USE OF STJERNØY'S ROCK POWDER AS A SLOW RELEASING PHOSPHORUS AND POTASSIUM FERTILIZER IN WHITE CLOVER

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Summary

Plant availability of K and P from biotite and apatite present in the carbonatite rock formation of Stjernøy, was investigated in a pot experiment with white clover. The pot experiment consisted of nine different treatments that included apatite and biotite alone or in combination with chemical fertilizers, lime alone or in combination with PK- fertilizer and PK-fertilizer alone, all added to a low fertility sandy soil. Each treatment had four pot replicates and four subsequent herbage cuts and stolons were sampled. Dry matter yield, concentrations and uptake of K, P and other elements in the herbage and stolons was analysed. Plants were grown in an artificially lighted growth chamber in Jord laboratory, UMB, Norway.

All treatments with rock application maintained high K concentration (> 25 g kg^{-1}DM) in the herbage. Application of rock powder with a full dose PK-fetilizer gave highest total yield (23.1 g pot^{-1}), highest total K-uptake (769 mg pot^{-1}), and higher uptake of Mg and Ca than rock alone. This study concludes that biotite releases K at rate that easily matches requirements by plants. On the other hand P bounded in magmatic apatite was not taken up by plant, and the presence of carbonatite reduced the availability of P present in the soil or added as soluble fertilizer in the sandy soil with low buffering ability. All plants receiving P fertilizer had significantly higher DM yield and improved K uptake compared to similar treatments without soluble P. This biotite carbonatite rock used alone as a fertilizer is not feasible for plant production. It was also found that plants easily absorbed nutrients from the applied fast-released soluble salts with no longer effect on plant availability. Further investigation needs special knowledge on mineral weathering processes and soil reactions especially enhancing P solubility for better understanding the potentiality of applied carbonatite rocks, relationship between nutrients released and plant uptake.

Abbreviations

K	Potassium
P	Phosphorus
Ca	Calcium
Mg	Magnesium
S	Sulphur
Ba	Barium
Sr	Strontium
CEC	Cation exchange capacity
C1	Fertilized
C2	Lime fertilized
C0	Lime unfertilized control
R1	Apatite
R2	Biotite
R1+C1	Rock fertilized
ABC	Apatite-Biotite-Carbonatitite
PR	Phosphate rock
RP	Rock powder
DM	Dry matter yield
LAC	Lillebukt alkaline complex
SIP	Seiland Igneous Province

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1 Introduction

Continuous farming declines soil production capacity that ultimately demand for the nutrient inputs in order to increase soil fertility for future crop production. Land degradation, soil erosion, deforestation, removal of vegetation or herbages particularly on sandy soils, and soil infertility are major problems leading to a failure on agriculture production (Ayoub 1999). This has compelled farmers to rely on various alternative nutrient sources such as organic manures, mineral fertilizers and rock-fertilizers Naturally available geological minerals (phosphate rocks, potassium salts and others) either in processed or in raw forms are identified as locally useful rock fertilizers, and are more applicable for the purpose of sustainable soil management and agricultural production (van Straaten 2002). A slow release of igneous grounded carbonatite rock from Stjernøy enriched with both apatite and biotite minerals have promising effect over long term nutrient availability of Potassium (K), Phosphorus (P), Magnesium (Mg) and Calcium (Ca) (Heim et al. 2010). This study suggested that these minerals are regarded as an agricultural lime with approximately 30% biotite, 40% calcite and 7.5% apatite consisting of K (2.6%), P (1.3%) and Mg (2.1%). This has capacity to ameliorate ion exchange capacity in soils and increases soil pH (Harley & Gilkes 2000).

In Nordic countries, the adverse environmental effects of fast soluble synthetic fertilizers might be controlled by promoting use of rock powders as major inputs for agricultural crops, which is public concern for sustainable soil fertility management (Heim et al. 2010). Nutrients release from rock powder remains in upper horizon of soil profile and are easily available to the plants (Harley & Gilkes 2000). Therefore, rock fertilizer in crop production is economically and ecologically viable means to adopt in organic farming especially in highly weathered and sandy soil than the conventional farming practices on the areas where only highly expensive commercial fertilizers are prioritized (Heim et al. 2010). Plants have shown a positive improvement in nutrients uptake by use of carbonatite rock powder (Bleken et al. 2008). Their study also found that there was higher uptake of K, P, Mg, Ca and S from biotite while apatite significantly has not shown much effect on P uptake in case of white clover. Use of higher amount of biotite has negative effects on P uptake. Carbonates containing biotite can surprisingly release higher amount of K in course of time than rock minerals (Bakken et al. 2000; Bakken et al. 1997; Heim et al. 2011). Furthermore, Heim et al. (2011) also pointed out that biotite combined with apatite has given P, K and Mg compounds whereas apatite alone showed a negative effect on P release in the limed soil.

Major constraint to crop production is a deficiency of available P in several agricultural soils where conventional fertilizers are unavailable or not easily affordable to farmers. Use of apatite is more challenging in such cases to replenish P level in soil (Wallander et al. 1997) since release of P from magmatic apatite through weathering is much slower at a high pH due to its lower dissolution nature, and therefore does not provide enough P to the crops as per their requirements (Heim et al. 2010; Heim et al. 2011). This is considered as one of the major problems for sustainable agriculture production. However, there was a potential growth of crops noted and after using basic P fertilizers, P still remained in soil with no P fertilization required even after 20 years, indicating a positive effect of apatite over a long run (Silfverberg & Hartman 1999).

Low solubility nature of the crushed rock is limiting mineral efficacy and prohibits its extensive use (Harley & Gilkes 2000). Several factors such as soil microbial activities, soil moisture, soil pH, particles sizes etc. affect P release in soil. Nearly 50% of ABC carbonatite by volume is occupied by calcite. Therefore, Heim et al. (2010) recommended separating apatite and calcite before applications by dry mineral separation so that removal of calcite can almost doubly raised the concentrations of K (5 %), P (2.5%) and Mg (4%), respectively (Heim et al. 2011). Later Heim et al. (2011) also ascertained that a dissolution of biological P accelerates preferably at low soil pH and buffer capacity. Furthermore, their study provided an evidence that increases in soil acidity, reduction in Ca content and supplement of adequate amount of organic matter that can enable rate of phosphate rocks (PR) dissolution. In addition, organic acids produced in rhizosphere can create ideal soil conditions for solubility of apatite. Other several studies have also declared that the globally adopted biological means as a phosphorus composting and crop genotypes enriched with P facilitates P solubility (Heim et al. 2011).

According to Harley and Gilkes (2000), in-situ techniques were recognized as effective approaches to study on the rock powder for determining geochemical reactions. The soil mineralogy, grain size, and solubility rate of silicate rock powders in relation to different cropping systems can be studied under this scheme. In advance, it is an important aspect of determining a release of nutrients for which grain size during rock powder preparation is the most influencing factors to be undertaken for the potential agriculture use. Specific surface of rocks and their mineralogy in association with nutrients availability need be considered for further investigation (Harley & Gilkes 2000).

Many investigations on the rock powders have already been carried out in different parts of Norway. However, main aim of this study is to find effectiveness of applied Stjernøy`s grounded carbonatite rock enriched with both apatite and biotite on K, P and other elements (Ca, Mg and S) availability and their uptakes in white clover (*Trifolium repens* L. cv Milkanova) grown in low fertility sandy soils. It is expected that this study will further support the concepts forwarded by many researchers and conclude the need for conducting further investigation on the grounded carbonatite rock.

2 General Part

2.1 Rock mineralogy

2.1.1 Potassium (K) bearing rocks and minerals

Potassium is released from K silicate minerals in indigenous soils. Primary K-silicate minerals are formed by igneous and metamorphic processes under high temperatures. However, secondary K-minerals, e.g. clay minerals, are formed by weathering at low temperature (Manning 2009). According to Van Straaten (van Straaten 2007), K is abundant in the earth crust and is usually combined with silicate minerals like:

1. Feldspars
2. Micas: biotite, muscovite
3. Feldspathoids: leucite and nepheline
4. Clays: illite, i.e. clay mica.

The clay minerals provide the exchangeable K in soils containing less organic matter, in intensely weathered and highly oxidized soils. K-silicate minerals are mostly available in combined form with other silicate materials. Potassium feldspar is the integral component of granite rocks and these also contain biotite and muscovite (Manning 2009).

The main potassium reserves for fertilization prospects are soluble K-sources (chlorides and sulphates). Concerning the substitution of soluble K-salts by K-silicate resources like ultrapotassic volcanites or phlogopite/biotite resources, adequate studies have not been done. Plentiful of these resources can be found in the ground as uncured rock material and also as waste material from mining workings, like mining works of igneous phosphates in Siilinjarvi, Finland, Phalaborwa, South Africa and Brazil and also mica workings in Sri Lanka (van Straaten 2007).

One of the most typical minerals, K-feldspar, is present in three dimensional complex of silica (SiO_4 and AlO_4) tetrahedra where Al^{3+} substitution for Si^{4+} lessens the density of positive charges that is neutralized by the interstitial cations of Na^+, K^+ or Ca^{2+}. K-feldspar is prevalent among alumosilicate minerals and commonly exists in numerous rock types (sandstone, granite, gneisses etc.). The alumosilicates dissolve by hydrolysis reaction that occurs on the surface of minerals. However the thermodynamic stability of K-alumosilicates differs based on kinetics of their dissolution reaction (Manning 2009). K-feldspars have a weathering resistant structure lattice. Due to strong bonding framework of K in the K-feldspars, release of K from K-feldspars is much less as compared to the K-bonding structure of micas and the clay mica illite. On the other hand, micas and micaceous clay group minerals which have weaker bonding nature in mineral lattice release K very easily and rapidly (van Straaten 2007). However, the structural framework of micas is complex. Here K is found in association with silica tetrahedral sheets and aluminum (muscovite) or magnesium/iron (phlogopite/biotite) octahedral sheets. Unlike biotite or phlogopite, muscovite micas are tightly packed so weathering of these is definitely slower. Thereupon, release of K from muscovite is lesser. Mg, iron (Fe) and K are released through weathering from biotites and phlogopites (van Straaten 2007). The structure of biotite is shown in Figure 1.

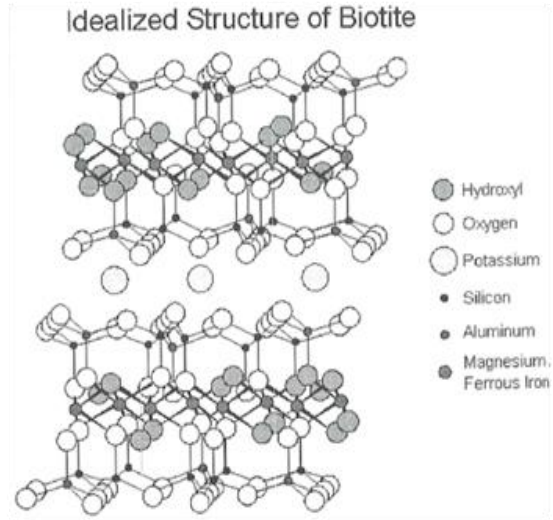

Figure 1: Biotite mineral Structure (with respect to Dr. L. Evans, University of Guelph, 2004) (Adapted from van Straaten 2007).

Minerals of feldspathoids namely, leucite, nepheline and kalsilite particularly occurs in silica undersaturated volcanic rocks, the alkaline rock group. Among these, leucite is one which contains most K (20 to 21%) with high soluble property. Rocks with leucite exist globally in East Africa, China, Brail, Indonesia and the United States. Survey showed that nepheline or leucite enriched rock materials are still not used in agriculture. According to Van Straaten (2007), these highly K-possessing rocks can be the a significant K-source when applied directly as fertilizer.

As based upon the statements of trials conducted on the mineral dissolution rates; dissolution rates of mineral nepheline are 100 times faster than feldspar. This suggests that rock powders

produced from nepheline can be a more potential source of potassium for plant growth than granitic rocks although with high K content. This fact was further supported by a crop experiments which proposed that uptake and availability of K from nepheline-bearing silicate rocks (containing K) was better than from granite rocks. K feldspar/ crushed granite is suitable to apply on highly leached soils, giving yields close to conventional fertilizers (Manning 2009).

Consequently, K from crushed biotite/nepheline-carbonatite is more accessible than K from K-feldspars. Carbonatites, agronomically determined as a lime with K, P, Mg constituents (Heim et al. 2011). In cultivated soils with ambient temperatures, pH and moisture conditions, K release from biotite and nepheline are higher than feldspar. The dissolution of carbonates is faster than silicates in several environments. Therefore, the release of K is quicker in rocks containing higher carbonate as they disintegrate faster by weathering as compared to pure silicate rocks (Bakken et al. 2000).

In developing countries, conventional soluble salts are widely applied to meet world's potash demand. Potassium silicate rocks are good sources of K nutrient for maximum plant yield as they can be readily utilized by plants. According to Manning (2009), it is suspected that as compared to readily available K salts from conventional fertilizers, slow weathering of feldspars and feldspathoids cannot provide enough K to soils and thus, in turn cannot contribute for plant growth.

2.1.2 Phosphorus (P) bearing rocks and minerals

The main source of phosphate fertilizers in world are phosphate rocks which contains the mineral apatite. Rock phosphates are geologically found as both sedimentary and igneous deposits. The rocks containing significant phosphate contents generally comprise of group of minerals called apatites as principal phosphate bearing material. Apatites are chemically very complex and variable. In sedimentary deposits (phosphorites), high concentrations of apatite series occurs however, and igneous deposit contain apatite as less abundant accessory minerals (Mayhew 2003). Sedimentary marine phosphate rock deposits allocate approximately 75 % of the global phosphate reserves, igneous and weathered deposits provide 15-20%, and 1-2% are allot from biogenic resources, mainly bird and bat guano collections (van Straaten 2002). Distribution of world's major phosphate deposits is shown in Figure 2.

Depending upon the mineral, chemical and textural properties, phosphate rocks vary widely. Among more than 200 different types of recognized phosphate minerals, the apatite group is the principal phosphate. These calcium phosphates are primarily found in the environments of sedimentary, metamorphic and igneous rocks and also in weathering environments. The remaining phosphates consists of crandallite group minerals together with variscite and strengite and are mainly available in environments of sedimentary weathering and includes Fe- and Al- phosphates (van Straaten 2002). Phosphate minerals mainly existing in the environment encloses such as Fluor-apatite (Ca_{10} $(PO_4)_6F_2$). They mostly occur in igneous and metamorphic environments, for instance, in carbonatite and mica-pyroxenites.

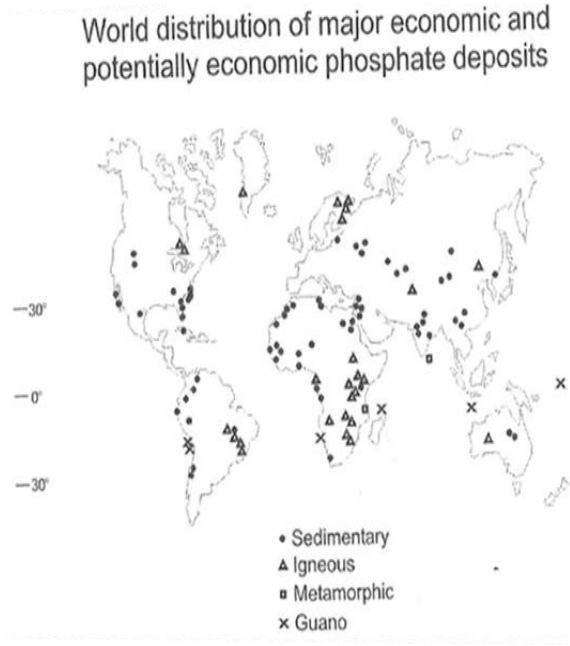

Figure 2: World's main phosphate deposits distribution (Adapted from van Straaten 2007).

The world distribution of carbonatite complexes in relation to major fold belts is shown in Figure 3. Carbonatites contains more than 50% of carbonate minerals (calcite, dolomite, magnesite or Fe-carbonate) and are intrusive and widely spread igneous rocks. Carbonatites are often exposed in the outer part of extensive granitic cratons and folded belts. They are connected with frequent regenerated faults and shear zones such as rift valleys and are likely to hold ring structures having diameters of 2-15 km. Remote sensing techniques can detect these ring structures from the air. The significant amount of carbonatites together with igneous phosphates are present in Brazil, Eastern and Southern Africa (at the East African Rift Valley), Kola Peninsula (in Russia and Finland) as well as in eastern and central Canada (van Straaten 2006). The sketched in Figure 4 represents the phosphate distribution and remaining minerals within carbonatite intrusions.

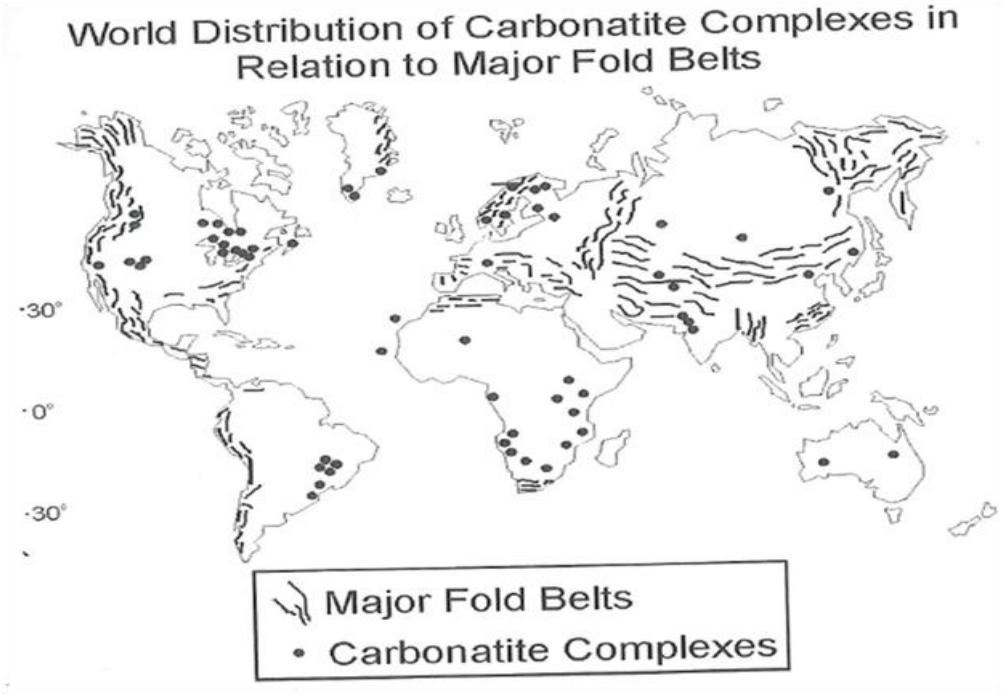

Figure 3: Carbonatites distribution in the world in connection to main fold belts (Adapted from Straaten 2007).

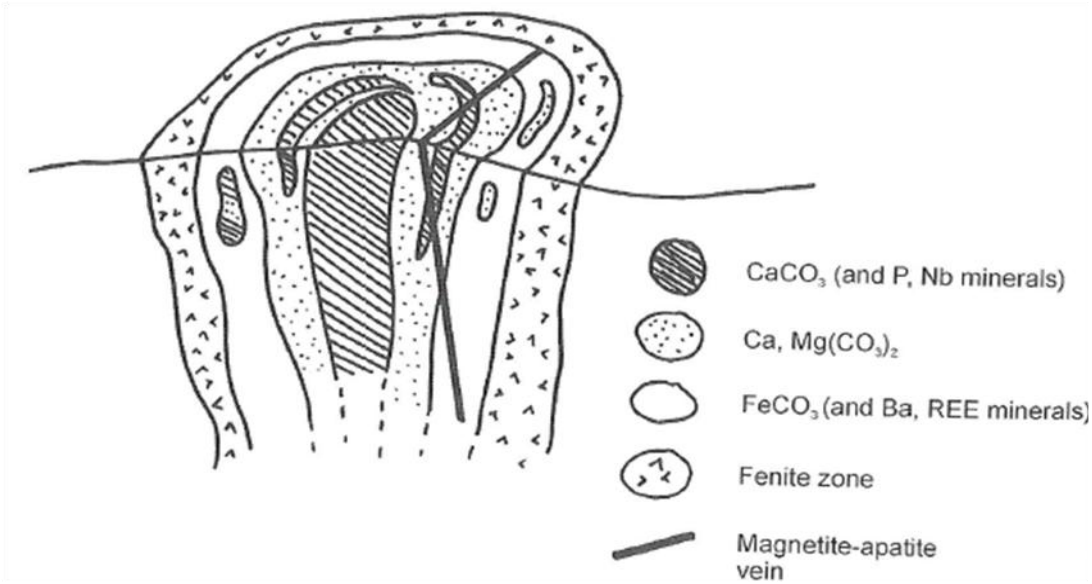

Figure 4: Structure of carbonatite ring with its major phases and associated mineralization (Adapted from van Straaten 2007).

2.1.3 Stjernøy`s biotite carbonatite

2.1.3.1 Geological formation of carbonatite

The geological map of the Northern Norway is represented in Fig. 5a. Stjernøy contains the Lillebukt alkaline complex (LAC) which is located in the centre of the Seiland Igneous Province (SIP). On Stjernøy, apatite-biotite-carbonatite (ABC) is found Fig. 5b.The mafic to ultramafic SIP was intruded at middle crust levels in late Neoproterozoic (570 Ma).This is part of the Caledonian Kalak Nappe complex, that was metamorphosed and thrust during the Scandian phase at nearly 420 Ma. The LAC (13 km^2), as shown in Fig. 5b also includes nepheline-syenite that has been mined to be used in glass and ceramics for 50 years, in addition to fenitized mafic and syenitic rocks, as well as surrounding hornblende-pyroxenite (Heim et al. 2011).

