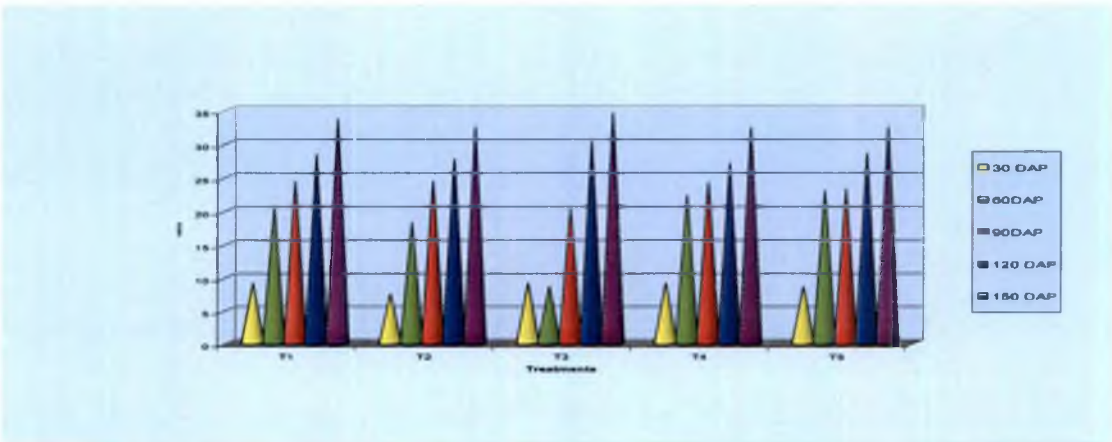

Fig 14 Plant spread as influenced by the treatments

Application of rock dust significantly influenced the number of tubers per plant as observed from Table.12. The highest number of tubers was recorded by the treatment (50 per cent NPK) + FYM @ 10 t ha $^{-1}$ + Rock dust @ 10 tons ha^{-1}, which was superior to all the other treatments. This treatment exerted positive influence on growth characters also. Improvement in the growth characters along with the increased production of tubers might have resulted in higher yield of coleus. Rock powder dusting in chickpea (*Cicer arietinum*) was studied by Pimbert and Srivastava (1989) in India and it was found that yield was significantly higher in dusted plants. Increased yield due to the application of different types of rock dust were reported in different crops. 80 per cent increase in yield of banana was reported by Edward (1993) in Australia. Yarrow (1997) reported that application of granite increased the yield of potato and sugar beet in USA.

5.2.4 Dry Matter Content of the Plants and Total Dry Matter Production as Influenced by Rock Dust

Dry matter production showed significant difference between treatments. A perusal of the data on the dry matter content of plant parts and total dry matter production presented in Table.13 revealed that application of rock dust @10 t ha $^{-1}$ along with 50 per cent of POP recommendations and FYM resulted in the highest dry matter content in aerial plant parts. This is in accordance with the reports published by Coroneos (1996) in Australia where the application of rock dust increased dry matter content of tomato. From the data, it was revealed that rock dust had a positive effect on dry matter production when compared to chemical fertilizers.

5.2.5 Quality Attributes as Influenced by the Application of Rock Dust

The characteristic flavour of coleus is due to the presence of essential oil, mainly composed of phenolics. Tubers are rich in carbohydrate, minerals and essential amino acids. Among the quality parameters, starch content of the tuber, which is the most important constituent as far as cooking quality is concerned, showed significant variation due to treatments. Rock dust treated plants gave highest content of starch yield than the control. Cooking quality of the tuber showed different trends. Rock dust applied plants showed very good cooking quality. Yarrow (1991) reported that application of gravel