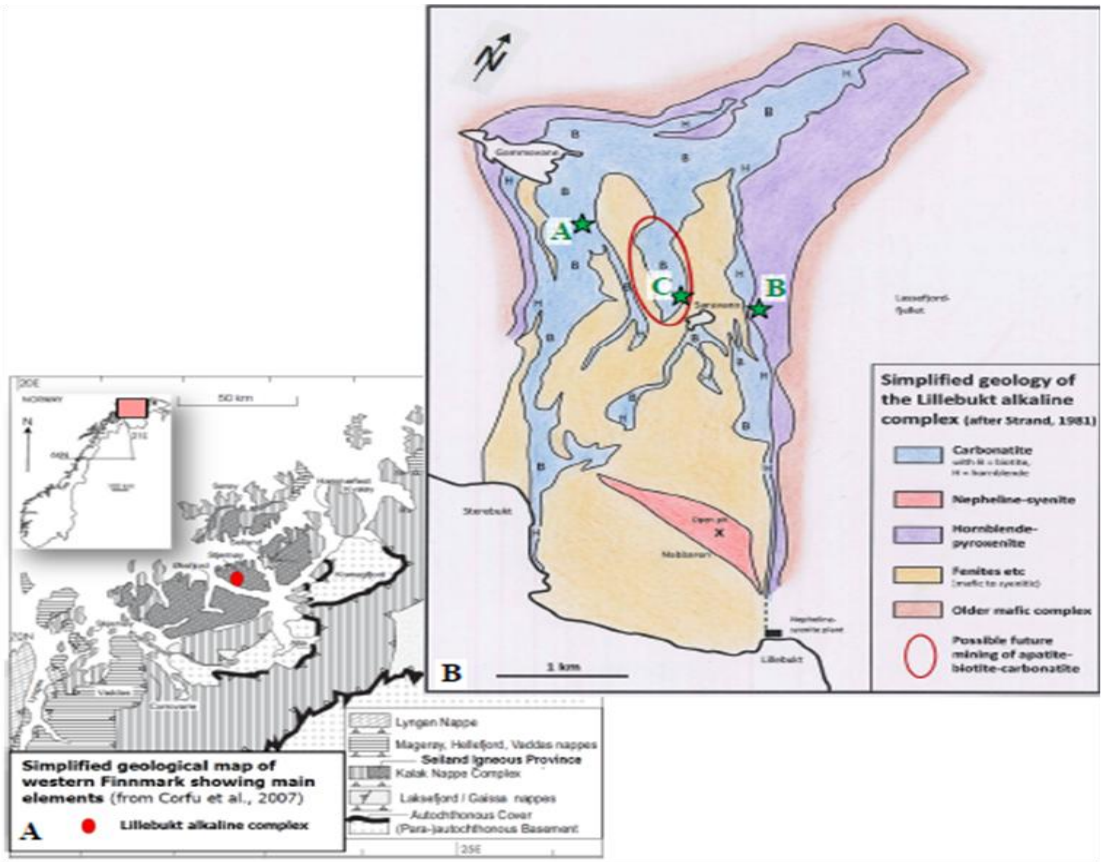

Figure 5: (a) Geotectonic units with Lillebukt alkaline complex on Stjernøy centrally located at Seiland Igneous Province, western Finnmark, Northern Norway. (b): Geological field of the Lillebukt alkaline complex, holds apatite- biotite- carbonatite which are appropriate for mining and that are potential to be use as rock fertilizers (Adapted from Heim et al. 2011).

There is a complex distribution of rock inside the LAC because of both primary and secondary genesis as carbonatites are centered to Northern Norway. Biotite is the dominating silicate in the center of the carbonatite and hornblende close to the pyroxenite. Biotite/ hornblende and calcite found in alternating layers are building up in between centimeter and decimeter scale. The rocks containing nearly 40 % by weight of carbonate are grouped as silico carbonatite. Apatite is the main component of Ca-enriched bands. The remaining distinguishable minerals are nepheline, alkali-feldspar, Fe-Ti- oxides, titanite and sulfides. The texture of rocks mainly biotite have coarse to very coarse type of grains. In the soil profile, a thick layer of biotite is formed by the chemical and mechanical weathering (Heim et al. 2011).

2.1.3.2 Rock composition and mineralogy

The geological survey in Norway extended drill sampling in 2008. Based upon the chemical composition of rocks the average mineral content is: biotite 30 %, apatite 7.5% and calcite 42%. This corresponds to Ca (19%), K (2.6%), P (1.3%) and Mg (2.1%) approximately, thus considered as an agricultural lime with an additional K-P-Mg fertilizing potential (Heim et al. 2011) .

The research conducted on the focus areas of Stjernøy has shown remarkable results. For instance, the extractions with ammonium lactate received from the soils on apatite-biotite-carbonatite, illustrate that the soil nutrients such as Ca and Mg, easily available to plants, are categorized as high to very high. However, P and K available to plants are determined as average or low (Heim et al. 2011).

Carbonatite rocks on Stjernøy contain biologically toxic elements like Barium (Ba) and Strontium (Sr) in high concentrations, corresponding to 2.7 and 4.2 g kg^{-1} in the targeted area and available in local sites is above 10g kg^{-1}. Ba is substituting K in biotite (up to 10 % of K sites). Sr is abundantly found in calcite (up to 2 % of Ca sites), and the remaining is bound to apatite (Heim et al. 2011).

2.2 K and P in soils

2.2.1 K in soils

Potassium in soil can be divided into four fractions with plant availability. Potassium is in readily available, slightly available and unavailable forms in equilibrium in soil system. They are enlisted as: soil solution K (0.1 to 0.2 % of total K), exchangeable K (1-2%), non-exchangeable/fixed K (1-10%) and mineral/structural K (90-98% of total clay) (Mclaren &

Cameron 1990). Among them, soil solution K and exchangeable K is readily accessible to plants for their growth whereas fixed K is usually regarded as slowly available and structural K is mostly unavailable. Soluble fraction of soluble K is found to be lower in organic soil than conventional soil (Mader et al. 2002) .

K release in soils primarily depends upon the type and content of K-bearing minerals. K in feldspar is strongly bound (covalently) in the crystals structure and is hardly released by weathering. Micas together with hydrous micas posses a layer framework, and there K is bound within the sheets through electrostatic forces (fixed K or interlayer K). The two different processes for K release from micas are; crystal structure dissolution or exchange of interlayer K for hydrated cations by which, K-bearing micas transform to expandable sheet silicates. By reason that K taken up by plants and leaching, there is reduction in the concentrations of soil solution K and exchangeable K by which the release of interlayer K can increases (Falk Øgaard & Krogstad 2005). Removal of fresh plants materials from the field also leads to high K losses (Beck & Sanchez 1994).

Soil K status in addition to the actual K removal from harvested plant material and leaching ought to be known accordingly in order to manage K deficiency. Soils containing little clay enable K unavailability to crops to a greater extent rather than the clay content soils since both K release and K leaching is keenly associated to the clay content (Askegaard et al. 2006). With respect to K availability, huge difference is noticed in between the soils. Applied K in high proportions on sandy results increased leaching. Inadequate K supply affects nitrogen fixation in legume plants and decline the soil fertility too (Kayser & Isselstein 2005). Increase in soil dispersion due to excess K fertilizer and hence, decrease infiltration rates can increase the soil erodibility. Because of over-fertilization, K content of agricultural land expands. This over-fertilization leads to contamination of water due to surface runoff, leaching and erosion.

2.2.2 P in soils

Usually, soil P is found in unavailable form or can be available in form outside of the rhizosphere even though the total soil P content is high. More than 80 percent of P is immobile and are not readily available to plants for uptake due to adsorption, precipitation or in organic form conversion (1998). This property of soil reduces P leaching in many soils (Holford 1997).

Soil P is found in different organic and mineral pools. About 20 to 80 percent of soil P is present as organic P. The remaining are found in the inorganic fraction consisting of at least

170 mineral forms of P (Holford 1997). In many soils, organic P is the main and most reliable P component if the pH is acidic and content of organic matter and nitrogen are adequate in amount (Holford 1997). Soil under pasture had 50-84% portion of P in organic form. With the decrease in pH, plant available P is found to be decreased as well (Bolan & Hedley 1990). Organic forms of P are mineralized by the microbes into the soil solution and accelerate the P immobilization processes in soil. High plant uptake rate can built the P depletion zone around the root surface as the diffusion rate of P is slow i.e. (10^{-12} to $10^{-15}$$m^2$ s^{-1}) (Schachtman et al.1998) .

Sekhar & Aery (2001), indicated that soil can fix available phosphates into the unavailable forms some days after application. In acid soils, phosphate ions is fixed by the Fe, Al and Mn (hydro)oxides of the soil whereas in alkaline soils, Ca and Mg oxides are responsible for the same action. P availability can be increase by increasing the soil organic matter content. With no doubt, there is a release of humic acid during decomposition of organic substances and thus, convert unavailable forms of phosphorus into available forms. The favorable soil pH for P availability is mainly in between 5.5 and 7 (Sekhar & Aery 2001). To increase P uptake, plant root geometry and morphology is also important as this possess greater proportions of surface area to volume that explore the soil volume effectively (Schachtman et al. 1998) .

2.2.3 K and P trends in Norwegian soils

The surface of Norwegian soils is more compact in microstructure in case of agricultural soil compared with forest soil (Sveistrup 1992). Potassium content is found to be exchanged between topsoil and subsoil. Change in potassium fixation was best explained by the percentage of clay content in the soil. With the higher content of clay the application of potassium was found more effective with following years (Falk Øgaard & Krogstad 2005). After analyzing different mineral soils of Norway in three years, only sandy soils with a low level of acid soluble K shows the yield response to K fertilization (Øgaard et al. 2002).

P level in Norwegian top soil is lower than subsoil, which indicates that there is flow of P from top level to the sub layer of soil (Løes & Øgaard 2001). In South Western part of Norway two soil types were distinguished on the mineral soils-Brown Podzolic Soils and Iron Humus Podzols. The later is associated with a lower pH, lower P content (Provan 1973).

2.3 K and P in Plant nutrition

2.3.1 K in plant nutrition

K is an indispensable mineral nutrient that is essential for plant growth and for completing its life cycle. Plants need ample amount of K during early growth stages than the maturity stages. In fact, K is found as ion in solution and in organic crystals, but not as structural component of any plant tissue (van Straaten 2007). Plant analysis can be performed either to confirm a suspected deficiency indicated by visual symptoms or for monitoring the regular effects of a selected fertilization programs. K can be seen as major osmotic regulator and charge carrier of plant cells (Hirsch et al. 1998). K is highly mobile within the plant and its supply in the guard cells of stomata helps to regulate the opening and closing of stomata and the water uptake by root cells (van Straaten 2007). The integral roles of K in plants are in photosynthesis (Brady 1990), enzyme activation, starch formation and translocation of carbohydrates, improvement on water use efficiencies and many others (van Straaten 2007).

Figure 6: (Left) Potassium-deficient Maize leaf; (Right) K deficiency causes necrotic leaf edges of banana on right side and healthy leaf of banana on left side of the plant (Adapted from van Straaten 2007).

Inadequate K retards crop growth, reduces yield and impairs lignifications of vascular bundles which is responsible for lodging of plants (Marschner 1986). Chlorotic and necrotic visible symptoms (Figure 6) occur in older plant leaves and K is translocated from mature leaves and stems to younger leaves (Marschner 1986). Plants become extremely sensitive to certain diseases, frost and drought in K depleted cases (van Straaten 2007).

High use of K negatively affects on plant uptake of Mg and Ca leading to accelerated leaching of these cations (Kayser & Isselstein 2005). There is an uptake competition in between K and Ca or Mg or both for entry to plants. Soils which contain both of these nutrients or either one of these cations also require sufficient K nutrition to meet the nutrient

demand of crops (Samuel et al. 1985). High K induce health problems for milch animals like milk fever (hypocalcaemia) and grass tetany (hypomagnesaemia) (Kayser & Isselstein 2005). Hypomagnesaemic tetany is defined as a metabolic disorder which is caused abnormally by the lower level of Mg in the blood serum (Goff 2008). Hypomagnesemic animals required immediate treatments that includes Ca and Mg solutions (Brozos et al. 2011).

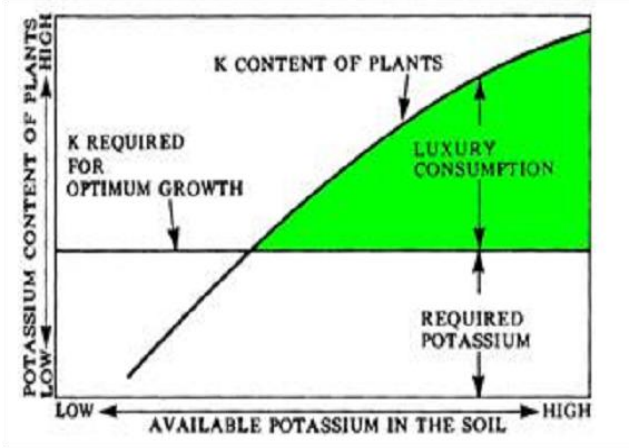

Figure 7: Relationship between potassium content in soil and potassium content in plants (Adapted from Spectrum analytic. 2003).

According to explanation from several researchers, K uptake by plants is more than as if required for ideal growth and so-termed as luxury feeding of plants on K. Luxury feeding is done for maximum yield. In case of alfalfa, luxury feeding helps to increase in amount of K content in the plants (Spectrum analytic. 2003). The process of luxury feeding could also be shown from the figure 7. Generally, K is removed from field by two ways; leaching down to root zone and by removal of harvested plant material. Various factors like drainage, soil texture and fertilization determine the amount of K leaching (Askegaard & Eriksen 2000).

The nutrient content in plant dry matter can be affected by the plant physiological age. In general, the young plants or plant parts contain a sufficient range of essential mineral nutrient concentration than the older plant (Marschner 1995). K required for the optimum plant growth is up to 2% of the dry weight of plant vegetative parts. K adsorption varies in between and within the plant species. Many others factor like soil properties, climate, fertilization and root volume can also be the cause that influence on plant nutrient uptake (Salomon 1999).

2.3.2 P in plant nutrition

As essential plant nutrient, P comprises about 0.2 % of plant dry weight. P is a key component of the molecules of nucleic acids, phospholipids, and ATP in plant cell (Schachtman et al. 1998). P is important in plants for performing various metabolic processes such as photosynthesis, crop maturation, nitrogen fixation, crop quality improvement (Brady 1990). Hogh-Jensen et al. (2002) reported that there is no growth at all upon acute P-

shortage. It is strongly bonded with soil particles resulting slow release and less availability at root surface. P deficiency symptoms seen in plants limit plant growth, appearance of dark-blue green color in mature leaves; inhibition of root development, poor seed and fruit set development as well as early senescence and delayed maturity. In condition of severe P-deprivation, the leaves edges and stems may become purple color (Figure 8), (van Straaten 2007).

Figure 8: Phosphorus deficiency causes purpling of leaf edges on maize (*Zea mays*) (Adapted from van Straaten 2007).

P is the basic mineral nutrient to determine yield among legumes. P-deprivation directly decreases photosynthetic processes in plants and thereupon affects leaf area development and subsequently impairs photosynthetic capacity per unit leaf area (Chaudhary et al. 2008). Severe P deficiency limits the nodulation and prevent the growth of nodules (Almeida et al. 2000). It is also reported that P inadequacy decrease leaf expansion and reduces the hydraulic conductance in plant root system (Chaudhary et al. 2008). P-content is higher in nodules than the concentrations hold by roots and shoot and also dry matter of root have higher P than shoots dry matter (Hogh-Jensen et al. 2002). According to Sa & Israel (1991), P-recovery can stimulates the symbiotic nitrogen fixation to the larger extent than host plant growth. The transformation of inositol phosphates, including phytic acid *(*myo-inositol hexakisphosphate) into plant nutrient P (orthophosphate) contribute understanding of P-cycling processes. This is of particular importance in P-burdened manure amended soils, where organic pools dominate (e.g., Histosols) or in soils with very low total P content (e.g., tropical soils), mention that inositol phosphates comprise up to 60% of soil organic P (Stevenson 1994).

2.4 Some consideration about P and K in organic farming

K and P nutrient depletion through mining by cultivation in soil are biologically reserved in the organic pools. Conventional farming systems have been criticized by highly promoting the use of synthetic fertilizers instead of replenishing the soil nutrients like P and K ecologically sustainable way. Irregular applications of P and K fertilizers like rock phosphate are endorsed in organic agriculture system and thus, conquer P and K reserves accusation

which was already mined by the conventional practices. Organically managed soils however, comprise a relatively less concentrations of extractable K and P which was reported after conversion to organic approach from the conventional farming system (Gosling & Shepherd 2005).

The use of farm yard manure, compost and green manures provides available P. P is released from the less supply of organic fertilizers like rock phosphate when applied as external sources. More soil P deprivation may occur when total P output increase considerably than the P input. These balances can be well estimated on the farm as well as field level. Increasing the content of clay reduces the P-AL concentration because the increasing ability of more clay content in slightly dissoluble forms can binds the soil P. The previous studies surmise that the organic farming for many years, showed that the larger volume explore by top soil are favorable for root growth of plants, increase the dissolution rate of organic P and transfer P from the top level to down horizons. The adopted farming systems and the amended fertilizers can make the big changes in soil P dynamics and these demands for further close research (Løes & Øgaard 2001).

Harvested crops removed more K and that results in insignificant level of K in many cultivated land. K potentiality in soil is mostly determined by its solubility rate. The slow release rate of K cannot fulfill the demand of high-yielding crops, but can be a great input for maintaining long term soil fertility status. The reliable K sources enhance organic crop production, with soluble minerals, like langbeinite, sylvinite and potassium sulphate. Besides, the other K sources are wood ash, greensand and sea weed and those are bulky in nature, less soluble, contain little nutrient and effects on soil pH. So, these materials require a suitable management. A number of rock minerals can give only a part of the K needed to plants however, many of them are very insoluble and they are less important for efficient use. (Mikkelsen 2007).

A 21-year survey report of central Europe illustrates about the agronomical and ecological attributes of biodynamic, bioorganic and conventional agriculture practices. The report showed that in organic systems, crop yields declined to 20% when fertilizer and energy input was minimized from 34 to 53% and input of pesticide up to 97%. Restoring of the soil fertility and immense biodiversity in organic field conditions was observed, as these methods can highly reduces the use of external inputs. On contrary to conventional systems, organic systems required 34 to 51 % less N, P, K, nutrient input with good productive attributes for long period of 21 years (Mader et al. 2002).

Land degradation, soil erosion and soil infertility is a major problem induced by inherent and human intervention leading to the failure on agriculture production, effects on human nutrition and thereby poverty. By the cause of nutrient depletion through surface run off and leaching, soil quality is deteriorating which also affects on sustainability. In these situations, by promoting rock powder as major inputs, soil fertility can be restored and thus can minimize the use of conventional expensive fertilizers (van Straaten 2006).

3 Review of Literature

3.1 Rock powder as slow release fertilizer

Rock powder can be use as slow release fertilizer in extensive agriculture system. Rocks release the desirable amounts of plant nutrients over several years. Rock powder focuses on organic farming, environmental issues and primarily acts as soil amendment fertilizer. Plant nutrients as K, P, Ca and Mg are slowly released from rock fertilizers which determine the potentiality of the crushed whole rocks or minerals while using as an agricultural input. Rock fertilizers are more superior to soluble industrial fertilizers in perspective of long term environmental conservation. High cost synthetic fertilizers and energy input have made the use of less expensive rock powders more effective (Heim et al. 2010).

These slow releasing minerals (apatite and biotite) are likely as alternatives to conventional fast release P, K and Mg salts as well as liming. Soil acidity is neutralized steadily by weathering of biotite, which improves the long term soil pH. In fields of the *Calluna vulgaris* and *Vccinium myrtillus* (heavy fertility area) types, with moderate and sustainable increase of soil pH was noticed from the application of apatite and biotite together. In the same manner, there was a moderate increase observed 5 years afterwards in five Scots pine strands in several geographical areas where compensatory fertilizers ; apatite (10%), biotite (60%) and Mg and Ca carbonates (20%) including 1000 kg ha^{-1} of lime and also without lime were used as a treatment. Compensatory fertilizers have increased the organic horizon soil pH from 3.6 to 4.0 while lime applied increased up to 4.7 (Aarnio et al. 2003).

Slow-release minerals gradually release the nutrients after their immediate application whereas the fast release salts move rapidly to downward horizons in soil, the organic horizon hold the ions (Aarnio et al. 2003). Use of slow release fertilizers (apatite/biotite/lime) increase the soluble P concentrations and exchangeable Mg^{2+} and Ca^{2+} in the top layer of mineral soil and controls soil nutrient losses occurred by leaching. From the trials, it was

accepted that the plants use the nutrients from slow-release fertilizers in which the compensatory fertilizers (apatite 10%, biotite 60%, Mg and Ca carbonates 20%) supplies huge amounts of P and K that was examined after fertilization for 5 years. The level of P has been significantly raised in foliage for continuously 20 years by use of rock phosphate (Aarnio et al. 2003).

Heavy use of soluble K fertilizers hinders Ca and Mg uptake by plants. So, slow release K bearing sources is more interesting and highly demanding today. In the Scandinavian countries, crushed rocks containing K-feldspar have been using K fertilizer in long run organic farming which is available in market under the trade name 'Adularia'. Some of the metamorphic rocks found in Norway are readily soluble K bearing minerals biotite and muscovite. It has not been mining and manufacturing commercially of such rocks yet for farming purposes in Norway (Bakken et al. 1997).

Experiments showed that biotite rich rock bears the fertility ability of K in soil for several years however the impact after soluble fertilizer such as potassium chloride (KCl) application had a short term remedies. There was a considerably increased in the plant growth from the area when biotite-carbonatite rock powder was applied in the green house and field K-fertilizing experiments use with crushed rocks and minerals (Bakken et al. 2000; Bakken et al. 1997). Under the high precipitation areas, KCl was used to forage grasses and thus was required to be added for many times in one season.

Application of selected biotite rich rock powder can enable organic farming deficient in P, K, Mg, Ca, and S. It can substitute liming application with wide spectrum advantages. In agriculture production systems, rocks and minerals can be used for various soil management purposes like fertility management, soil pH improvement, nutrients and water conservation and provide nutrients like P, K, Ca, Mg, S and micro-nutrients critical for plant growth. To correct the nutrients imbalance in soil, plant growth and for sustainable agriculture production, a dynamic farming system requires the continuous addition of soil nutrients. The foreign agriculture inputs like synthetic fertilizers can have short term remedies on food security. For this reason, it is important to be conscious and made attempt within these constraints (van Straaten 2006).

3.2 Growth Experiments with rock powder

Bakken et al. (1997) showed that K-feldspar concentrate and Adularia fertilizers only provided significance supply of K to barley. They also explained that the K availability to the

plants and acid solubility are correlated. But finally when analyzed between the same acid soluble K content rocks (two carbonatites), plant obtaining K differ with the rocks having similar amount of acid soluble fertilizers which also indicates that acid solubility K is not the perfect explanation of plant availability K and acid solubility. When above ground yield is considered for first and second harvest plants treated with fieldspar, microcline and adularia was found as low as non fertilizer treated plants. Furthermore for when third harvest is concerned yield of treatments with KCl and Deduster augnegnsis, carbonatite with nephaline epidote schist, carbonate with biotite and biotite concentrate had no significant difference.

4 Materials and Method

4.1 Soil and Rock Materials

In the experiment we used ground carbonatite rock from Stjernøy containing both apatite and biotite minerals supposed to have positive impact on the K, P, Ca and Mg nutrition and yield of plants. Further, rock powder can be the potential source when use as a fertilizer as this effects can be determined significantly to a greater extent on K and P uptake.

4.1.1 R1: R1 is referred as fine rock powder Saravann 1. This is an apatite enriched, biotite depleted fraction (Table 1) compared to the total rock, obtained by dry sieving and removing the fraction that did not pass through 1.7 mm mesh. R1 at the rate of 120 g in every pot (equivalent to 4724 g RP m^{-2}, and ca 90.4 g K and 147.7 g P m^{-2}, P:K ratio 1.63) was used. R1 was used in the treatments 4, 7, 8 and 9 (R1, R1+1/2 P, R1+1/2 K and R1+C1) (Table 3).

4.1.2 R2: The biotite carbonatite used here was sampled on Stjernøy Island (Finnmark) in 2007. R2 represents the RP with the same mineral composition (Table 1) as the total rock. It was obtained by crushing the biotite enriched fraction removed by the sieving process (95 % below 2 mm) and re-adding it to the fine fraction. It was applied at the same dose as R1 or half as much, corresponding to 4724 and 2362 g RP m^{-2} respectively. R2 at the rate of 120g in treatment 5 and 60 g in treatment 6 (1/2R2 and 1/5PK) (Table 3) was used.

4.2 Chemical analysis

Karl Andreas Johnsen (Chief Engineer) Jord department, UMB explains how the chemical analysis of K, P, Ca, Mg and S were performed: 5 ml. of ultrapure subboiled HNO_3+2ml of H_2O was added to 0.2-0.3 g of sample. The samples were digested at 250°C for 20 minutes in

an Ultra Clave III from Milestone. Then samples were diluted to 500 ml with H_20. The samples were analysed on an ICP-OES, Optima 5300 DV from Perkin Elmer.

Table 1: Total composition. R1 was examined from geological survey of Norway, Trondheim, while R2 and sand was determined from XM company of Canada. XRF method was followed.

Main elements	R1	R2	Sand
SiO_2	15	18.3	83.8
Al_2O_3	4.56	6.00	6.98
Fe_2O_3	10.9*	13.46	2.94
FeO			
TiO_2	2.02	2.29	0.35
MgO	3.38	4.46	0.46
CaO	33.1	28.24	0.51
Na_2O	0.92	0.95	1.35
K_2O	2.31	3.26	2.86
MnO	0.22	0.21	0.03
P_2O_5	7.17	4.69	0.06
Lol	18.8	17.38	0.35
Sum	98.38	99.59	99.78
Total Carbon		4.82	0.04
Total Sulphur		0.04	0.02
Trace elements			
S	540		

*Fe-total

According to the data from Gautneb & Bakken (1995), R2 composition is quite similar to sample Saravann 1993.

Table 2: Common extraction methods of elements

Parameter	Unit	R1	R2	Sand
pH		8.5	8.8	9.3
Phosphorus (P-AL)	mg/100	<2.0	<2.0	1.5
Magnesium (Mg-AL)	mg/100	58	58	0.5
K-HNO_3	mg/100	640	600	13

4.3 Other components

The other components used in our mixtures were elverum sand, peat, lime, potassium chloride and micronutrients.

4.3.1 Elverum sand: This is a nutrient poor sand used at the department for testing and demonstrating mineral deficiency in pot experiments. When RP was not used, 2800 g of sand was added. Whereas, in pots with rock powder, the sand amount in each pot was reduced to 2700 g in the pots containing 120g RP, and to 2760 g in pots with 60 g R2 (Table 3). The pots had been erroneously filled with 800 g sands more than that mention in the protocol. So we added 2800 g sand whereas the actual amount written in protocol was 2020g.

4.3.2 Peat: Since sand has low Cation exchange capacity (CEC), we used unfertilized peat in our trial in an adequate amount to decrease soil pH of the treatment with R1 only to nearly 6.5, and to increases the CEC. The same amount, 230g peat pot^{-1}, was added to all treatments. Peat used was sieved through 5 mm sieve.

4.3.3 Lime: Application of lime raises pH of acidic soils, increase Ca-ions and decrease Al-toxicity. Calcium carbonate ($CaCO_3$) @ 6.90 g was added to limed controls (C2 and C0) (Table 3).

4.3.4 Micronutrients: All pots received whole quantity of micronutrients (Table 4) except Mg since RP was expected to supply (Mg was however supplied to the controls C1 and C2). Mixture of ($FeSO_4.6H_2O$, $MnSO_4.H_2O$ and $CuSO_4.2H_2O$) and $ZnSO_4.7H_2O$ at the rate of 25 ml per pot was added together with 25 ml of $(NH_4)_6Mo_7O_{24}*4H_2O$), ($Na_2BO_7.10H_2O$), $MgCl_2.6H_2O$ at the rate of 25 ml pot^{-1} was added to fertilized treatments (C1 and C2) only.

4.3.5 Potassium chloride (KCl): KCl is essential for plant growth and to obtain high yield. KCl was added to two control treatments (C1 and C2).

4.4 Treatments

Three controls were used; fertilized (C1) fertilized and limed (C2), only limed (C0). In addition to the treatment with only R1 and R2 were used, there were 4 treatments with different concentrations of RP and P or K fertilizer.

Recommended doses of sand, rock powders, R1 and R2 and peat moss were weighed separately for each bucket and mixed in a big metal tray before refilling each pot. There were 9 treatments (Table 3) with 4 replications, with giving a total number of 36 pots. Pots were labeled in ascending order from 1-36. The diameter of the pot was 17.5cm with height 16.7 cm and volume determined is 4014 .78 cm^3.

Figure 9: Different treatments containing sand, peat, R1 and R2 in pots before mixing

Table 3: Overview table of treatments

	Treatments	Amount					
		Elverum sand (g)	Rock Powder (g)	Lime (g)	Mg Solution (ml)	P solution (ml)	K Solution (ml)
C1	Soluble P, K and Mg	2820			0.025	0.025	0.025
C2	Soluble P, K, Mg and lime	2820		6.90	0.025	0.025	0.025
C0	Control + lime	2820		6.90			
R1	Rock powder with P > K	2700	120				
R2	Rock powder with K > P	2700	120				
1/2R2+1/5PK	Half K-rich rock powder + 1/5 soluble P and K	2760	60			0.005	0.005
R1+1/2P	P-rich rock powder + half soluble P	2700	120			0.0125	
R1+ 1/2K	P-rich rock powder +half soluble K	2700	120				0.0125
R1+ C1	P-rich rock powder + soluble P, K and Mg	2700	120			0.025	0.025

Table 4: Table with Molarity of solution

Micronutrients	IUPAC Name	Molecular weight of solutes (g)	Concentration of the solution ($g\ L^{-1}$)	Litres of Solution (ml pot $^{-1}$)	Molarity of Solution
$(FeSO_4).\ 6H_2O$	Ferrous Sulphate Hexahydrate	216	5.00	25	0.00092593
$MnSO_4.H_2O$	Manganese Sulphate Monohydrate	215	2.5	25	0.00046512
$ZnSO_4.7H_2O$	Zinc Sulphate Heptahydrate	225	2.5	25	0.00044444
$(NH_4)_6Mo_7O_{24}.4H_2O$	Ammonium Paramolybdat	901	0.05	25	0.0000222
$Na_2B_4O_7.10H_2O$	Borates, tetra, sodium, salts (Decahydrate)	818	0.25	25	0.00001222
$MgCl_2.6H_2O$	Magnesium Chloride Hexahydrate	95	12.5	25	0.05555556

4.5 pH of soil mixtures

The pH of the intended treatments CO, R1, R2 using about 50 g of the soil mixture and 50 ml of deionized water and shaking overnight. Since the pH was unstable during the first hours, measurements were repeated after about 7 days (Table 5).

Table 5: pH of soil mixtures at the start of the experiment, and of rock powder and peat alone.

Mixture	pH	
	After 20 hours	After 7 days
C0, C2	6.1	6.45
C1	4.6	5.0
Pure rock powder, type R1	8.9	8.4
Pure peat	3.8	n.d.

Due to larger use of sand than planned, the pH might have been somewhat more basic since the sand had a basic reaction. However, the CEC of the sand was very low, and the values in the table can be taken as representative. Parallel measurements of a mixture with R1 and sand but no peat gave the same pH (ca 9 after 20 hours, 8.4 after 7 days) as the pure rock powder. When ratio of sand: peat was 11.7, we used 2 g peat, the amount of sand was 23.5 g and rock powder 1.043 g and 0.522 g in case of half dose. In case the ratio sand:peat was 12.3, 24.5 g of sand and 0.060 g of lime was used. The weighing list for pH measurements based on the calculation above. The jar was prepared of each and 50 ml of deionized water was poured, shaken and left for 24 hours and shaken again before measuring pH.

Table 6: The weighing list for pH measurements based on the calculation above.

Treatment	Sand	Peat	RP	$CaCO_3$	Jar No.	pH		
						d1	d2	Difference
C1- no limestone	24.5	2.0	0	0	1,2	4.07	4.55	0.535
						3.91	4.5	
C2 and C0 – limestone	24.5	2.0	0	0.060	3,4	4.98	5.55	0.465
						5.28	5.64	
R1	23.5	2.0	1.04	0	5,6	6.16	6.18	0.305
						6.21	6.8	
R2	23.5	2.0	1.04	0	7,8	6.25	6.56	0.445
						6.21	6.79	
½ R2	23.5	2.0	0.52	0	9,10	5.98	6.8	0.805
						6.02	6.81	

4.6 Growing Chamber

The trial was conducted in the chamber in the soil basement at UMB, in Ås in Norway. The room temperature was 20-22 °C. The type of light used in lab throughout the experiment period was Halogen metal halide lamps, Powerstar HQI-BT 400W/D Daylight E40 Ca. 8000 lux.

4.7 Cultivation of white clover

4.7.1 Seed sowing, transplanting, planting of clover

White clover (*Trifolium repens* L. cv Milkanova) was sown in a peat/sand mixture on a tray in a warm greenhouse. After 10-14 days (first permanent leaf), on 3rd August, 2010, the seedlings were transplanted into 32×32 mm "plug" (Figure 10). (Pluggbrett, 160 plugg/ Brett) filled with clay soil from an organically managed field (ØstreVoll), to ensure that the roots were infected with rhizobium, and also to establish the vigorous growth of the seedlings. Excess of plugs were prepared and thus, the most vigorous and healthy seedlings were selected for the pots. Clover seedlings were planted in pots on 13th September, 2010 where the seedlings were transferred from the plugbrett to the pots that were prepared earlier and kept on the trollies under the light (Figure 11).

Figure 10: Clover seedlings just transplanted into the plug filled with organically managed clayey soil.

Figure 11: Examples of pot on trolley at planting

4.7.2 Irrigation

At the time of planting 700 ml of deionized water was added to make about 60 percent of field capacity. Water was poured gently in every 2 to 3 days at first to 50 and then 60 % of field capacity (measured by weighing the pots). We went above 60 % to the pots with much growth. The positions of the pots on the trollies were re-randomized every time they were watered.

4.7.3 Plant registration

Before each harvesting, the number of dry leaves, number of stolon's crossing the pot borders and number of flowers in each pot was counted. Signs of nutrient deficiency in old and young leaves, grayish spots, chlorotic or mottled necrotic spots, yellowing and partially opened leaves were registered.

4.7.4 Harvest

Clover leaves were harvested four times: 2nd November and 15th December 2010, as well as 27th January and 25th February, 2011 (Figure 12). Numbers of stolons were reported for only those that were crossed out of the pot borders, and which were cut and included in the harvested foliage. At the last harvest, stolons were also recovered (Figure 12).

Figure: 12 Examples of pot with harvested stolons at the last harvest

4.7.5 Samples handling

Harvested plants were immediately put into paper bags and dried at 60°C to constant weight

and weighed. Paper bags had been weighted in advance in order to calculate net weight. The sizes of paper bag used were 3.1 and 8.42 grams. The dried samples were grounded. Firstly plants were re-dried for a few hours to facilitate the milling.

4.8 Soil pH test after harvesting

Soil pH was measured at the end of the experiment 20 g wet soils were added 50 ml deionized water. This was done for two soil depths: 0-5 cm and 5-15 cm. For pot number one only one soil measure (Ca 10g) was used in 25 ml deionized water.

4.9 Statistical Analysis

Total herbage yield was calculated by summing four subsequent harvests. Statistical analysis was performed using MINITAB (Version16.1.1) package (Minitab Inc.). DM, uptake and concentration of P, K, Ca, Mg and S both in herbage and stolons were analyzed by ANOVA to understand the main and interaction effect of different factors namely, apatite, biotite, lime and soluble fertilizers (P and K) on aforementioned character of white clover. Multiple comparisons of means were performed by Tukey method at 5% level of significance.

5. Results

5.1 Clover growth and nutrients deficiency

Vigorous seedlings were established after some days of transplantation. Afterwards, we observed that the leaves on some pots were severely wilted, dried and yellowish in colour. Also, some drought symptoms and unevenly distributed plants were occurred on treatment with fertilized (C2). A number of injured leaves were found on some pots. All plants had recovered from wilting when we had started first harvesting.

We observed the plant characteristics in all pots during fourth growth period. P deficiency symptoms were started from the older leaves (in R1) and then spread to younger leaves. All the replicated pots had older leaves but small differences were also found between the plants. Similar to R1, all the replicates of R2 had spots on old leaves but minor remarkable differences were also found between the plants. Leaves were severe stunting (Figure 13 and 14), purple colour stem (Figure 15) that might be the cause of acute P deficiency.

More damage was observed older leaves in C2 treatment, while less damaged was found in younger leaves. The other peculiar visible leaf characteristics were whitish spots. Some

Leaves on C2 had yellow patches on the older leaves which could be the cause of K deficiency (Figure 17).

In R1+1/2P, spots were appeared in both old and younger leaves. Older leaves were severely affected but the young ones were less affected. Subjecting to R1+1/2K, some light spots were seen in older leaves, while old and young both leaves were found.

Figure 13: Severe Stunting left leaf (P deficiency), adequate P received right leaf.

Figure 14: -P on left side, Severe stunting and +P on right side, Increasing plant growth.

Figure 15: Purple color stem due to inadequate P.

Figure 16: Normal stem (P received).

Figure 17: Chlorotic leaf edges on the older leaves of lime-fertilized treatment showing K deficiency.

Figure 18: Necrotic leaf edges on the older leaves of lime unfertilized control treatment showing K deficiency (b), some partially opened leaves appearing in younger leaves of unfertilized control indicating P deficiency.

5.2 Dry matter (DM) yield of herbages and stolons of four harvesting

1st Harvest: Significant difference ($p<0.05$) between different treatments were found in the first harvest of clover herbages (Table 7). C2, R1+C1 and C1 had significantly higher yield than other treatments respectively in decreasing order. And the remaining treatments had comparatively lower yield of clover. R1, R1+1/2K, R2 and C0 had very low yield compared to other treatments (Figure 19 and Appendix-Table 3).

2nd Harvest: Yields of clover herbages in second harvest was also significantly different (Table 7). R1+C1 and C2 had significantly higher ($p<0.05$) yield in comparison to other treatment (Figure 19 and Appendix-Table 3). Furthermore R1 and R2 were significantly lower than C0.

Table 7: ANOVA table for treatments for DM yield of herbages.

Source	DF	MS				
		Harvest 1	Harvest 2	Harvest 3	Harvest 4	Total
Treatments	8	24.680*	21.259*	6.1054*	1.5938*	158.28*
Error	27	0.660	0.283	0.2237	0.0672	1.28

*indicates significant difference at, $p<0.05$

3rd Harvest: Treatment R1+C1 had significantly higher yield (5.27g pot^{-1}) than other treatments (Figure 19 and Appendix-Table 3).

4th Harvest: There was a significant difference in yield of clover herbages between different treatments in fourth harvest (Table 7). Furthermore, R1+C1 had highest yield (2.96 g pot^{-1}) followed by C0, R1+1/2P, C2, C1, 1/2R2+1/5PK, R1+1/2K, R2 and R1 (Figure 19 and Appendix-Table 3).

Total herbage yield: R1+C1 and C2 had statistically similar total yields (23.1 g pot^{-1} and 20.9 g pot^{-1} respectively) and significantly larger than all other treatments ($p<0.05$). C1 (fertilized only) had a lower total yield then R1+C1 and C2, but higher than C0 (limed only) (Figure 19 and Appendix-Table 3). R1+1/2P were statistically similar to C1 and C0 while significantly higher than the remaining treatments with RP. Addition of a small dose of soluble P to RP raised the yield to the same level as the limed unfertilized control. All other treatment with RP and no addition of soluble P (R1+1/2K, R1 and R2) reduced the yield significantly compared to the unfertilized control (C0).

Stolons: There were significant differences between different treatments in yield of stolons recovered after the fourth harvest (Appendix-Table 3). C2, R1+C1 and C1 had significantly higher yields than other treatments in decreasing order. Treatments with RP and no addition of soluble P had the lowest yields, although the difference from C0 was not statistically significant (Figure 20 and Appendix-Table 3).

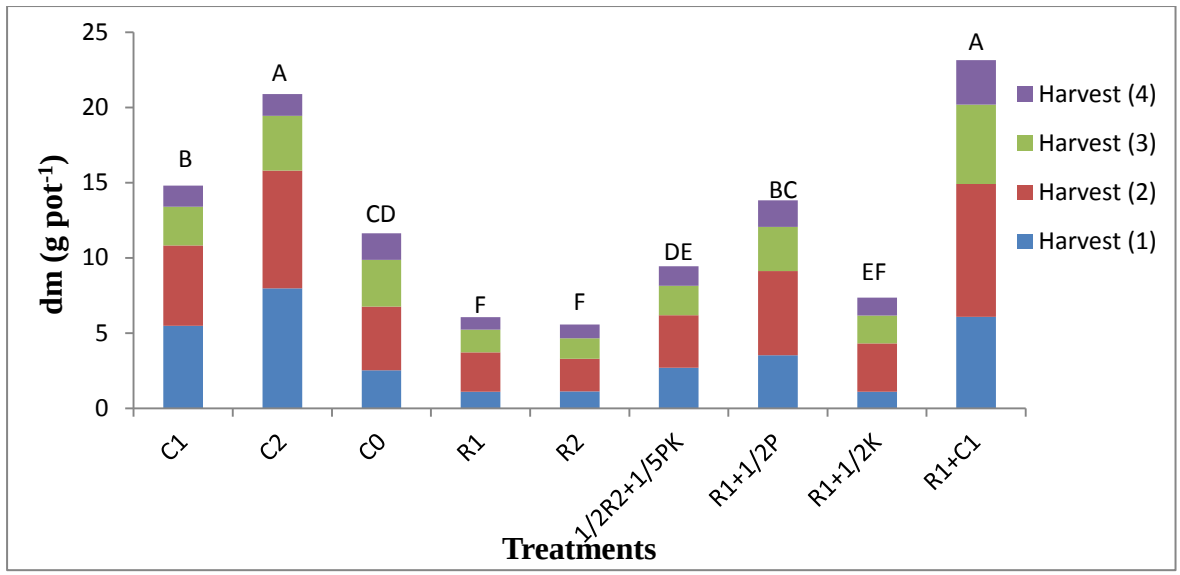

Figure 19: The total dry matter yields (g pot^{-1}) in the herbages (Sum of 4 successive harvests, stolons not included). Data are mean value of the replicates in a treatment (n= 4) and bars headed by same letters(s) are not significantly different ($p<0.05$).

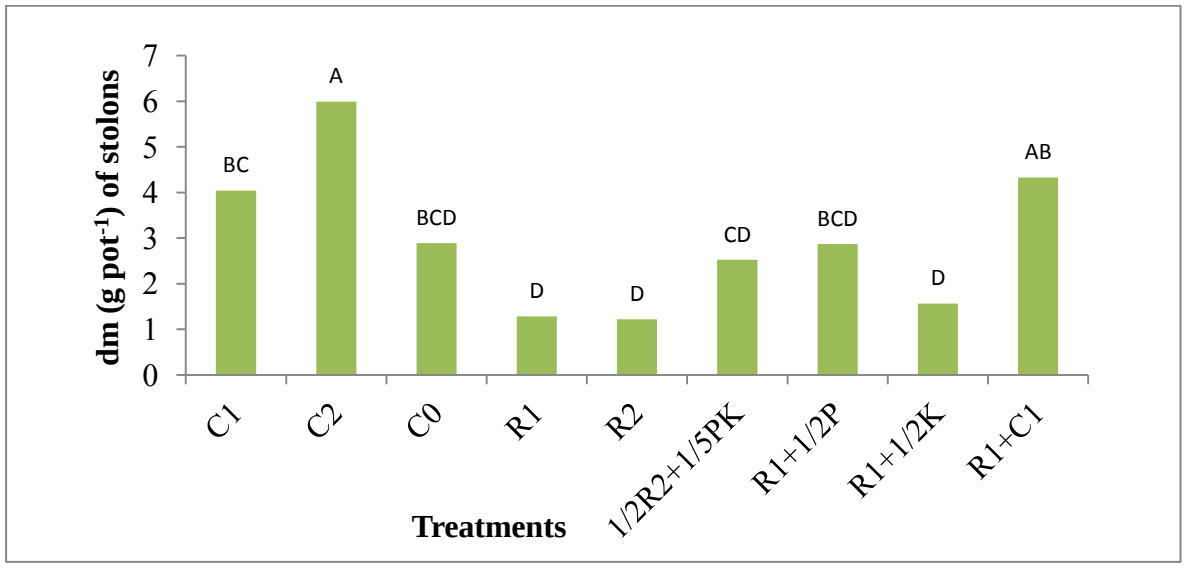

Figure 20: Effects of fertilizers treatments on DM yield (g pot^{-1}) of stolons at 4th harvest. Data are mean value of the replicates in a treatment (n=4) and bars headed by same letters(s) are not significantly different ($p<0.05$).