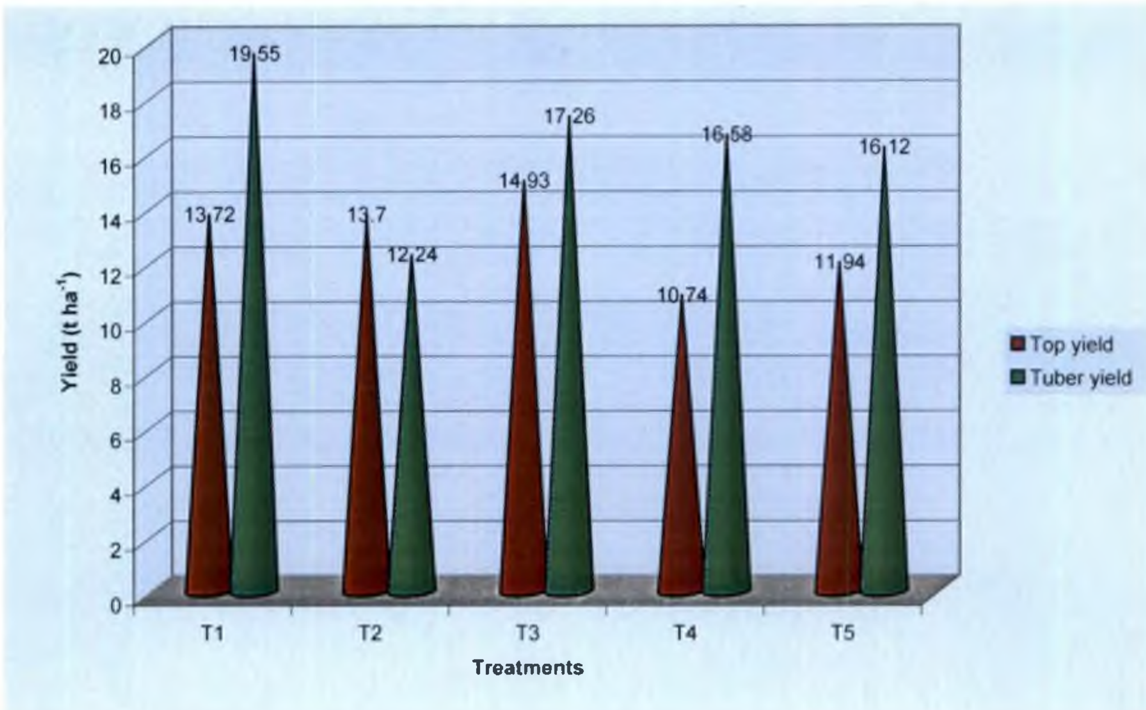

Fig. 18. Yield of Coleus as influenced by the treatments

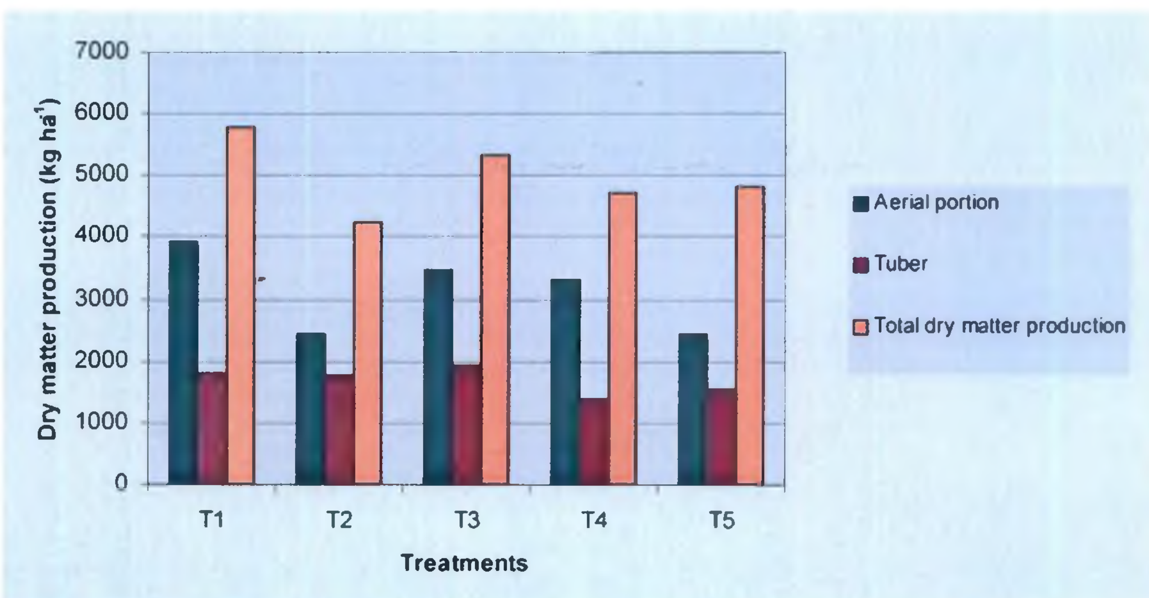

Fig. 19. Dry matter content of different plant parts as influenced by the treatments

dust resulted in good taste, strong, healthy, disease and pest resistance in various food crops.