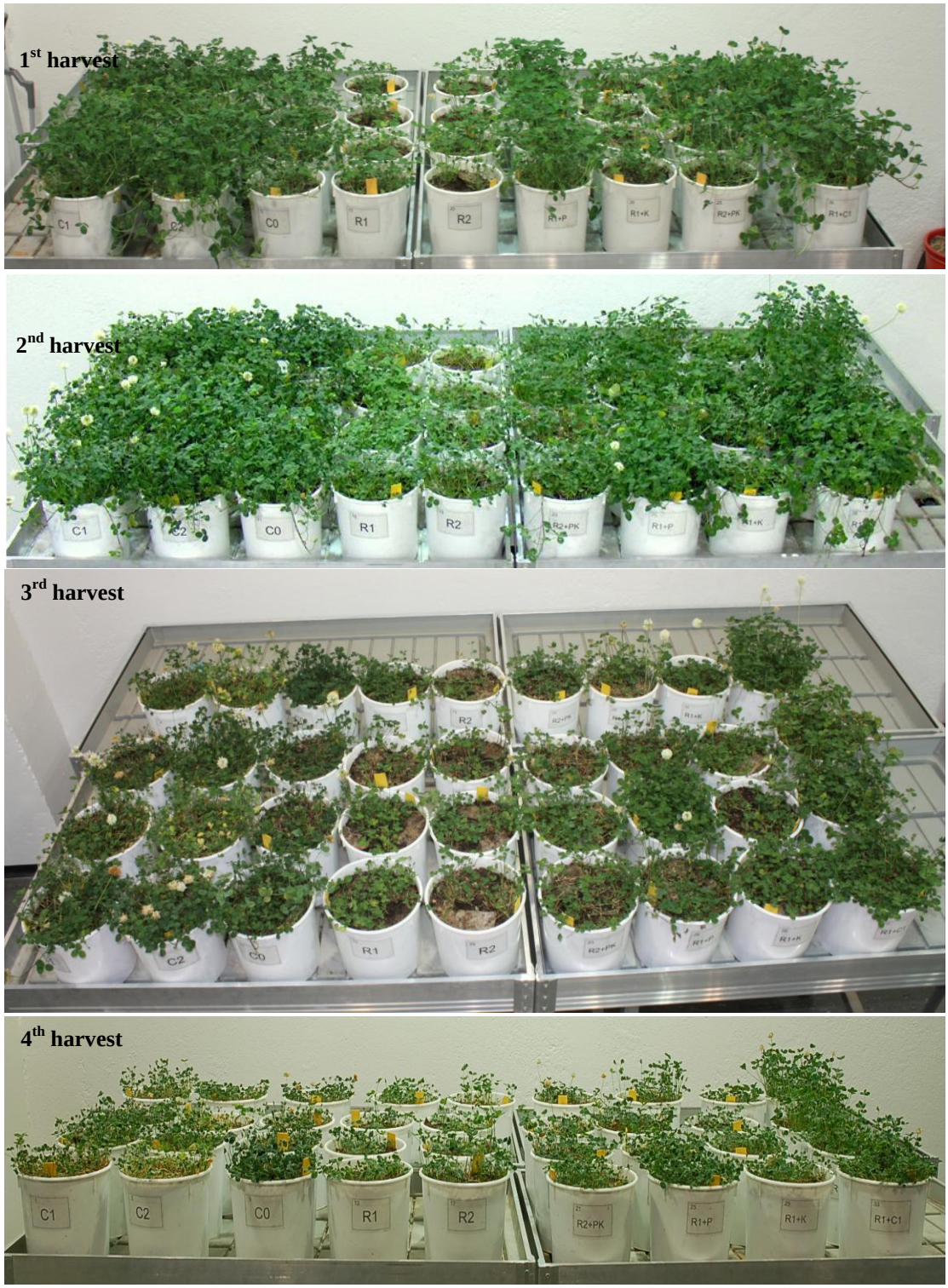

Figure 21: Clover growth in soil basement showing 9 different fertilizer treatments with four replications (Figure; M.A.Blekken and M.Heim. Date for 1st, 2nd, 3rd and 4th harvest 2 November 2010, 15 December 2010, 26.January, 2010 and 25 February 2011 respectively).

5.3 Nutrient concentrations of herbages

5.3.1 Potassium

Significant difference was observed between the treatments at all harvesting times (Table 8). Potassium concentration in treatments with RP was significantly higher than control treatments, except at the first harvest. Among all, R1+C1 had significantly higher K concentration than other treatments. In treatments R1, R2 and R1+1/2P , K concentration increased with the following harvesting while for C1, C2, potassium concentration decreased noteworthy after the first harvest (Figure 22 and Appendix-Table 4)

Table 8: ANOVA table for treatments for potassium concentrations of herbages.

Source	DF	MS			
		Harvest1	Harvest 2	Harvest 3	Harvest 4
Treatments	8	161.90*	309.11*	360.13*	347.37*
Error	27	5.30	9.44	7.82	6.88

*indicates significant difference at, $p<0.05$

5.3.2 Phosphorus

When P concentration was analyzed in plants significant differences in between the treatments were found at all harvesting times (Table 9). C1 had significantly and much higher ($p<0.05$) P concentration followed by C2, C0 and R1+C1. The remaining treatments had less and similar concentration of P. Observing concentration trends within single treatments there was often a decreasing pattern in P (Figure 23 and Appendix-Table 5).

Table 9: ANOVA table for treatments for phosphorus concentrations of herbages.

Source	DF	MS			
		Harvest 1	Harvest 2	Harvest 3	Harvest 4
Treatments	8	2.6853*	3.0814*	3.0495*	4.0878*
Error	27	0.0862	0.0765	0.0492	0.1283

*indicates significant difference at, $p<0.05$

5.3.3 Magnesium

The concentration of Mg was significantly higher in treatments C1, C0 and C2 (Table 10). In case of C1 and C2, Mg concentration increases with the further harvesting periods. Among the treatments, C1 contain significantly higher ($p<0.05$) Mg with C2 and C0 as following and furthermore R1, R2, 1/2 R2+1/5 PK, R1+1/2 P and R1+C1 respectively. In all the treatments, R1+1/2 K had least concentration of Mg than other (Figure 24 and Appendix-Table 6).

Table 10: ANOVA table for treatments for magnesium concentrations of herbages.

Source	DF	MS			
		Harvest 1	Harvest 2	Harvest 3	Harvest 4
Treatments	8	1.4190*	2.7282*	5.5475*	5.2349*
Error	27	0.0919	0.0792	0.1092	0.1785

*indicates significant difference at, $p<0.05$

5.3.4 Calcium

In case of first harvest, C1 had significantly lower Ca concentration compared to other treatments. C2 and C0 had significantly higher concentrations of Ca in harvest two (Table 11). Followed by this, R2 and C1 had significantly lower Ca concentrations than all other remaining treatments. In case of third harvest, rock combination treatments had significantly lower Ca concentrations than control except R1+C1 treatments. In case of fourth harvest, C1 had significantly lower ($p<0.05$) Ca concentration than other treatments (Figure 25 and Appendix-Table 7).

Table 11: ANOVA table of treatments for calcium concentrations of herbages.

Source	DF	MS			
		Harvest 1	Harvest 2	Harvest 3	Harvest 4
Treatments	8	93.503*	146.88*	120.16*	61.937*
Error	27	6.187	4.57	5.19	4.470

*indicates significant difference at, $p<0.05$

5.3.5 Sulphur

Significant difference was observed between the treatments in case of S concentration (Table 12). In first harvest, control treatments had significantly higher S concentration than RP treatments. C0 had significantly higher concentration of S in second harvest with least concentration in R1+1/2K. In third harvest also C0 had significantly higher S concentration compared with other treatments with least concentration on C2. Fourth harvest showed that C0 had significantly higher S concentration followed by R1, R2 and R1+1/2P respectively. Moreover R1+1/2K had significantly lower S concentration followed by C2 as least concentration (Figure 26 and Appendix-Table 8).

Table 12: ANOVA table for treatments for sulphur concentrations of herbages.

Source	DF	MS			
		Harvest 1	Harvest 2	Harvest 3	Harvest 4

Treatments	8	0.26132*	0.21049*	0.25125*	0.50403*
Error	27	0.03083	0.04491	0.06704	0.04435

*indicates significant difference at, p<0.05

5.4 Nutrient uptake per pot of herbages:

5.4.1 Potassium

Data showed significant difference between treatments in K uptake in plants (Table 13)**.** At the first harvest, treatments R1+C1, C2, C1 had significantly higher (p<0.05) K uptake than all other treatments. Furthermore C0, R1+1/2K, R2 and R1 had lower K uptake in decreasing order than all other treatments. At the second, thirds and fourth harvest, R1+C1 had significantly larger K uptake than R1+1/2P, and both had much greater uptake than all other treatments (Figure 27 and Apendix-Table 9).

Table 13: ANOVA table for treatments for K uptake per pot of herbages

Source	D.F.	MS				
		Harvest 1	Harvest 2	Harvest 3	Harvest4	Total
Treatments	8	23277*	241.27*	6985.5*	2820.7*	158946*
Error	27	390	217	122.3	72.1	909

*indicates significant difference at, p<0.05

5.4.2 Phosphorus

The uptake of P per pot was significantly different between the treatments at all the harvests (Table 14). At the first and second harvest C1 and C2 had significantly higher (p<0.05) amount of P uptake than all other treatments. Uptakes decreased with successive harvest, particularly at the third and fourth harvest. R1+C1, which had received the same amount of soluble P as C1 and C2, had significantly lower uptake than them, except in the fourth harvest. R1, R1+1/2K and R2 had invariably the lowest P-uptakes, which were significantly lower than those of C0, except in the fourth harvest. This trend was seen in all the harvesting time, but during the last two harvesting amount of P uptake per pot was found to be considerably decreased (Figure 28 and Appendix-Table 10). C1 and C2 had significantly the highest total P uptake (55.5 and 51.4 g pot^{-1} respectively) in total than the other treatments while R1+C1 had the highest P uptake (40 g pot^{-1}) among all rock applied treatments.

Table 14: ANOVA table for treatments for P uptake per pot of herbages

Source	D.F.	MS

		Harvest 1	Harvest 2	Harvest 3	Harvest4	Total
Treatments	8	241.71*	186.39*	40.191*	13.792*	1497.3*
Error	27	3.62	1.79	0.547	0.915	8.5

*****indicates significant difference at, $p<0.05$

5.4.3 Magnesium

In first harvest, Mg uptake in herbages of plants was significantly different between the treatments (Table 15). C1 and C2 had significantly higher ($p<0.05$) Mg uptake than C0, R1+1/2P and 1/2R2+1/5PK. On contrary, R1+1/2K, R1 and R2 had lower uptake of Mg except first harvest which shows no statistical difference. Also, the same result was found in the remaining harvests of herbages except in first harvest where these are statistically similar. While in case of total harvest C2 had significantly higher yield compared to other treatments followed by C1 and C0. In total harvest, RP alone shows significantly lower uptake of Mg compared to other treatments (Figure 29 and Appendix-Table 11)

Table 15: ANOVA table for treatments for Mg uptake per pot of herbages.

Source	D.F.	MS				
		Harvest 1	Harvest 2	Harvest 3	Harvest4	Total
Treatments	8	240.14*	241.85*	90.086*	27.734*	1999.9
Error	27	8.62	3.17	1.641	1.723	24.0

*indicates significant difference at, $p<0.05$

5.4.4 Calcium

In total harvest, C2 and R1+C1 had significantly higher Ca uptake in herbages than all other treatments (Table 16). Furthermore, R1+1/2K, R2 and R1 had significantly lowest uptake of Ca in total less than a fourth of the Ca removal of C2 and R1+C1.

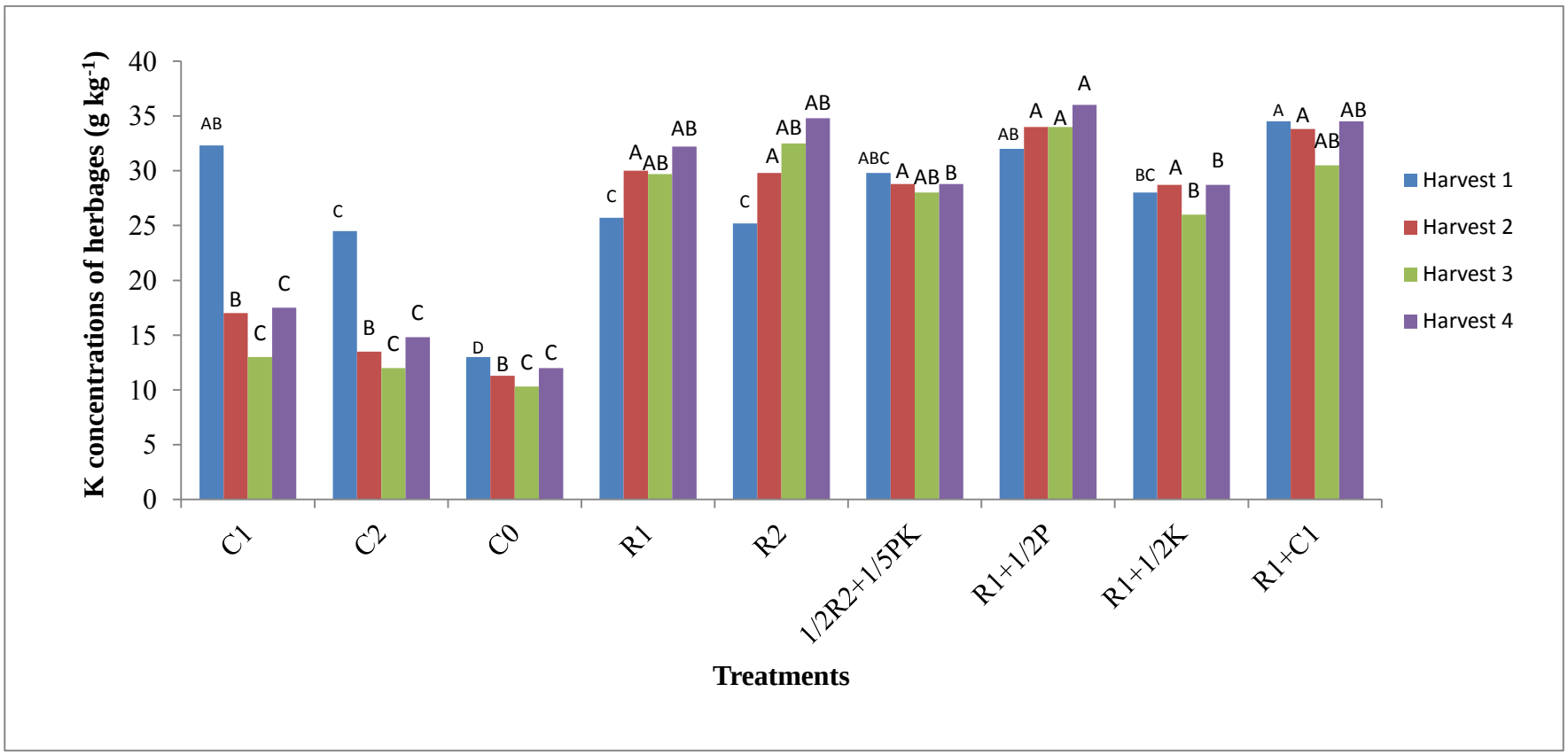

Figure 22: Potassium concentrations (g kg^{-1}) in herbages dry matter of four subsequent harvests. Data are mean value of the replicates in treatments (n=4) and bars headed by same letters(s) are not significantly different ($p<0.05$).

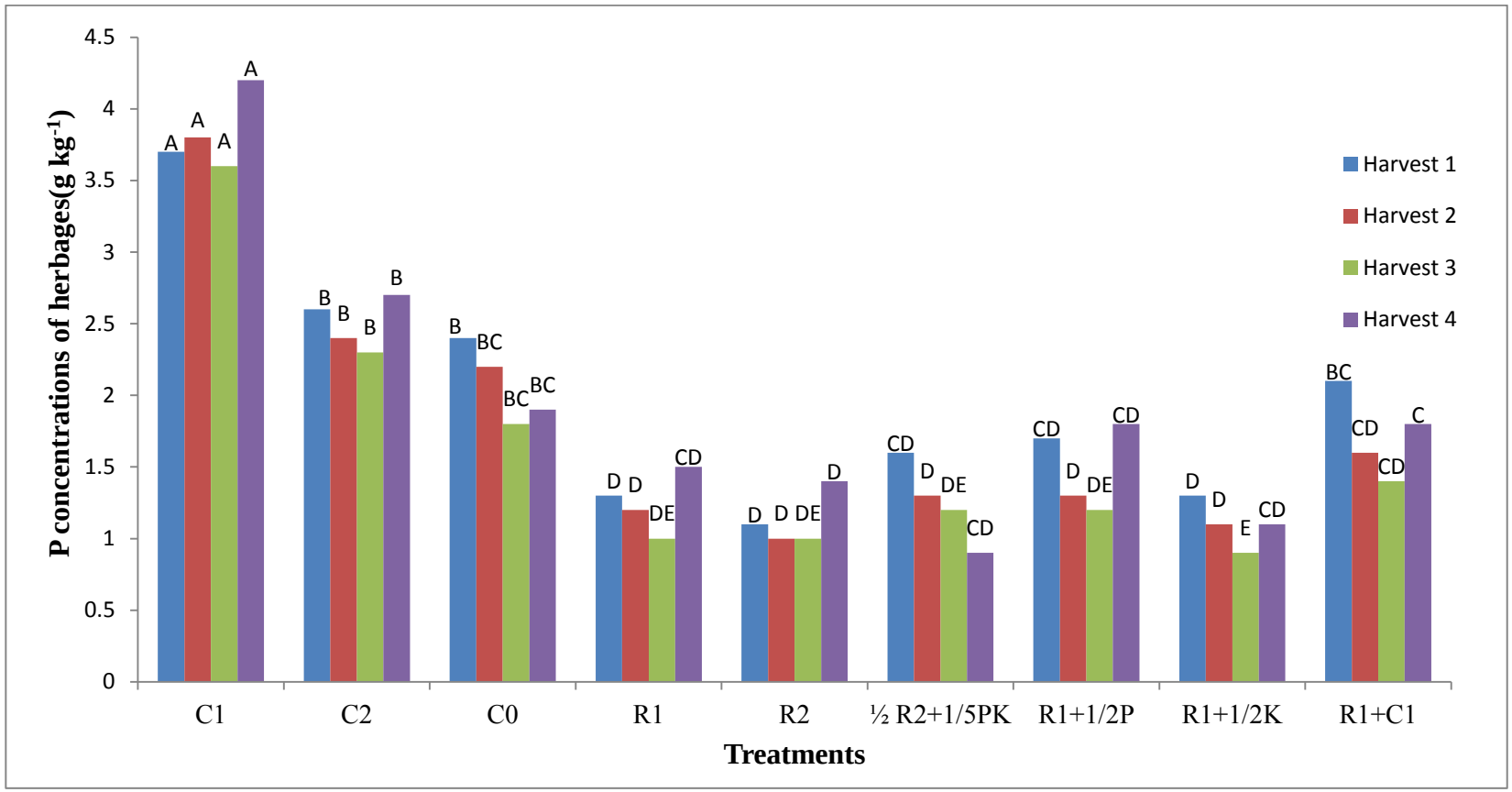

Figure 23: Phosphorus concentrations (g kg^{-1}) in herbages of four subsequent harvests. Data are mean value of the replicates in a treatment (n=4) and bars headed by same letters(s) are not significantly different ($p<0.05$).

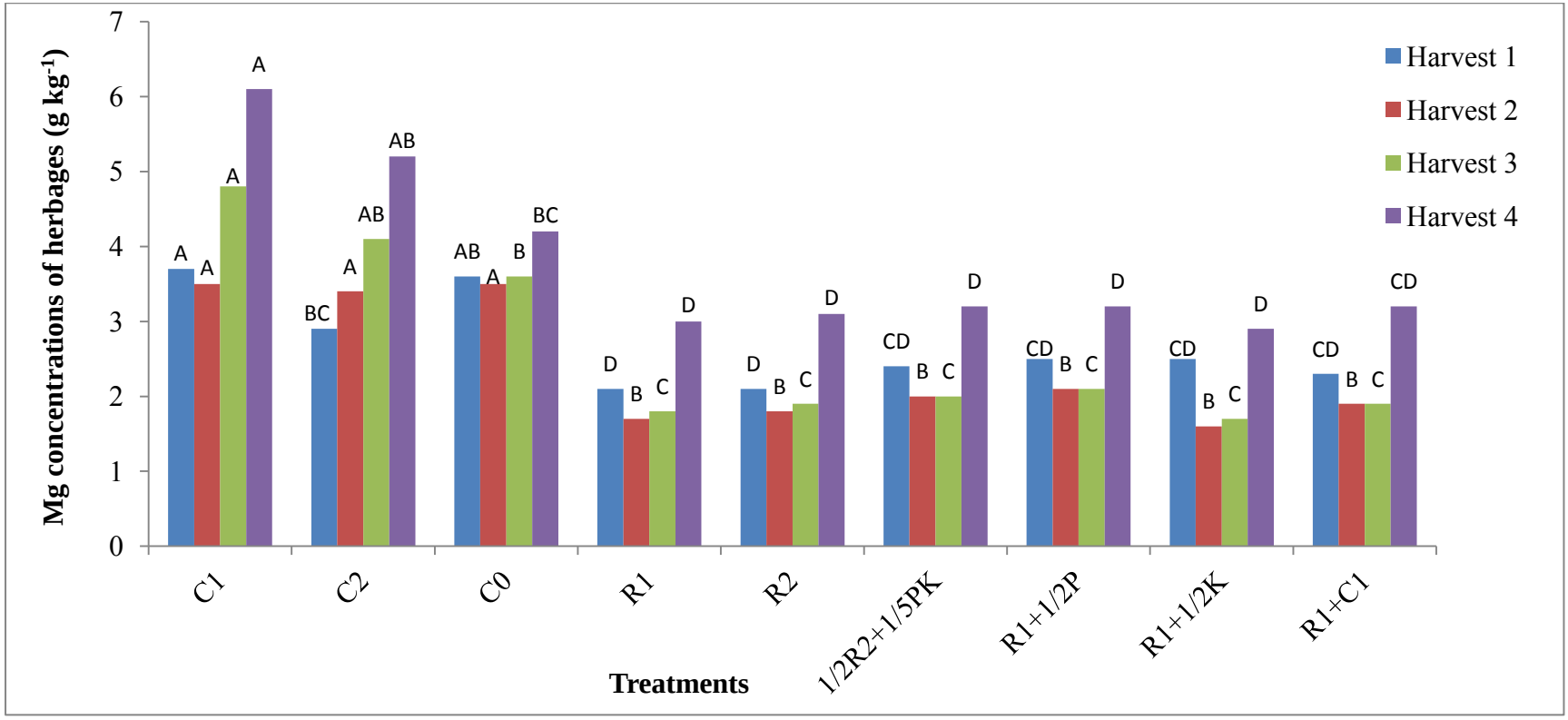

Figure 24: Magnesium concentrations (g kg^{-1}) in herbages of four subsequent harvestings. Data are mean value of the replicates in treatments n=4) and bars headed by same letters(s) are not significantly different ($p<0.05$).