5.2.6 Nutrient Content and Uptake as Influenced by the Application of Rock Dust

It is known that plant growth is the result of inter-related utilization of different elements concerned in nutrition *viz.* N, P, K., Fe, Mn and Zn. The nutrient content of different plant parts did not show any variation due to the treatments. This shows the efficiency of rock dust to provide the major as well as micronutrient almost equal to that provided by full dose of chemical fertilizers for the growth of the crop. Hamaker and Weaver (1982) reported that application of rock dust in the corn crop resulted in an increase in 57 per cent P, 90 per cent K, 47 per cent Ca and 60 per cent Mg than chemically grown crop from the same seed.

Rock dust @ 10 t ha^{-1} along with 50 per cent of NPK and FYM produced highest nitrogen uptake in aerial portion of coleus when compared to 100 per cent recommendation. Uptake of Fe by aerial portion was highest when rock dust @ 10 t ha^{-1} along with an equal quantity of FYM was applied. Mn uptake was the highest when plants were supplied with rock dust@ 10 t ha^{-1} mixed along with equal quantity of FYM and kept for 15 days, and this was on par with recommendations of KAU. Zn uptake by tubers was the highest for the treatment, which received rock dust @ 10 t ha^{-1} along with 50 per cent of NPK recommendation and FYM.

5.2.7 Soil Reaction and Nutrient Availability as Influenced by Rock Dust

A perusal of the data presented in Table.16 and 17 revealed that the application of rock dust resulted in an increase in soil pH both at tuberization and at harvest stages of the crop. The specific effect of rock dust in increasing the pH of the soil solution until the system is saturated at nutrient levels equivalent to the ground water composition was reported by Leonardos et al. (1985). The application of rock dust @ 10 t ha^{-1} along with FYM mixed and kept for 15 day resulted in higher soil pH than that of recommended dose. There was an increase of 0.7 units in pH value. Analytical data of rock dust revealed that it has a pH of 7.7 and application of rock dust reduced soil acidity in all the treatments. Campe et al. (1996) reported that rock dust neutralize the soil to a great degree in forest soil where limestone is not recommended which destroy the humus building complex.

Application of rock dust resulted in the lowering the EC of all the treated plots. The threshold limit of EC in the soil is 700 ($\mu S\ m^{-1}$) and all the rock dust treated plots registered lower EC values

As seen from the Table.2, the red loam soils of Vellayani has an initial nitrogen content of 329.28 kg ha $^{-1}$. Medium nitrogen content was maintained through out the growth period of the crop irrespective of the treatments. This shows that rock dust along with FYM was able to supply the nitrogen required for the crop growth. Korcak (1996) stated that out of the 16 elements considered to be essential for the growth of the plants, most of them are provided by rock dust and from the environmental healthy soil systems. Fragstein and Vogtmann. (1987) also reported that rock dust contained most of the nutrients essential for plant growth.

Rock dust is a good source of available P and K. Rock dust @ 10 t ha $^{-1}$along with an equal quantity of FYM (mixed and kept for 15 days) provided the highest available P and K both at the tuberization and harvest stages of the crop. Studies conducted by Anderson (1994) also revealed that incorporation of rock dust influenced the soil pH which may affect the microbial activity and consequent material degradation which in turn released chemical ions in the system. The P and K levels in the soil during tuberization and harvest stages were significantly superior to the chemically fertilized plots. The percentage increase in available P was 34.55 per cent at tuberization where as, it was 43.12 per cent during the harvest over chemically fertilized plants. The available K content was increased by 47.96 and 58.49 per cent during the tuberization and harvest stages respectively for the rock dusted pants when compared to chemically treated pants. The results of five year pot experiment with 5 per cent rock powder in the growth medium on various crops like oats, timothy, red clover and rye grass showed that there was substantial increase in available K content through out the period (Baerug, 1991).