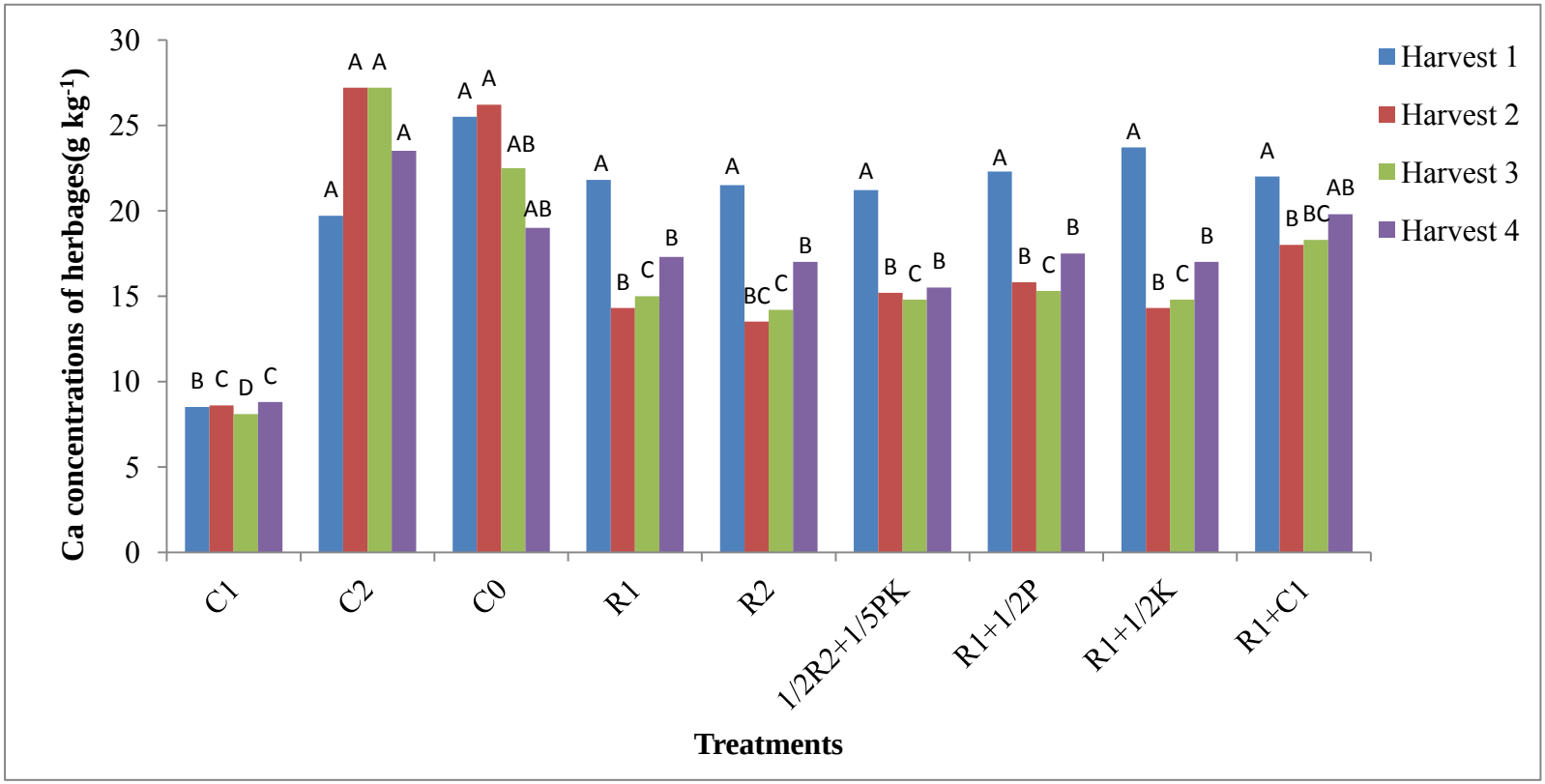

Figure 25: Calcium concentrations (g kg^{-1}) in herbages of four subsequent harvests. Data are mean value of the replicates in treatments (n=4) and bars headed by same letters(s) are not significantly different ($p<0.05$).

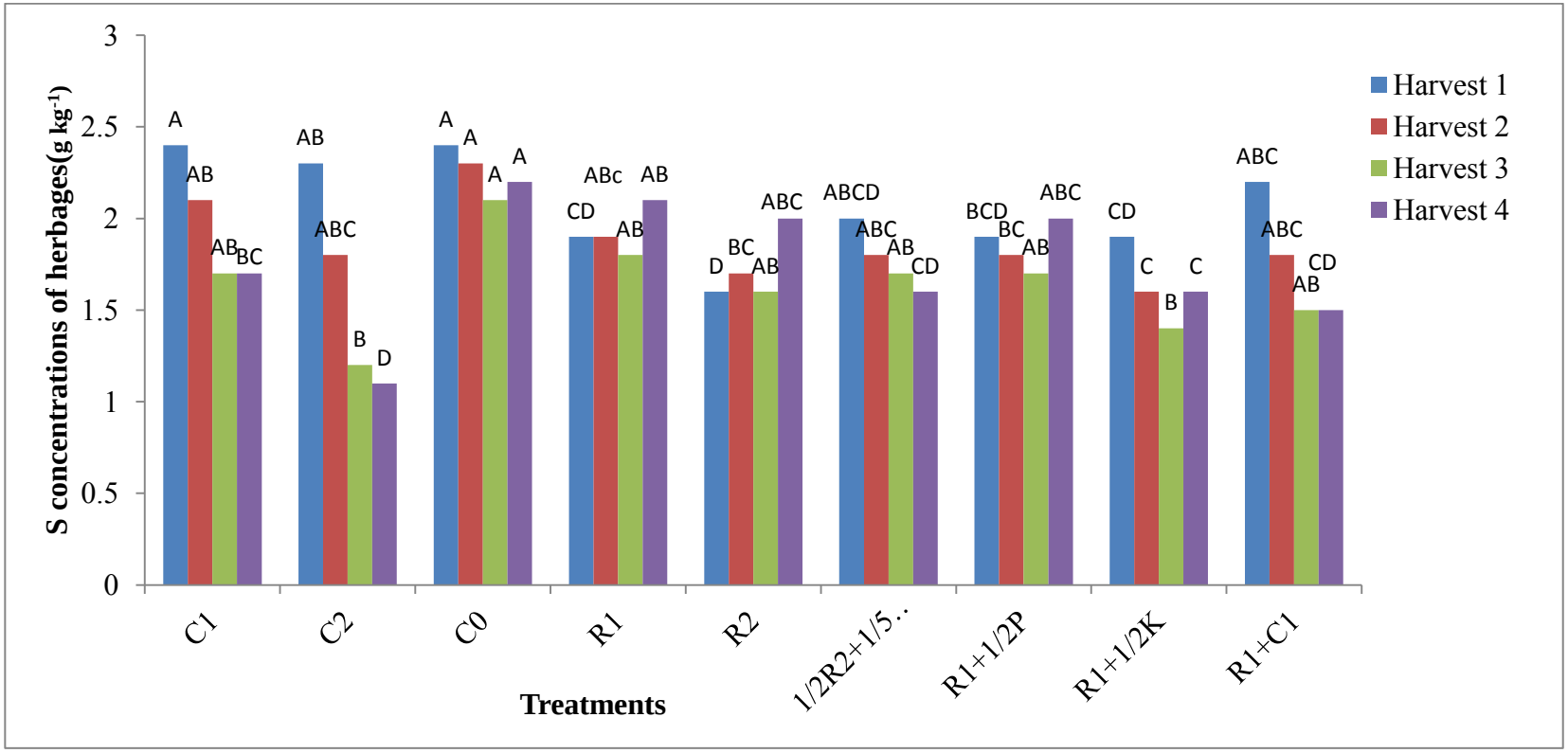

Figure 26: Sulphur concentrations (g kg^{-1}) in herbages of four subsequent harvests. Data are mean value of the replicates in a treatment (n=4) and bars headed by same letters(s) are not significantly different ($p<0.05$).

Table 16: ANOVA table for treatments for Ca uptake per pot of herbages

Source	D.F.	MS				
		Harvest 1	Harvest 2	Harvest 3	Harvest4	Total
Treatments	8	9325.9*	16116*	4276.6*	869.42*	95907*
Error	27	408.5	282	120.3	40.28	1620

*indicates significant difference at, $p<0.05$

While in second harvest, C2, R1+C1 and C0 had significantly higher ($p<0.05$) uptake of Ca than remaining treatments. R1and R2 had lowest Ca uptake than the other treatments. In case of third harvest, C2 and R1+C1 had significantly higher Ca uptake. In fourth harvest, R1+C1 had significantly higher ($p<0.05$) Ca uptake than other treatments. However, R2, R1 and C1 had significantly lower Ca uptake (Figure 30 and Appendix-Table 12).

5.4.5 Sulphur

First harvest data showed that C2, C1 and R1+C1 had significantly higher S uptake than all other treatments, with uptake in C2 also significantly higher than in C1 and R1+C1 (Table 17). The similar pattern was observed in second harvest. However, in all treatments there was a sharp decline of S uptake with successive harvests, but this decline was less pronounced in R1+C1 than in C2, and C1. As a consequence of this, the total S removal in 4 harvests of R1+C1 was similar to that of C2, and larger than of all other treatments. RP without addition of soluble P gave significantly lower total S uptake than any other treatment (Figure 31 and Appendix-Table 13).

Table 17: ANOVA table for treatments for S uptake per pot of herbages

Source	D.F.	MS				
		Harvest 1	Harvest 2	Harvest 3	Harvest4	Total
Treatments	8	137.97*	74.555*	14.912*	4.5471*	570.18
Error	27	1.91	1.240	0.581	0.2883	4.65

*****indicates significant difference at, $p<0.05$

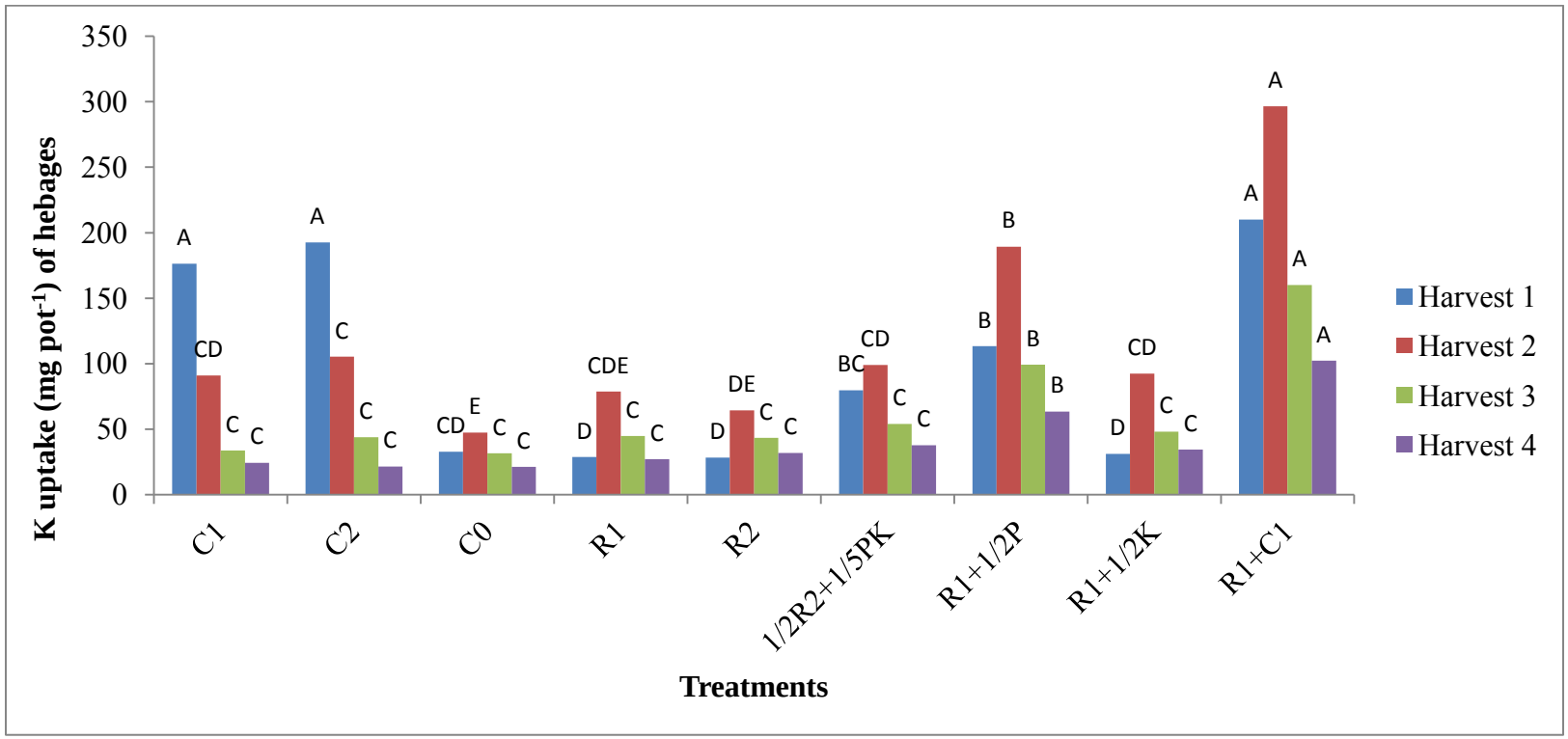

Figure 27: K removal (mg pot^{-1}) in the herbage at four subsequent harvests. Data are mean value of the replicates in a treatment (n=4) and bars headed by same letters(s) are not significantly different ($p<0.05$).

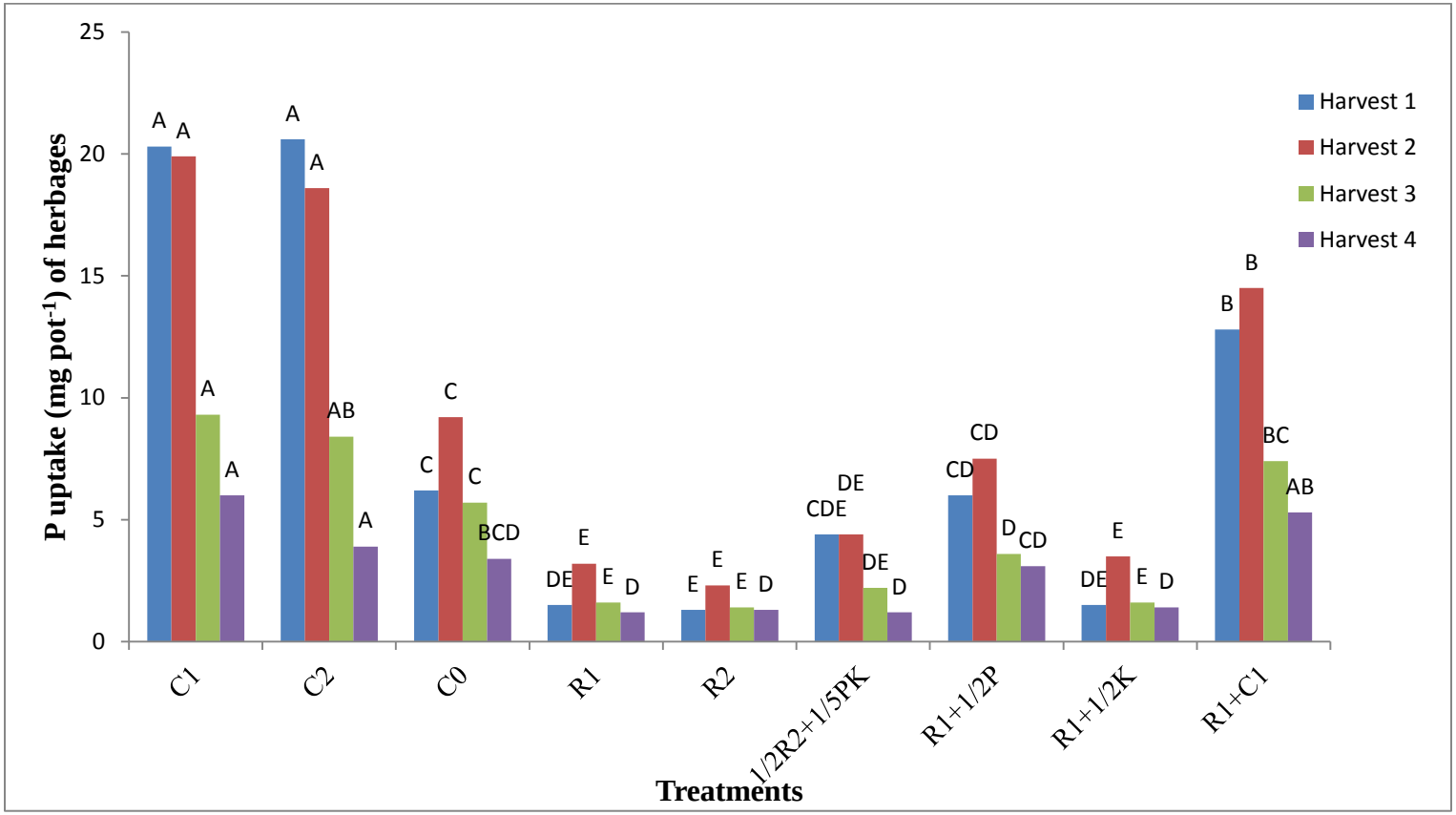

Figure 28: P removal (mg pot^{-1}) in the herbage at four subsequent harvests. Data are mean value of the replicates in a treatment (n=4) and bars headed by same letters(s) are not significantly different ($p<0.05$).

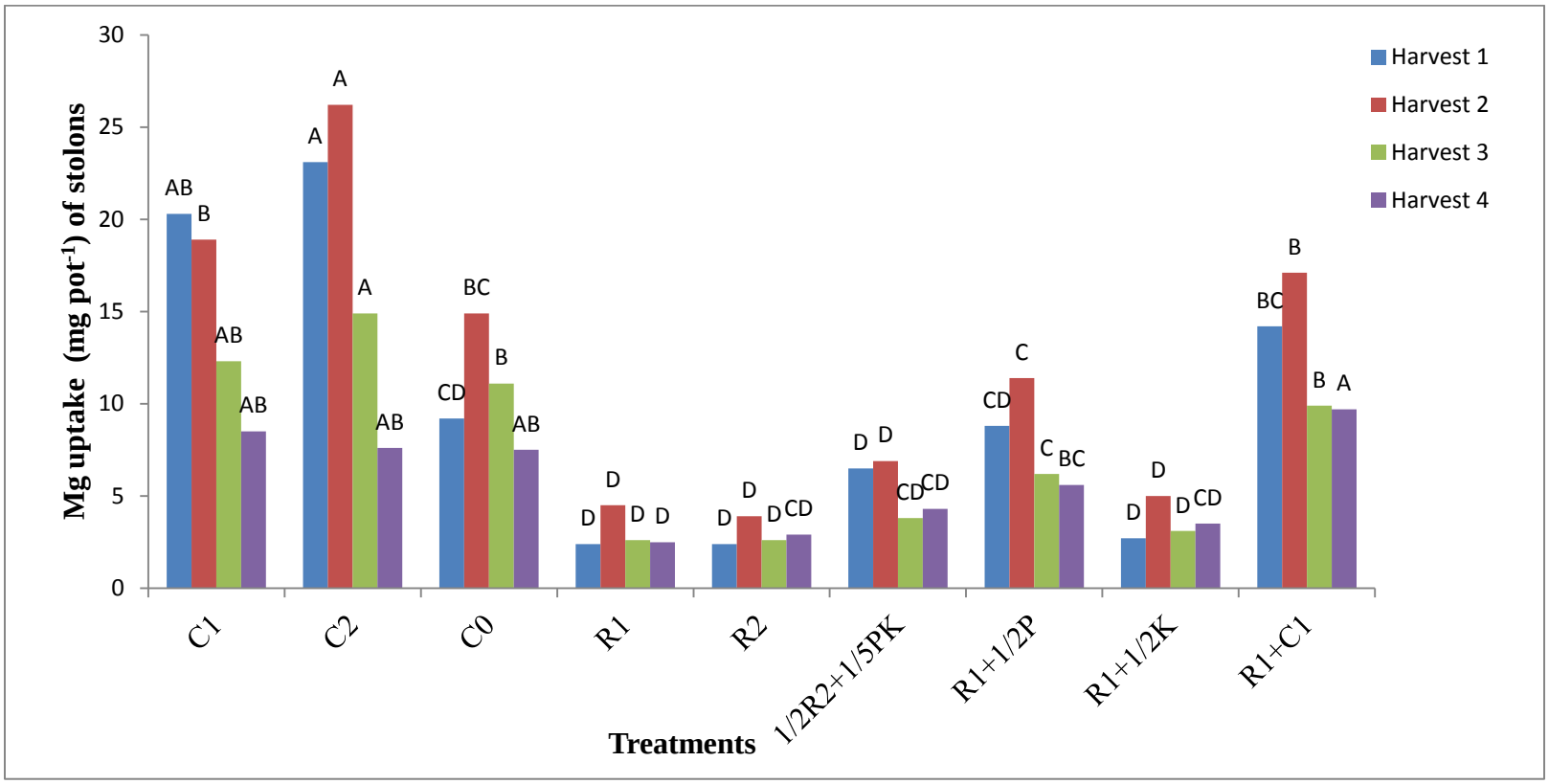

Figure 29: Mg removal (mg pot^{-1}) in the herbage at four subsequent harvests. Data are mean value of the replicates in a treatment (n=4) and bars headed by same letters(s) are not significantly different ($p<0.05$).

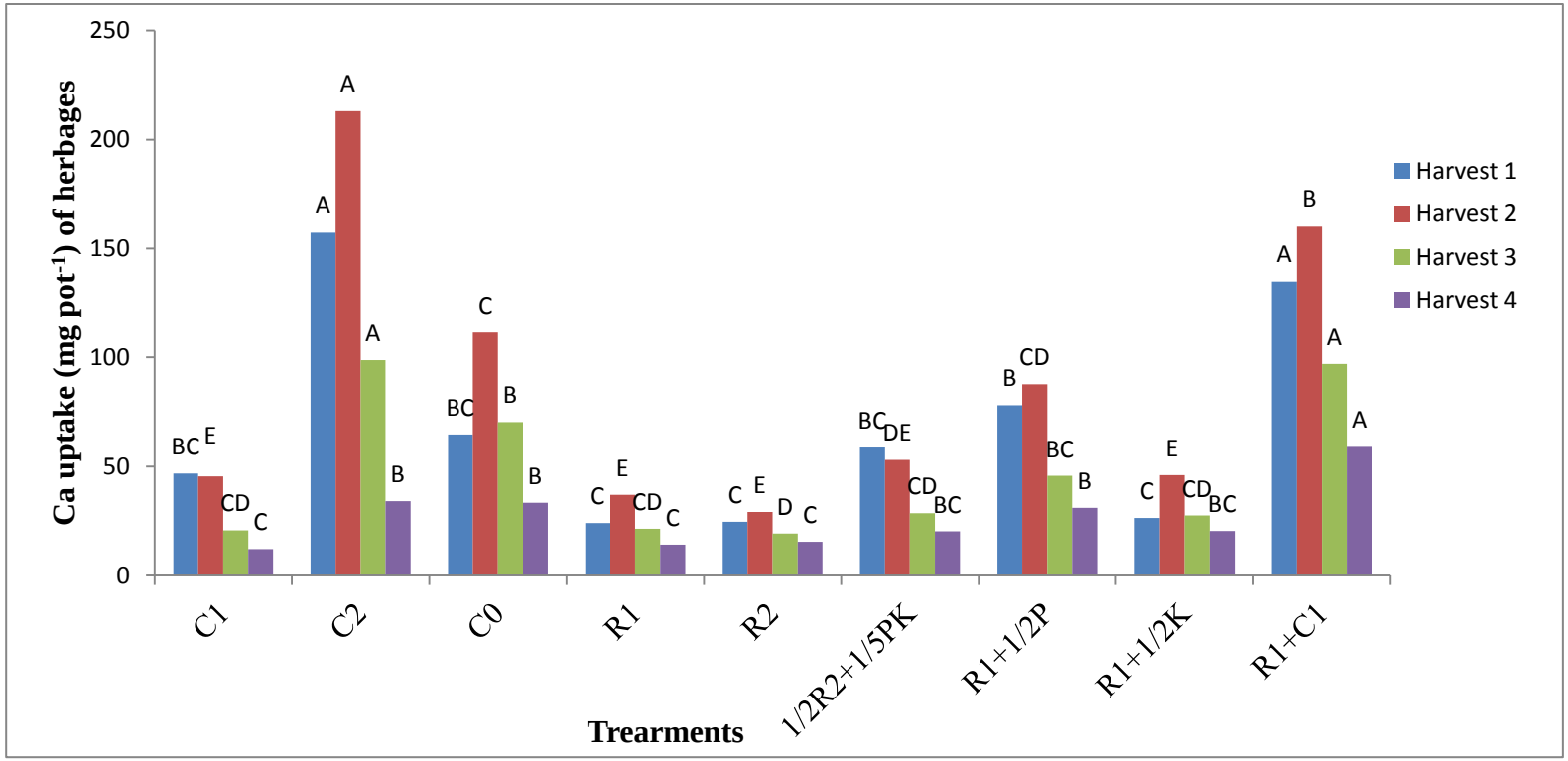

Figure 30: Ca uptake (mg pot^{-1}) in the herbage at four subsequent harvests. Data are mean value of the replicates in a treatment (n=4) and bars headed by same letters(s) are not significantly different ($p<0.05$).

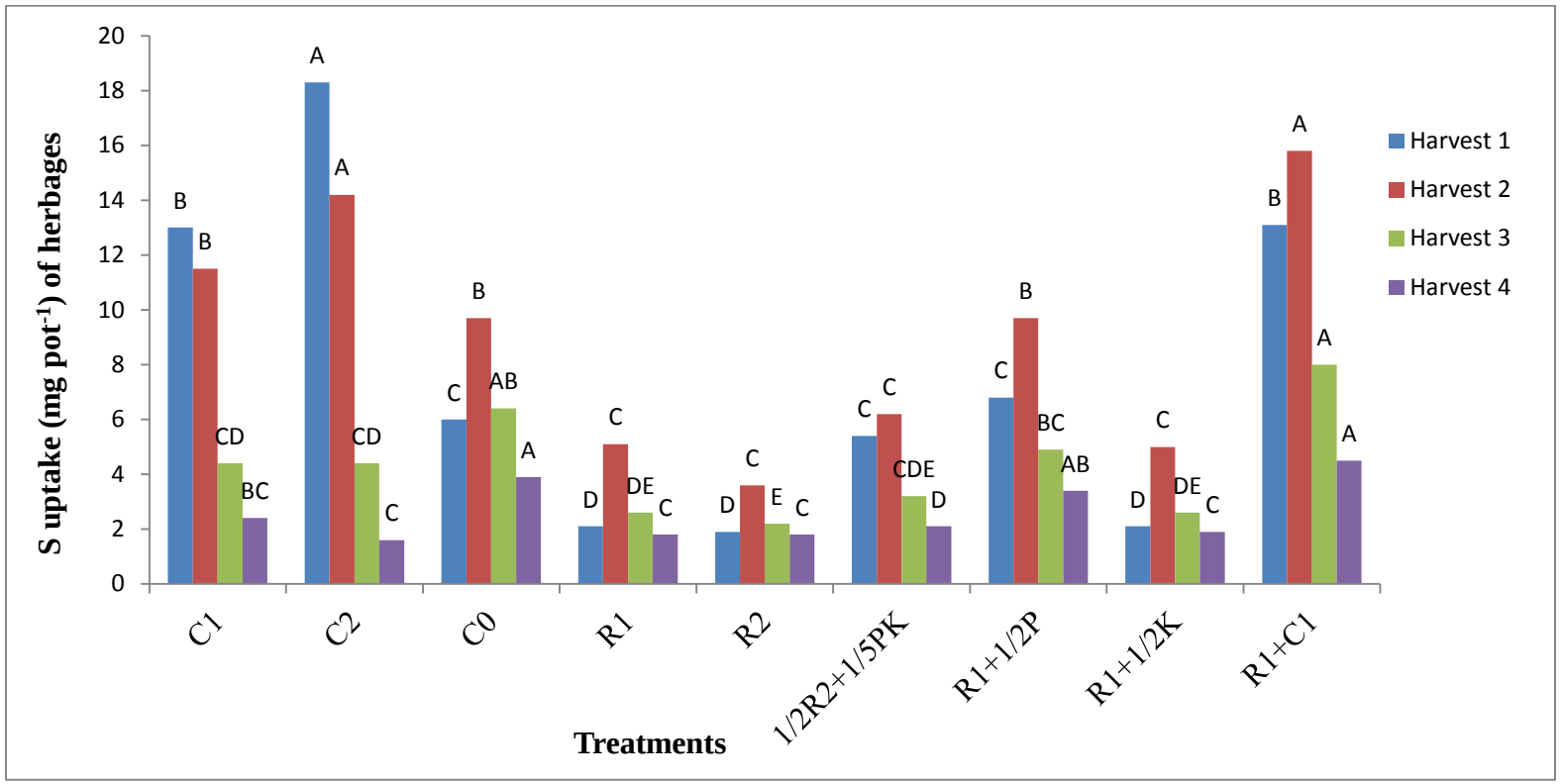

Figure 31: S removal (mg pot^{-1}) in the herbage at four subsequent harvests. Data are mean value of the replicates in a treatment (n=4) and bars headed by same letters(s) are not significantly different ($p<0.05$).

5.5 Nutrients concentration of stolons

Significant differences between treatments were found while analyzing the total nutrients concentration of stolons (Table 18). The treatments with RP and its combination with other nutrients showed significantly higher ($p<0.05$) concentration of K in stolons compared to control treatments (Figure 32 and Appendix-Table 14). R1+C1 had the highest K concentration, however it was not significantly larger than that of the other treatments with RP. The P concentration in stolons was significantly highest in C1 than in any other treatment, followed by that of C2. All treatments with RP, including R1+C1 had similar very low P concentrations, which however were not statistically different from those of C0 (Figure 33 and Appendix-Table 14).

Table 18: ANOVA table for total nutrients concentration in stolons.

Source	DF	MS				
		K	P	Mg	Ca	S
Treatments	8	168.81*	5.3480*	2.1980*	37.751*	0.63799*
Error	27	13.97	0.1736	0.3886	4.054	0.05241

*indicates significant difference at, $p<0.05$

Moreover, C0 had significantly higher Mg concentration followed by C1 and C2. Furthermore R1, R2, 1/2R2+1/5PK, R1+1/2P, R1+1/2K and R1+C1 had lower concentration of Mg in stolons (Figure 34 and Appendix-Table 14).

Regarding to Ca in the stolons, R1+C1 had significantly higher Ca concentration than all other remaining treatments. C1 and C2 had significantly lower concentration of Ca in stolons. While other treatments had higher concentration of Ca compared to C1 and C2 (Figure 35 and Appendix Table 14).

Concentration of S was significantly different between different treatments. C0, R1, R2, R1+1/2P and R1+1/2K had significantly higher concentration than C2 and R1+C1 (Figure 36 and Appendix-Table 14).

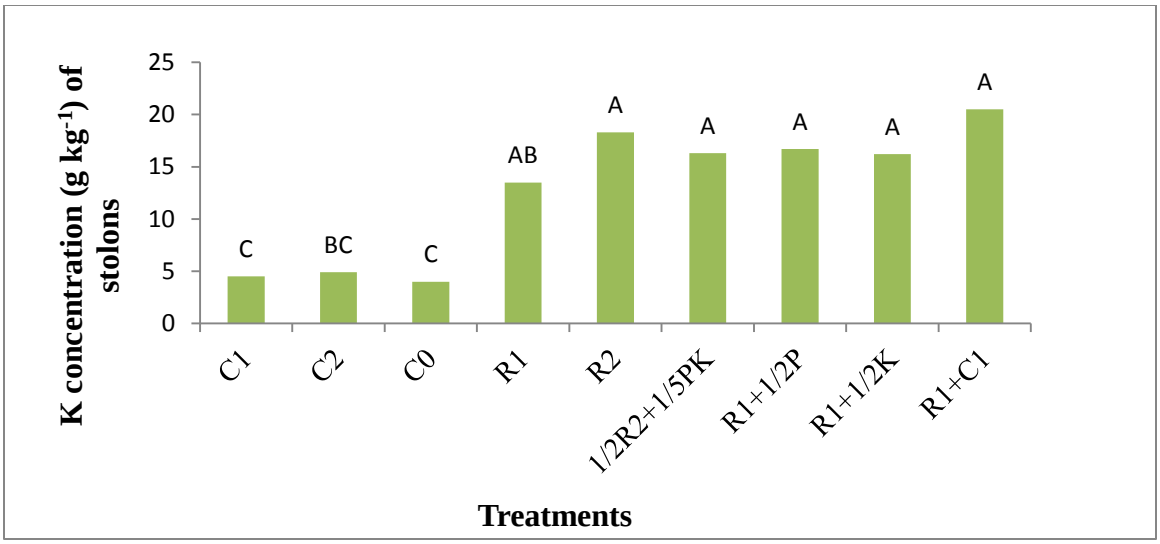

Figure 32: Potassium concentrations (g kg^{-1}) of stolons. Data are mean value of the replicates in a treatment (n=4) and bars headed by same letters(s) are not significantly different ($p<0.05$).

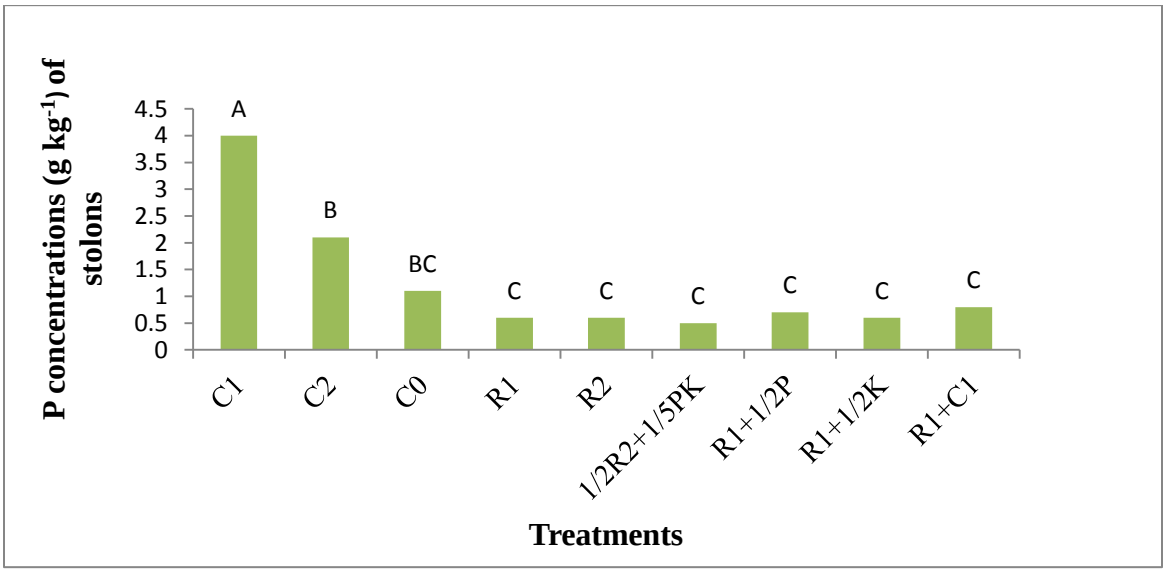

Figure 33: Phosphorus concentrations (g kg^{-1}) of stolons. Data are mean value of the replicates in a treatment (n=4) and bars headed by same letters(s) are not significantly different ($p<0.05$).

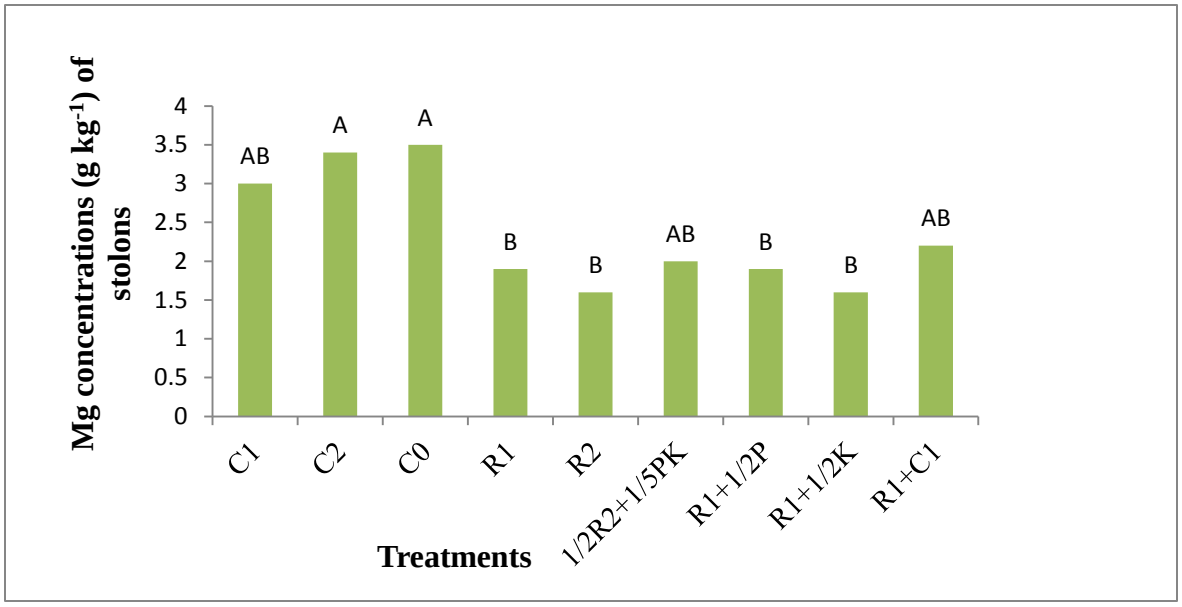

Figure 34: Magnesium concentrations (g kg^{-1}) of stolons. Data are mean value of the replicates in a treatment (n=4) and bars headed by same letters(s) are not significantly different ($p<0.05$).

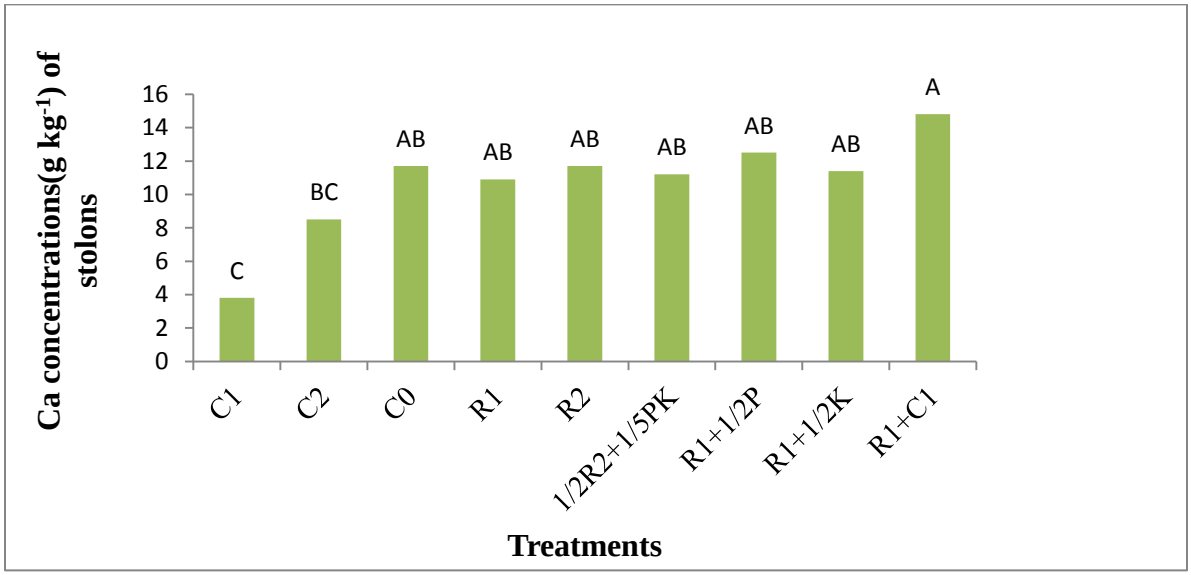

Figure 35: Calcium concentrations (g kg^{-1}) of stolons. Data are mean value of the replicates in a treatment (n=4) and bars headed by same letters(s) are not significantly different ($p<0.05$).

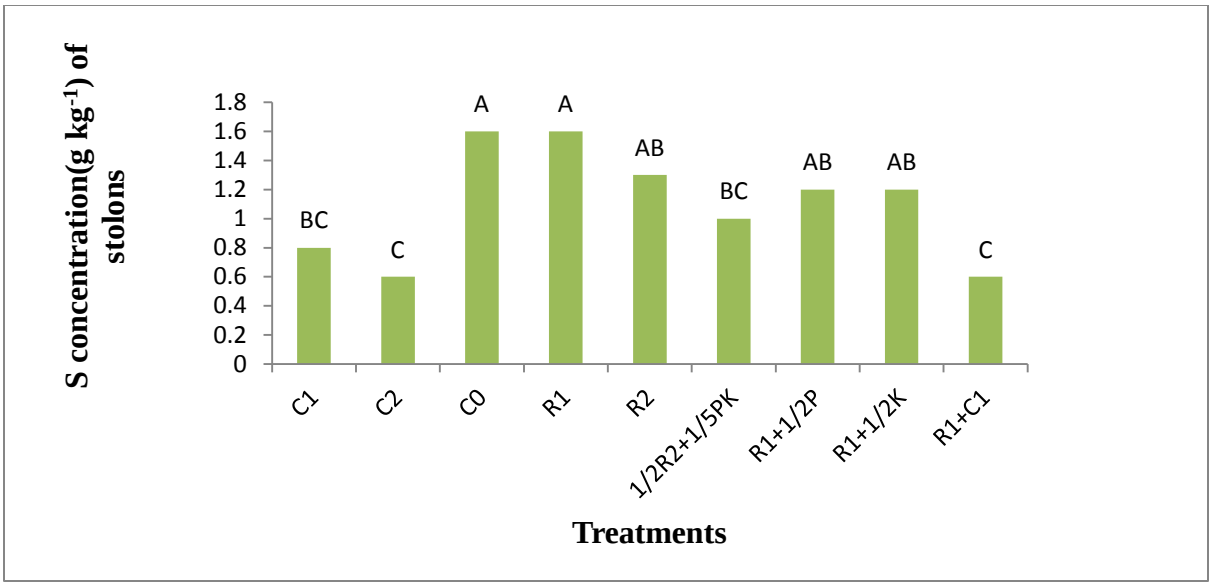

Figure 36: Sulphur concentrations (g kg^{-1}) of stolons. Data are mean value of the replicates in a treatment (n=4) and bars headed by same letters(s) are not significantly different ($p<0.05$).