Greater concentration of secondary nutrients *viz.* Ca, Mg, and available micronutrients *viz.* Fe, Mn, and Zn was observed in soils treated with 10 t ha $^{-1}$ rock dust along with equal quantity of FYM and kept for 15 days. The role of micro organisms in dissolution of minerals has been well established. The solubilisation of P from phosphate rock by micro organisms like *Bacillus* sp had been reported. Similarly the organic acids or chelating agents such as α 2- keto gluconic acid produced during the decomposition of organic matter helped in the release of nutrients from applied rock or insoluble minerals in the soil, (Russel, 1988). Improved uptake of Fe and Mn by crops through microbial intervention involving the chelating agent had been reported by Russel (1988). Russel further opined that micro organisms were also involved in the enhanced weathering of alumino silicates through the removal of divalent cations and the solubilisation of silica, which was observed on newly exposed rock faces. This can be attributed to the increased availability of Ca, Mg, Fe and Mn in soils supplied with equal quantity of rock dust and FYM. The percentage increase in Mg content in soil at tuberization stage was 20 per cent when compared to the chemically treated plots. The increased availability of Fe content was 78.67 per cent at tuberization and 74.50 per cent at harvest due to the application of rock dust in coleus. The increase in available Mn content due to rock dust application was 17.55 and 55.00 per cent in coleus during tuberization and harvest stages respectively.

An important outcome from the study is that priming rock dust with FYM two weeks prior to field application resulted in higher nutrient release from rock dust. The pH and available N content were found to be increased due to priming. Apart from this, the highest value for available P and K content at tuberization and harvest were recorded by this treatment. A high concentration of Ca, Mg, Fe, Mn and Zn was obtained for the particular treatment.

Priming of rock dust with FYM for two weeks before field application has been claimed to increase its efficiency in increasing the soil pH, available N, P, K, Ca, Mg. Fe, Mn and Zn content apart from increasing the leaf chlorophyll concentration and producing better plant spread. The percentage increase due to priming ranged from 1.80 to 3.77 per cent in pH, 10.08 to 15.08 per cent in available N, 1.7 to 5.2 per cent in available P, 6.97 to 12.18 per cent in available K, 8.53 to 10.54 per cent in available Fe and 17.55 to 55.02 per cent in available Mn content in soil.

5.3 ECONOMIC ANALYSIS

Economic feasibility of using rock dust for nutrient management of coleus revealed that application of 10 t ha $^{-1}$ along with equal quantity of FYM registered the highest B:C ratio and was on par with the same treatment with 15 days priming (T_5) and the recommended dose of nutrients (T_1). Reducing the recommended dose to 75 - 50 per cent with application of FYM and rock dust did not cause any reduction in the economic returns indicating the feasibility of reducing the nutrient recommendation up to 50 per cent in conjunction with rock dust. Rock dust being locally available and comparatively cheaper in price can substitute the chemical fertilizers without deleterious effect on the returns. Reducing the fertilizer recommendation to 75 per cent or 50 per cent reduce the cost of cultivation without any appreciable yield reduction thereby enhancing the net income. Similar improvement in economic returns by using rock dust as a substitute for chemical fertilizers was also reported from the experiments on cassava by Shehana (2006)

SUMMARY

6. SUMMARY

An investigation entitled "Rock dust as a nutrient source for coleus *(Solenostemon rotundifolius)* was carried out at the College of Agriculture, Vellayani during 2006 - 2007 to monitor the nutrient release pattern from rock dust under laboratory conditions and to study the influence of rock dust application either alone or in combination with FYM and chemical fertilizers on the growth and yield of Coleus, variety Sreedhara released from CTCRI, Sreekariyam. The salient results of the study are summarized below:

Incubation study

Representative soil samples from the field of Instructional Farm, Vellayani was incubated at 60 per cent of field capacity under laboratory conditions for a period incubation of 180 days to study the pattern of solubilisation of major as well as micronutrients from rock dust applied both alone and with FYM .

The periodical changes in pH and available nutrients with progressive incubation were monitored. There was an increase in the pH of the soil during the initial period extending up to 45 days and a more or less uniform pH was maintained there after. pH of the incubated soils where rock dust @ 8, 10 and 12 t ha $^{-1}$ was applied along with equal quantities of FYM was higher when compared to the treatments with rock dust alone.

Application of rock dust at a higher rate *i.e.* 12 t ha $^{-1}$ along with equal quantity of FYM resulted in the maximum release of almost all the nutrients *viz.* N, P, K, Fe, Mn, and Zn through out the incubation period.

Addition of rock dust along with equal quantity of FYM resulted in percentage increase from 7 to 17.5, 19.50 to 29.22, 22.95 to 45.38, 10.47 to 14.14, 15.58 to 26.36 and 1.3 to 8.6 for available N, P, K, Fe, Mn and Zn respectively when compared to the application of rock dust alone.

Application of rock dust at different rates *viz.* 8, 10 and 12 t ha $^{-1}$ resulted in corresponding increases in available P, K, Fe, Mn and Zn in the soil.

The solubility of available N was found maximum during 30th day of incubation and for P, the highest value was recorded during 120th day of incubation. The release of

K was found to increase over time reaching the maximum during the later part of the study.

The pattern of solubilisation of micronutrients *viz.* Fe, Mn and Zn revealed that there was a gradual increase in the concentration of these nutrients during the early period of experiment reaching the highest values during the later stages of incubation.

Field experiment

The salient results from the field experiment conducted to evaluate the efficiency of rock dust in providing the nutrients to coleus and its effect on growth and yield of the crop are summarized below.

The plant growth characters like number of branches per plant at 90 DAP and plant spread at 60 DAP showed significant variation due to the application of rock dust @ 10 t ha $^{-1}$ mixed with equal quantity of FYM and kept for 15 days before the field application.

Leaf chlorophyll concentration was increased by 47.36 per cent due to the application of rock dust when compared to POP recommendation.

Yield component like number of tubers per plant was also increased by 14.81 per cent due to the application of rock dust.

Application of rock dust @ 10 t ha $^{-1}$ along with equal quantity of FYM produced almost similar yield (16.58 t ha $^{-1}$, with a B: C ratio of 2.89) as that of POP recommendation (19.55 t ha $^{-1}$, with a B: C ratio of 2.63).

Application of rock dust @ 10 t ha $^{-1}$ along with equal quantity of FYM and 50 per cent of the chemical fertilizers, *i.e.* NPK @ 30:30:50 kg ha $^{-1}$ also produced yield (17.26 t ha $^{-1}$, with a B: C ratio of 2.63) equivalent to POP (19.55 t ha $^{-1}$, with a B. C ratio of 2.39). This treatment also produced highest number of tubers per plant, dry matter content of plant parts and total dry matter production.

The starch content and cooking quality of the tubers were also favoured by the application of rock dust @ 10 t ha $^{-1}$. Starch content increased by 35.02 per cent due to the application of rock dust.

Rock dust application resulted in the percentage increases of 34.55 to 43.12 P, 47.96 to 58.49 K, 20 Mg, 17.55 to 55.00 Fe, 74.50 to 78.69 Mn and 20 per cent Zn respectively when compared to the application of inorganic fertilizers in coleus.

Priming rock dust with FYM two weeks prior to field application resulted in the maximum release of P, K, Ca, Mg, Fe, Mn and Zn.

Rock dust @ 10 t ha^{-1} along with equal quantity of FYM resulted in highest returns per rupee invested (B: C ratio 2.89).

The study revealed that 50 to 100 per cent substitution of inorganic fertilizers with rock dust can be recommended provided it is applied along with FYM where ever it is locally available. It can be concluded that rock dust being cheaper and environment friendly it can be recommended as an effective alternative to inorganic fertilizers to a certain extent.

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ABSTRACT

ROCK DUST AS A NUTRIENT SOURCE FOR COLEUS
(*Solenostemon rotundifolius* (POIR) MORTON)

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Abstract of the
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ABSTRACT

The effect of application of rock dust at different rates alone as well as in combination with FYM and chemical fertilizers and the resultant effect on growth and yield of Coleus (*Solenostemon rotundifolius*) var. Sreedhara was evaluated by conducting a laboratory incubation study and field experiment at College of Agriculture , Vellayani during 2006- 2007.