5.6 Nutrients uptake per pot of stolons

Significant difference was observed between treatments in terms of nutrients uptake per pot in stolons (Table 19). R1+C1 had significantly higher uptake of K than other treatments. R1+1/2P had significantly higher uptake than C0 and R1. The remaining treatments had intermediate uptakes, and were statistically similar with each other (Figure 37 and Appendix-Table 15).

Considering P uptake, C1 and C2 were statistically similar and larger than all other treatments. C0 and R1+C1 had higher P uptake than the remaining RP treatments, but differences were not statistically significant. Besides, the remaining treatments were also non-significantly different with each other (Figure 38 and Appendix-Table 15).

Table 19: ANOVA table for nutrients uptake per pot in stolons.

S.	DF	MS				
		K	P	Mg	Ca	S
Treatment	8	2221.6*	125.97*	127.21*	1276.0*	3.4459*
Error	27	148.3	3.30	2.43	76.3	0.3495

*indicates significant difference at, $p<0.05$

C2 had significantly higher uptake of Mg per pot followed by C1 and C0 respectively. All rock powder combination treatments except R1+C1 had significantly lower Mg content (Figure 39 and Appendix-Table 15). There was also significantly higher uptake of Ca in R1+C1 followed by R1+1/2P, C2, C0 and 1/2R2+1/5PK in a decreasing order (Figure 40 and Appendix-Table 15). In relevant to S uptake per pot, significantly highest value was found in C0. Followed by this C2 and R1+1/2P had higher S content. R1+1/2K and R2 had significantly lower S content in decreasing order (Figure 41 and Appendix-Table 15). R1, R2 and R1+1/2K had the lowest uptake of P, Mg, Ca and S in the stolons.

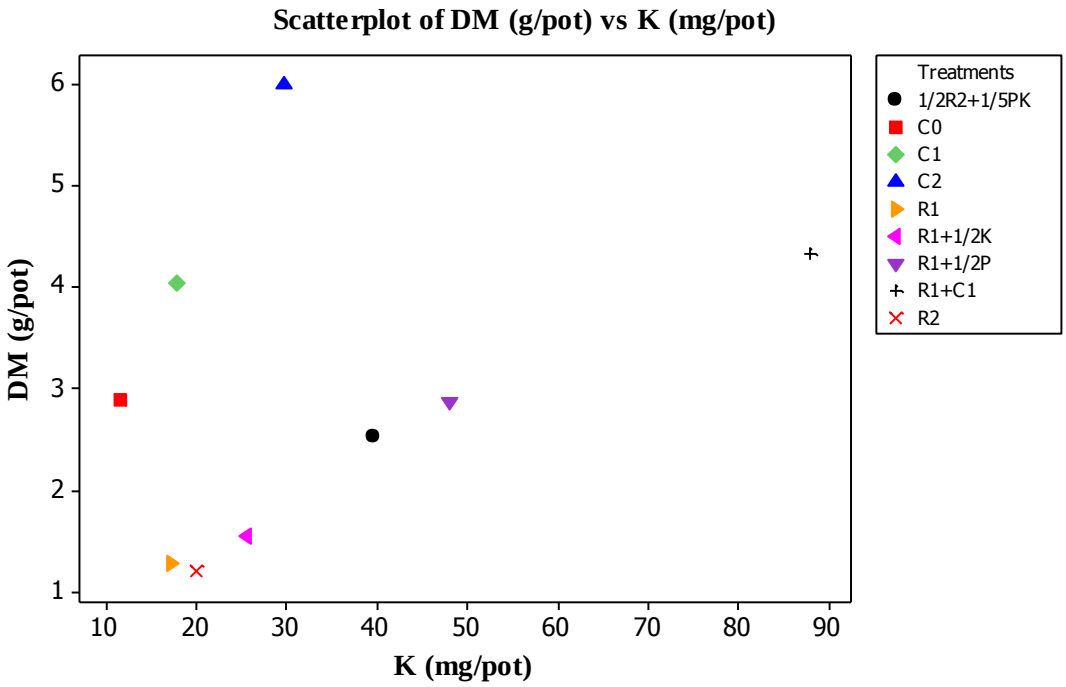

Figure 37: Dry matter of stolons and K uptake.

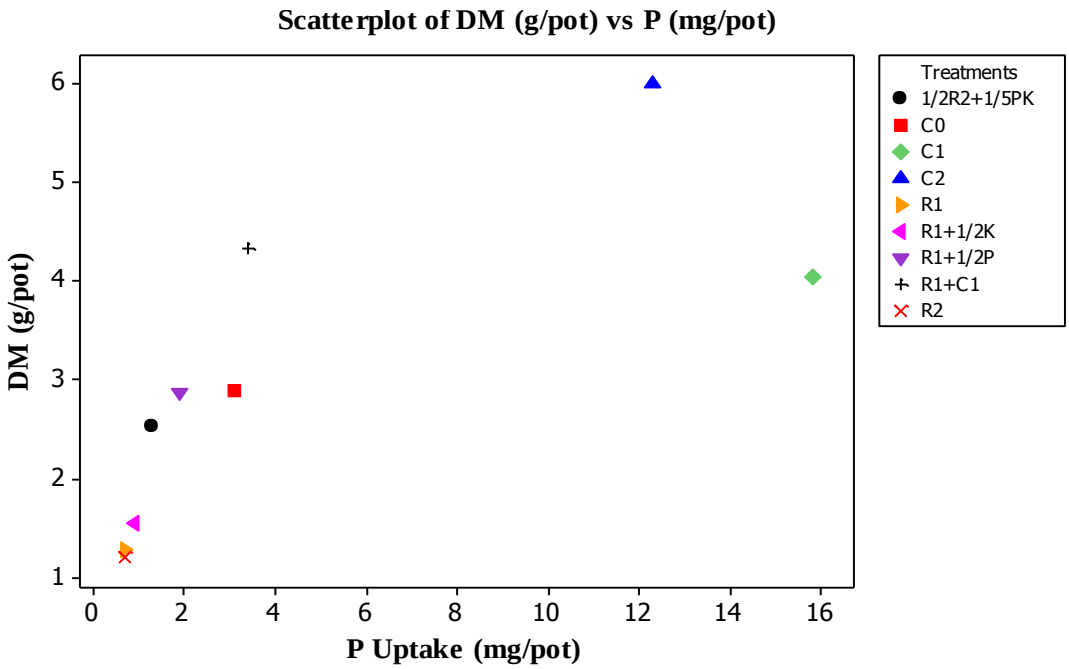

Figure 38: Dry matter of stolons and P uptake.

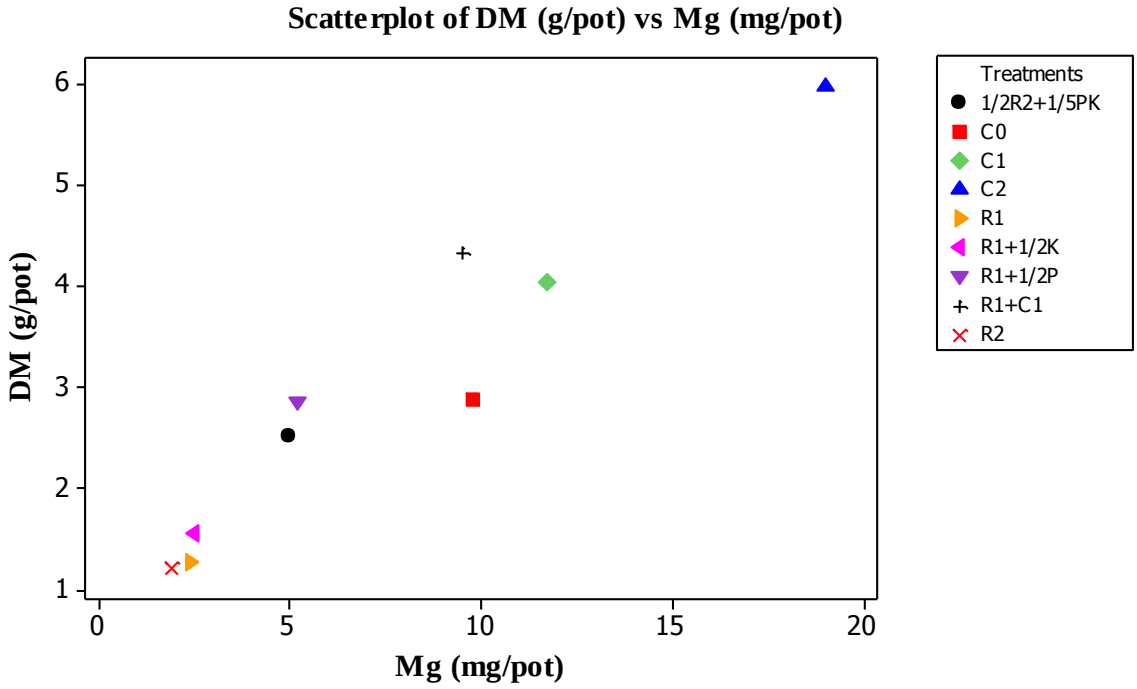

Figure 39: Dry matter of stolons and Mg uptake.

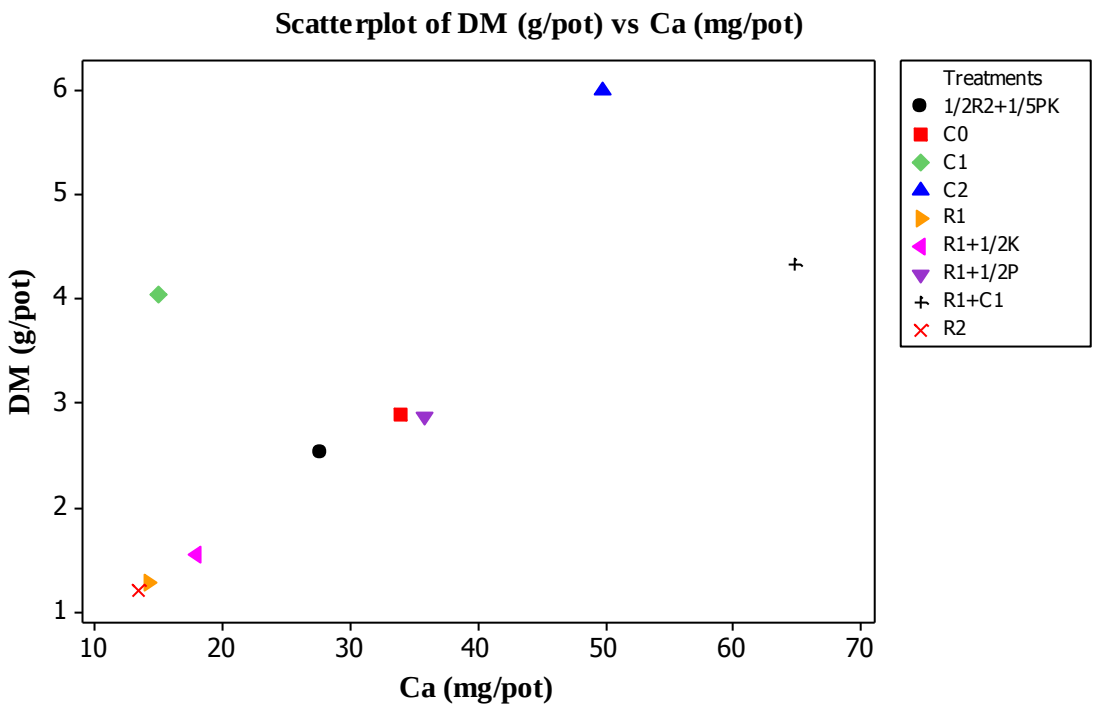

Figure 40: Dry matter of stolons and Ca uptake.

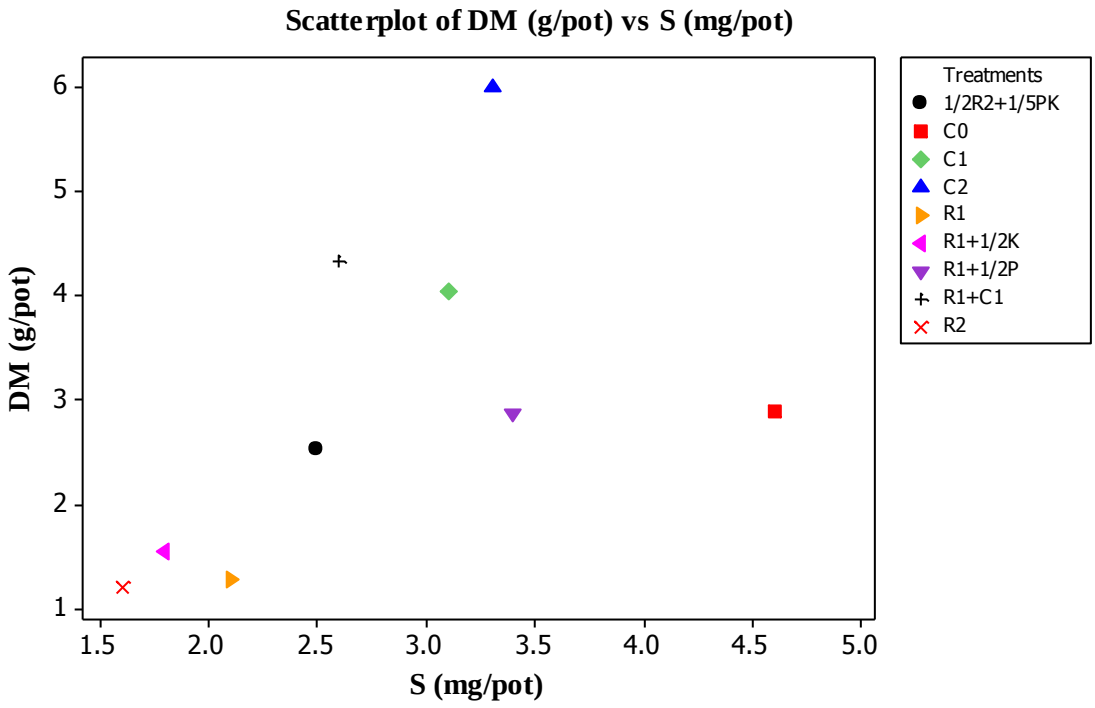

Figure 41: Dry matter of stolons and S uptake.

6. Discussion

The result of the pot experiments on DM yield (herbages) of white clover showed differences within treatments. Among them, rock-fertilized (R1+C1) had a positive effect on yield than fertilized (C1) only. Moreover, when half amount of soluble phosphorus (P) was given in addition to R1, the total DM yield increased substantially to nearly the same extent as C1. Also, half doses of soluble potassium (K) salts applied more to R1 did not show any positive response on growth of clover. This indicated that P is most important nutrients for the clover growth. Further, when rock powder was given alone (R1 and R2), it had a negative effect. Rock powder might have positive effects on plant growth if the experiments would have been continued for the long periods. Lime-fertilized (C2) had a positive effect as compared to fertilized one, however, Ca deficiency can reduce plant growth (Aarnio et al. 2003). The same trend was seen in case of the growth of stolons.

The DM yield of herbages increased in second harvest and further decreased with following harvesting. This might be the reason that plants were grown in severely P-deficient sandy soil. P deficiency was found limiting white clover growth (Hogh-Jensen et al. 2002). According to their study, P was inaccessible to plant root zone because the exchangeable phosphate was tightly bond with other compounds in soil. The dry yield of shoots greatly increases in beans, corns, rice and wheat after P is available to plants (Fageria et al. 1995). Also, Nieminen & Jarva (2000) mentioned about the decrease of growth of trees due to P deficiency on drained peat lands.

The sufficient range of P and K concentration in white clover is in between 2.5- 3 (g kg^{-1} DM) and 17-25 (g kg^{-1} DM) respectively (Pilbeam & Barker 2007). In herbages, the highest P level of C1 from 4 successive harvests (Appendix-Table 5) was found 3.7 (g kg^{-1}), 3.8 (g kg^{-1}), 3.6 (g kg^{-1}) and 4.2 (g kg^{-1}), respectively, which goes beyond the sufficient range of P concentrations in white clover while it's concentration from other treatments lied below the critical P values < 2.5 g kg^{-1} (Pilbeam & Barker 2007). On the other hand, with exception to C0 and C2 (harvest 1 was not included), all other plants (Appendix-Table 4) received plant available K in ample amount that crossing over the sufficient range 17-25 (g kg^{-1}) of K concentration in white clover (Pilbeam & Barker 2007). Likewise, they have also mentioned for clover (*Trifolium repens*), as the critical nutrient ranges of Magnesium (Mg) is 0.20-0.60 g kg^{-1} DM, while for Ca, a deficient range for shoots is 1.4 g kg^{-1}DM and 1.1 g kg^{-1}DM for S. As based upon results, it seems that the

concentration of Mg, Ca and S (Appendix-Tables 6, 7, and 8) extended above the critical ranges, mitigating the plant demand for these nutrients.

Analysis of K concentration in the herbage showed that, all rock fertilized plants had similar and very high K concentrations in the herbages, and this indicated that K in RP was easily available to plants. Plants received less P because it's dissolution was relatively very slow and that limited the plant growth. This reflects that lower total K uptake in some rock applied treatments was due to poor plant growth rather than lower K availability. Increase in P amount fosters plant growth and promotes nutrient uptake due to proper root growth (Marschner 1995). All P received plants have significantly increased DM yield and improved K and other ions uptake of all plants to a greater extent. The highest total dry matter yield and K yield was found in the treatment with rock and fertilizers. Fageria et al. (1995) illustrates that there was an improvement in nutrients uptake in four different crops (beans, corns rice and wheat) when P level was significantly raised.

Biotite disintegrates more quickly than other rock minerals though weathering and dissolution rate which can be affected by soil pH, biological activity, temperature, soil moisture etc. (Bakken et al. 2000; Bakken et al. 1996). Their studies also indicated that crushed carbonatite containing biotite had much more potentiality to release more plant available K. K released from biotite can be sufficiently reserved for long time in soil (Silfverberg & Hartman 1999). Their results are supported by our study also. K might not only release from bitiote (R2, 1/2R2+1/5PK) but also from apatite (R1, R1+ 1/2P, R1+1/2K and R1+C1). Also, biotite treatments had released more K than lime unfertilized control (C0). The same trend was noted in the previous experiment where increased rate of biotite with nephenine had uplifted grass yields as compare to control (Manning 2010).

Among the RP amended treatments, rock and fertilized (R1+C1) had the highest concentrations of K, P and S with large amount of Ca and Mg. The identical result was also found in case of stolons for the concentrations of K, P, Mg and Ca but limiting the availability of S. Additionally, R1+C1 showed the highest total plant uptake of K (769 mg pot^{-1}), P (40 mg pot^{-1}), Mg (51 mg pot^{-1}), Ca (451 mg pot^{-1}) and S (41.5 mg $pot^{-1)}$ in comparison to other rock powder added treatments. Similar results were found in stolons for uptake of K (87.8 mg pot^{-1}), P (3.4 mg pot^{-1}), Mg (9.5 mg pot^{-1}) and Ca (64.7 mg pot^{-1}) except for S.

Plants with KCl had increased dry matter yield mainly at the initial harvests in the experiment. However, no yield difference was found between KCl and biotite applied treatments during third harvest in a trial conducted by Bakken et al. (1997). Some rock powder applied treatments (R1, R2 and R1+1/2P) had raised K concentrations with subsequent harvesting in this experiment. This is also supported by Bakken et al. (1997). They explained that KCl supplied above 70% of the total K to plants at the first harvest, and had relatively higher amount of K than other treatments. Further, it seems that, biotite eventually provided a huge amount of K at the second harvest and the result was similar to KCl. But comparatively, there was a higher release of K from biotite and other minerals than KCl during the third growing season (Bakken et al. 1997), that also determines the genuine effects of biotite when amended rock-fertilizer in the soil.

The result revealed that only rock powder application have not shown any positive significant results in plants nutrient uptake. This is also supported by previous research (Aarnio et al. 2003), where rock powder was found as a slow releasing fertilizer. This might be slow release of nutrients from rock powder application alone. R1 had some more P release than R2 and plants taken up even little P from R1 sources which indicates that apatite can be the good source of P nutrient. Apatite alone has shown more soluble P concentrations than apatite-biotite applications (Aarnio et al. 2003). The highest total P concentrations and uptake found in C1 was due to short term effects of fast-release soluble P fertilizers. In addition to R1+1/2P, treatments with R1+C1 and R1 showed increased P concentrations over time. It might be due to long term effects of rock fertilizer application where P release was more in later periods than initial time.

The P concentration of igneous rock is usually slow (van Straaten 2007). Soil pH also affects a lot on nutrient concentrations within plants (Edmeades et al. 1983). The availability of P increases with pH above 7 but its availability further decrease in alkaline range (Brady & Weil 2002). This is a reason of having less P concentrations in first harvest in present experiment. In case of rock-fertilized (R1+C1) treatment, adsorbed P was due to high pH level of apatite. Heim et al. (2010) explained that the apatite-biotite-carbonatite constituents containing 50% calcite can possibly use as agricultural lime. Their study also showed that plants receive a little amount of P from magmatic apatite at higher soil pH. In alkaline soils $H_2PO_4^-$ reacts with Ca^{2+} and forms insoluble compounds like tricalcium phosphate. The reactions may occur again, forming extremely insoluble compounds like hydroxyl carbonate and fluro apatite that causes unavailability of P to

plants (Brady & Weil 2002). The finely grounded apatite can be one of potential sources that accelerates the weathering rate, and have some positive response to plants for P availability (Brady & Weil 2002).

In case of nutrients uptake, rock with P combination had higher uptake than rock with K combination in case of K and S, but in other cases all treatments had the same level of uptake. In contrast to some other studies, this explains about negative interaction of S and P in yield and uptake (Aulakh & Pasricha 1977). Unlike fertilized treatments, lime fertilized treatments showed reduced K uptake over subsequent harvestings in which high content of Ca and Mg might have prevented K uptake. Cations of these molecules strongly compete against one another in soil that restricts absorption of K ions to move towards plant root zone for uptake by plants (Brady & Weil 2002). Comparatively unfertilized control had less effect on K uptake. The nutrient uptake rate decreases with increasing harvesting periods of time.