The results of the incubation study revealed that increasing the rate of application of rock dust resulted in an increase in the available nutrient contents of soil. Application of rock dust in conjunction with an equal quantity of FYM also enhanced the availability of all the major as well as minor nutrients. The pattern of release of available N was found maximum during 30^{th} day of incubation and for P, the highest value was recorded during 120^{th} day of incubation. The release of K was found to increase over time reaching the maximum during the later part of the study. The pattern of solubilisation of micronutrients *viz.* Fe, Mn and Zn revealed that there was a gradual increase in their concentration from the start of experiment, reaching the highest values during the later stages of incubation. Application of rock dust at a higher rate *i.e.* 12 t ha^{-1} along with an equal quantity of FYM resulted in the maximum release of almost all the nutrients *viz.* N, P, K, Fe, Mn, and Zn through out the incubation period. Addition of rock dust along with an equal quantity of FYM resulted the percentage increases from 7 to 17.5, 19.50 to 29.22, 22.95 to 45.38, 10.47 to 14.14 15.58 to 26.36 and 1.3 to 8.6 respectively for available N, P, K, Fe, Mn and Zn when compared to the application of rock dust alone.

The results from the field experiment conducted to evaluate the efficiency of rock dust revealed that the plant growth characters like number of branches per plant at 90 DAP and plant spread at 60 DAP showed significant variation due to the application of rock dust @ 10 t ha^{-1} mixed with equal quantity of FYM and kept for 15 days before the field application. Leaf chlorophyll concentration was increased by

47.36 per cent due to the application of rock dust when compared to POP recommendation. Yield component like number of tubers per plant was also increased by 14.81 per cent due to the application of rock dust. Application of rock dust @ 10 t ha $^{-1}$ along with equal quantity of FYM and 50 per cent of the chemical fertilizers NPK @ 30:30:50 kg ha $^{-1}$ also produced yield (17.26 t ha $^{-1}$, B. C ratio 2.63) equivalent to POP (19.55 t ha $^{-1}$, B. C ratio 2.39). This treatment also produced the highest number of tubers per plant, dry matter content of plant parts and total dry matter production. The highest yield of 19.55 t ha $^{-1}$ was obtained for POP recommendation. But application of rock dust along with half the recommended dose of NPK and FYM also produced the similar yield as (17.26 t ha $^{-1}$) that of POP recommendation. This shows that partial substitution (50 per cent) of chemical fertilizers with rock dust can be recommended to the farmers where ever it is locally available.

The starch content and cooking quality of the tubers were also favoured by the application of rock dust @ 10 t ha $^{-1}$. Starch content increased by 35.02 per cent due to the application of rock dust. Priming rock dust with FYM two weeks prior to field application resulted in the maximum release of P, K, Ca, Mg, Fe, Mn and Zn from rock dust. Rock dust application resulted in the percentage increases of 34.55 to 43.12, 47.96 to 58.49, 20, 17.55 to 55.00, 74.50 to 78.69 and 20 for P, K, Mg, Fe, Mn and Zn respectively when compared to the application of inorganic fertilizers for coleus. Rock dust @ 10 t ha^{-1} along with equal quantity of FYM resulted in the highest returns per rupee invested (B.C ratio 2.89).

It can be concluded from the results of the study that the present recommended dose of in organic fertilizers for coleus can be reduced to half provided it is applied along with rock dust @ 10 t ha $^{-1}$. 100 per cent substitution of chemical fertilizers with rock dust 10 t ha $^{-1}$ and FYM 10 t ha $^{-1}$ can be recommended for coleus wherever rock dust is locally available.

APPENDIX

Appendix -I

Weather data during the experimental period (September 2006 to march 2007)

Period	Maximum temperature ^0C	Minimum temperature^0c	Rain fall mm	Relative humidity Per cent
September 2006	30.18	23.08	5.27	86.33
October	30.06	22.80	8.75	88.25
November	30.31	22.78	10.80	87.56
December	31.40	21.80	5.70	83.20
January 2007	31.39	21.00	3.00	78.24
February	31.80	21.20	0.60	77.10
March	32.70	23.40	2.20	76.00