Furthermore, addition of lime decreased P availability in our experiment (pH 6.5 observed after 7 days (Table 5) in both herbages and stolons. Calcium carbonate in combination with soluble fertilizer (C2) had increased the content of exchangeable Ca in plants. Lime increases yields, enhances Ca content and however, decreases the concentrations of Mg and K, without any response to P availability (Andrew 1960). Low P uptake might be a cause of high Ca content in soil. Ca predominantly exists in soil in the form of Ca-carbonates as a calcite or dolomite (van Straaten 2007). On contrary, lime treated plants had greatly increased availability and uptake of S in case of herbages.

The lime fertilized treatments showed steadily increased Mg concentrations over following harvestings. Study regarding liming incubation were interpreted by Edmeades et al. (1985) and confirmed that Mg fixation would take place if pH went above 6.2. Martini & Mutters (1985) also showed the results where extractable Mg concentrations in A horizon is strongly raised over increased time in case of lime treated plots. Liming had improved Mg uptake to some extent but not much as K and S uptake; as being competitor, K^+ most often substitutes Mg^{2+} ions extensively. This mechanism has been well illustrated by Straaten (2007). Similar effect can be seen on R1 and R2 as well.

Rock with P combination had quite higher Mg and Ca uptake than rock with K combination because increased content of exchangeable K^+ could not have promoted Mg^{2+} and Ca^{2+} ions for uptake by plants. Mg release declined over increased time in rock powder applied treatments. This may be due to the interference of K^+ against the Mg^+ ions. Apatite and biotite had some negative impact on Ca uptake that might be due to the strong antagonistic effects of K for plant Ca uptake. The experiment carried out by Jakobsen (1993) has also reported that high amount of K in soil used by plant uptake mechanism had severely depressed the uptake of Ca and Mg. Because of ionic reaction mechanism occurring in between the cations and anions linkage, there was also a positive effect of phosphate ions on availability of Mg within plants, and this also improves P accumulation by availability of Mg ions (Pilbeam & Barker 2007).

In herbages, unfertilized control had higher rate than combined treatments with P, Ca and Mg. In case of Ca; C1 had a quite less concentration of Ca as compared to other treatments. In case of Mg, higher rate was obtained with soluble fertilized treatment. In case of S nutrient, unfertilized control treatment had higher S concentration. This showed little difference in use of other fertilizers and rock powder application. In case of nutrient concentration of stolons, rock with K combination had higher effects than unfertilized control, but they are similar in nature in case of Ca and S nutrients. But in case of P and Mg, control treatment had higher nutrient content than combined treatments. This might be due to higher adsorption of these nutrients in natural fertilizers than the chemical ones. A higher adsorption reduced readily available of P to the plants (Schachtman et al. 1998) .

For stolon's DM yield and uptake, C2 had shown higher DM yield and more K, Mg and Ca uptake than C1 and C0 which could be due to liming effect. C1 had higher P uptake than C2. R1+C1 had shown higher uptake of K, P, Mg and Ca with high dry matter yield than other rock powder applied treatments. However, among all, control treatment had shown higher S uptake by plants. Higher S (3.4 mg pot^{-1}) uptake was found in R1+1/2 P as compared to other rock powder added treatments. Because of synergistic effect of P for plant growth and that leads to an increase in S availability and uptake. Previous researcher, Smith et al. (1985) have reported that availability of P to plants has significantly induced S uptake.

Aarnio et al. (2003) found that the total K, P, and Mg composition and also exchangeable Mg and soluble P concentrations in soil were stepped up even after 10 years of apatite-biotite application

and not any counterfactual evidence regarding leaching was observed. After all, the nutrients release from fast soluble fertilizers had not any significant results over long term. They are mobile and quickly available to plants after fertilization and are very susceptible to leaching. Because of slow nutrients release nature of rock powder, effects on nutrient concentration and uptake might not have much more positive effect on white clovers. A slower releasing minerals gradually release the nutrients after their immediate application whereas the faster releasing salts move rapidly to downward horizons in soil (Aarnio et al. 2003). So, long term experiments are needed to find correct results due to effect of rock powder as a nutrient. Our short term experiment have thrown message that rock powder can be used in organic farming as a slow nutrient releasing fertilizer as well as demand further clarified by long term experiments.

7. Conclusion

The results from this study confirmed a relatively rapid release of K from carbonatite rocks containing biotite, indicating that it can be used as K fertilizer. On the contrary, a slow release of P from apatite through weathering did not provide sufficient amount of phosphate to meet crop's demand for attaining higher DM yields. The P is one of the most essential plant nutrient for increasing plant growth. A specific knowledge on mineral weathering process and soil reactions should be further elaborated to enhance P availability to the plants.

The sole application of apatite-rich biotite carbonatite did not affect plant grown positively. The result indicates that a rock powder used alone as fertilizer in very poor sandy soils is not a feasible solution. In contrast to rock applied treatments, the fertilized treatments responded quickly after the application. However, the judicious application of this rock powders in addition to soluble fertilizers seemed to be more effective. The Ca and Mg availability were found to be raised substantially in lime treated plants.

There was a gradual release of soil nutrients from biotite-carbonatite and further reserves for maintaining long term availability of K, P, Mg, Ca and S. This rock can be regarded as slow releasing fertilizers in acidic soils, and therefore can have a significant role in sustainable soil nutrient management.

The interactions between soil and rock powder on nutrients release and plant uptake should be considered in order to understand the effectiveness of applied rock fertilizers. Some unconfirmed results and drawback of this study call for further investigations. However, this study is expected to become important basis for similar studies in the future.

8. References

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9. Appendixes

Table 1: Soil pH measures 1-2 days after the last harvest, 10 ml soil in 50 ml water

Soil Samples	Treatments	Soil pH
1	C1	4.45
2	C2	5.70
3	C0	6.00
4	R1	7.19
5	R2	7.37
6	1/2R2+1/5PK	6.79
7	R1+1/2P	7.27
8	R1+1/2K	7.50
9	R1+C1	7.25

Table 2: Number of dry leaves, stolons and flowers of four time harvestings registered before each harvesting.

Pot No.	Treatments	Number of completely dry leaves				Number of stolons above pot border				Number of flowers			
		Harvest				Harvest				Harvest			
		1	2	3	4	1	2	3	4	1	2	3	4
1	C1	4	25	15	-	12	10	3	0	0	5	1	0
2	C1	4	0	3	-	11	13	1	0	0	0	3	1
3	C1	4	2	3	-	9	10	1	0	3	9	8	1
4	C1	4	3	6	-	5	8	0	0	1	7	2	0
5	C2	4	40	31	-	10	21	3	0	0	5	0	0
6	C2	2	2	2	-	12	11	1	0	0	0	1	1
7	C2	8	45	17	-	17	12	3	1	0	0	1	0
8	C2	1	2	5	-	11	12	1	0	0	2	8	1
9	C0	3	3	2	-	1	3	3	0	0	0	1	0
10	C0	3	45	46	-	5	9	5	1	0	0	2	0
11	C0	1	2	3	-	5	6	3	0	0	0	0	2
12	C0	3	24	17	-	3	4	3	0	0	0	5	4
13	R1	1	4	3	-	3	6	0	0	0	0	0	0
14	R1	3	2	9	-	0	0	0	0	0	0	2	0
15	R1	3	65	19	-	0	2	0	0	1	0	0	0
16	R1	2	2	6	-	0	4	1	1	1	0	0	0
17	R2	2	1	1	-	1	6	3	0	0	0	0	0
18	R2	2	3	11	-	1	0	0	0	0	0	0	0
19	R2	3	5	10	-	1	2	1	0	0	0	0	0
20	R2	3	20	14	-	0	3	0	0	1	0	0	0
21	1/2R2+1/5PK	5	35	9	-	5	9	0	0	1	0	0	0
22	1/2R2+1/5PK	23	55	24	-	5	1	1	0	0	0	2	2
23	1/2R2+1/5PK	1	2	0	-	5	1	0	0	0	0	0	0
24	1/2R2+1/5PK	4	2	2	-	1	5	0	1	0	0	1	3
25	R1+1/2P	4	0	2	-	1	6	2	0	1	0	8	4
26	R1+1/2P	4	26	34	-	3	4	1	0	0	5	0	0
27	R1+1/2P	9	42	60	-	5	5	1	0	0	0	0	0
28	R1+1/2P	5	12	15	-	1	12	2	0	0	0	4	1
29	R1+1/2K	3	1	1	-	1	4	1	0	0	0	0	0
30	R1+1/2K	2	0	6	-	0	1	0	0	0	0	0	0
31	R1+1/2K	1	0	2	-	0	0	0	0	0	0	0	1
32	R1+1/2K	2	2	4	-	0	1	0	0	0	0	0	0
33	R1+C1	1	17	18	-	11	13	4	1	1	0	1	1
34	R1+C1	2	13	1	-	11	28	1	3	0	0	0	0
35	R1+C1	1	14	7	-	8	16	8	1	0	0	0	0
36	R1+C1	1	4	9	-	12	18	4	0	0	6	8	7

Table 3: Total dry matter yield (g pot^{-1}) of 4 successive harvests of clover herbages, stolons at the fourth harvest. Values are means of 4 replicates. Within a column, treatments without similar letters are statistically different with 5% confidence interval (Tukeys test).

Treatment	Dry matter yield (g pot^{-1}) of herbages					Herbages total yield (g pot^{-1})
	Harvest					
	1(H)	2(H)	3(H)	4(H)	4 (S)	
C1	5.48^{B}	5.34^{BC}	2.58^{BCD}	1.40^{BCD}	4.04^{BC}	14.8^{B}
C2	7.98^{A}	7.83^{A}	3.63^{B}	1.45^{BC}	5.99^{A}	20.9^{A}
C0	2.54^{CD}	4.23^{CD}	3.11^{B}	1.76^{B}	2.89^{BCD}	11.6^{CD}
R1	1.10^{D}	2.63^{EF}	1.50^{DE}	0.83^{D}	1.28^{D}	6.1^{F}
R2	1.13^{D}	2.16^{F}	1.37^{E}	0.91^{CD}	1.22^{D}	5.6^{F}
1/2R2+1/5PK	2.69^{CD}	3.49^{DE}	1.96^{CDE}	1.31^{BCD}	2.52^{CD}	9.5^{DE}
R1+1/2P	3.54^{C}	5.58^{B}	2.95^{BC}	1.75^{B}	2.87^{BCD}	13.8^{BC}
R1+1/2K	1.11^{D}	3.21^{DEF}	1.84^{CDE}	1.20^{BCD}	1.56^{D}	7.4^{EF}
R1+C1	6.09^{AB}	$8..82^{A}$	5.27^{A}	2.96^{A}	4.33^{AB}	23.1^{A}

*H indicates Herbages and * S for Stolons

Table 4: Potassium concentration in the herbage (g kg^{-1} dry matter) of various fertilized treatments at four subsequent harvests Values are means of replicates in a treatment. Within a column, treatments without similar letters are statistically different with 5% confidence interval (Tukeys test).

Treatments	Potassium concentration (g kg^{-1}) of herbages			
	Harvest 1	Harvest 2	Harvest 3	Harvest 4
C1	32.3^{AB}	17.0^{B}	13.0^{C}	17.5^{C}
C2	24.5^{C}	13.5^{B}	12.0^{C}	14.8^{C}
C0	13.0^{D}	11.3^{B}	10.3^{C}	12.0^{C}
R1	25.7^{C}	30.0^{A}	29.7^{AB}	32.2^{AB}
R2	25.2^{C}	29.8^{A}	32.50^{AB}	34.8^{AB}
1/2R2+1/5PK	29.8^{ABC}	28.8^{A}	28.0^{AB}	28.8^{B}
R1+1/2P	32.0^{AB}	34.0^{A}	34.0^{A}	36.0^{A}
R1+1/2K	28.0^{BC}	28.7^{A}	26.0^{B}	28.7^{B}
R1+C1	34.5^{A}	33.8^{A}	30.5^{AB}	34.5^{AB}

Table 5: Phosphorus concentration on the herbage (g kg^{-1}) of various fertilized treatments at four subsequent harvests. Values are means of replicates in a treatment. Within a column, treatments without similar letters are statistically different with 95% confidence interval (Tukeys test).

Treatments	P concentration (g kg^{-1}) of herbages			
	Harvest 1	Harvest 2	Harvest 3	Harvest 4
C1	3.7^{A}	3.8^{A}	3.6^{A}	4.2^{A}
C2	2.6^{B}	2.4^{B}	2.3^{B}	2.7^{B}
C0	2.4^{B}	2.2^{BC}	1.8^{BC}	1.9^{BC}
R1	1.3^{D}	1.2^{D}	1.0^{DE}	1.5^{CD}
R2	1.1^{D}	1.0^{D}	1.0^{DE}	1.4^{CD}
½ R2+1/5PK	1.6^{CD}	1.3^{D}	1.2^{DE}	0.9^{D}
R1+1/2P	1.7^{CD}	1.3^{D}	1.2^{DE}	1.8^{CD}
R1+1/2K	1.3^{D}	1.1^{D}	0.9^{E}	1.1^{CD}
R1+C1	2.1^{BC}	1.6^{CD}	1.4^{CD}	1.8^{C}

Table 6: Magnesium concentration (g kg^{-1}) of various fertilized treatments at four subsequent harvests of herbages. Values are means of replicates in a treatment. Within a column, treatments without similar letters are statistically different with 5% confidence interval (Tukeys test).

Treatments	Magnesium concentration (g kg^{-1}) of herbages			
	Harvest 1	Harvest 2	Harvest 3	Harvest 4
C1	3.7^{A}	3.5^{A}	4.8^{A}	6.1^{A}
C2	2.9^{BC}	3.4^{A}	4.1^{AB}	5.2^{AB}
C0	3.6^{AB}	3.5^{A}	3.6^{B}	4.2^{BC}
R1	2.1^{D}	1.7^{B}	1.8^{C}	3.0^{D}
R2	2.1^{D}	1.8^{B}	1.9^{C}	3.1^{D}
1/2R2+1/5PK	2.4^{CD}	2.0^{B}	2.0^{C}	3.2^{CD}
R1+1/2P	2.5^{CD}	2.1^{B}	2.1^{C}	3.2^{D}
R1+1/2K	2.5^{CD}	1.6^{B}	1.7^{C}	2.9^{D}
R1+C1	2.3^{CD}	1.9^{B}	1.9^{C}	3.2^{CD}

Table 7: Calcium concentrations in the herbage (g kg^{-1}) of various fertilized treatments at four subsequent harvests of herbages. Values are means of replicates in a treatment. Within a column, treatments without similar letters are statistically different with 5% confidence interval (Tukey's test).

Treatments	Ca concentrations (g kg^{-1}) of herbages			
	Harvest	Harvest 2	Harvest 3	Harvest 4
C1	8.5^{B}	8.6^{C}	8.1^{D}	8.8^{C}
C2	19.7^{A}	27.2^{A}	27.2^{A}	23.5^{A}
C0	25.5^{A}	26.2^{A}	22.5^{AB}	19.0^{AB}
R1	21.8^{A}	14.3^{B}	15.0^{C}	17.3^{B}
R2	21.5^{A}	13.5^{BC}	14.2^{C}	17.0^{B}
1/2R2+1/5PK	21.2^{A}	15.2^{B}	14.8^{C}	15.5^{B}
R1+1/2P	22.3^{A}	15.8^{B}	15.3^{C}	17.5^{B}
R1+1/2K	23.7^{A}	14.3^{B}	14.8^{C}	17.0^{B}
R1+C1	22.0^{A}	18.0^{B}	18.3^{BC}	19.8^{AB}

Table 8: Sulphur concentration on the herbages (g kg^{-1}dry matter) of various fertilized treatments at four subsequent harvests of herbages. Values are means of replicates in a treatment. Within a column, treatments without similar letters are statistically different with 95% confidence interval (Tukeys test).

Treatments	Sulphur concentration (g kg^{-1}) of herbages			
	Harvest 1	Harvest 2	Harvest 3	Harvest 4
C1	2.4^{A}	2.1^{AB}	1.7^{AB}	1.7^{BC}
C2	2.3^{AB}	1.8^{ABC}	1.2^{B}	1.1^{D}
C0	2.4^{A}	2.3^{A}	2.1^{A}	2.2^{A}
R1	1.9^{CD}	1.9^{ABC}	1.8^{AB}	2.1^{AB}
R2	1.6^{D}	1.7^{BC}	1.6^{AB}	2.0^{ABC}
1/2R2+1/5PK	2.0^{ABCD}	1.8^{ABC}	1.7^{AB}	1.6^{CD}
R1+1/2P	1.9^{BCD}	1.8^{BC}	1.7^{AB}	2.0^{ABC}
R1+1/2K	1.9^{CD}	1.6^{C}	1.4^{B}	1.6^{C}
R1+C1	2.2^{ABC}	1.8^{ABC}	1.5^{AB}	1.5^{CD}

Table 9. Potassium uptake (mg pot^{-1}) in the herbage of various fertilized treatments at four subsequent harvests. Values are means of replicates in a treatment. Within a column, treatments without similar letters are statistically different with 5% confidence interval (Tukeys test).

Treatments	K uptake (mg pot^{-1}) of stolons				
	Harvest 1	Harvest 2	Harvest 3	Harvest 4	Total
C1	176.3^{A}	90.9^{CD}	33.7^{C}	24.4^{C}	325.3^{CD}
C2	192.6^{A}	105.3^{C}	43.9^{C}	21.5^{C}	363.2^{C}
C0	32.8^{CD}	47.4^{E}	31.5^{C}	21.2^{C}	133.0^{G}
R1	28.7^{D}	78.7^{CDE}	44.8^{C}	27.2^{C}	179.4^{FG}
R2	28.4^{D}	64.4^{DE}	43.4^{C}	31.8^{C}	168.1^{FG}
1/2R2+1/5PK	79.6^{BC}	99.0^{CD}	54.0^{C}	37.7^{C}	270.2^{DE}
R1+1/2P	113.4^{B}	189.4^{B}	99.2^{B}	63.5^{B}	465.6^{B}
R1+1/2K	31.1^{D}	92.5^{CD}	48.2^{C}	34.5^{C}	206.2^{EF}
R1+C1	210.0^{A}	296.5^{A}	160.1^{A}	102.3^{A}	769.0^{A}

Table 10: Phosphorus uptake (mg pot^{-1}) in the herbage of various fertilized treatments at four subsequent harvests. Values are means of replicates in a treatment. Within a column, treatments without similar letters are statistically different with 5% confidence interval (Tukeys test).

Treatments	P uptake (mg pot^{-1})				
	Harvest 1	Harvest 2	Harvest 3	Harvest 4	Total
C1	20.3^{A}	19.9^{A}	9.3^{A}	6.0^{A}	55.5^{A}
C2	20.6^{A}	18.6^{A}	8.4^{AB}	3.9^{ABC}	51.4^{A}
C0	6.2^{C}	9.2^{C}	5.7^{C}	3.4^{BCD}	24.4^{C}
R1	1.5^{DE}	3.2^{E}	1.6^{E}	1.2^{D}	7.6^{D}
R2	1.3^{E}	2.3^{E}	1.4^{E}	1.3^{D}	6.2^{D}
1/2R2+1/5PK	4.4^{CDE}	4.4^{DE}	2.2^{DE}	1.2^{D}	12.2^{D}
R1+1/2P	6.0^{CD}	7.5^{CD}	3.6^{D}	3.1^{CD}	20.1^{C}
R1+1/2K	1.5^{DE}	3.5^{E}	1.6^{E}	1.4^{D}	7.9^{D}
R1+C1	12.8^{B}	14.5^{B}	7.4^{BC}	5.3^{AB}	40.0^{B}

Table 11: Magnesium uptake (mg pot^{-1}) in the herbage of various fertilized treatments at four subsequent harvests. Values are means of replicates in a treatment. Within a column, treatments without similar letters are statistically different with 95% confidence interval (Tukeys test).

Treatments	Mg uptake (mg pot^{-1})				
	Harvest 1	Harvest 2	Harvest 3	Harvest 4	Total
C1	20.3^{AB}	18.9^{B}	12.3^{AB}	8.5^{AB}	60.1^{B}
C2	23.1^{A}	26.2^{A}	14.9^{A}	7.6^{AB}	71.9^{A}
C0	9.2^{CD}	14.9^{BC}	11.1^{B}	7.5^{AB}	42.7^{CD}
R1	2.4^{D}	4.5^{D}	2.6^{D}	2.5^{D}	11.9^{F}
R2	2.4^{D}	3.9^{D}	2.6^{D}	2.9^{CD}	11.7^{F}
1/2R2+1/5PK	6.5^{D}	6.9^{D}	$3.8C^{D}$	4.3^{CD}	21.5^{EF}
R1+1/2P	8.8^{CD}	11.4^{C}	6.2^{C}	5.6^{BC}	32.0^{DE}
R1+1/2K	2.7^{D}	5.0^{D}	3.1^{D}	3.5^{CD}	14.2^{F}
R1+C1	14.2^{BC}	17.1^{B}	9.9^{B}	9.7^{A}	51.0^{BC}

Table 12: Calcium uptake (mg pot^{-1}) in the herbage of various fertilized treatments at four subsequent harvests. Values are means of replicates in a treatment. Within a column, treatments without similar letters are statistically different with 5% confidence interval (Tukeys test).

Treatments	Ca uptake (mg pot^{-1})				
	Harvest 1	Harvest 2	Harvest 3	Harvest 4	Total
C1	46.8^{BC}	45.5^{E}	20.7^{CD}	12.1^{C}	125.2^{D}
C2	157.3^{A}	213.0^{A}	98.7^{A}	34.1^{B}	503.2^{A}
C0	64.7^{BC}	111.4^{C}	70.3^{B}	33.3^{B}	279.7^{B}
R1	24.0^{C}	37.0^{E}	21.4^{CD}	14.1^{C}	96.4^{D}
R2	24.6^{C}	29.2^{E}	19.2^{D}	15.5^{C}	88.5^{D}
1/2R2+1/5PK	58.7^{BC}	53.1^{DE}	28.6^{CD}	20.2^{BC}	160.6^{CD}
R1+1/2P	78.1^{B}	87.7^{CD}	45.7^{BC}	31.1^{B}	242.5^{BC}
R1+1/2K	26.4^{C}	46.0^{E}	27.5^{CD}	20.4^{BC}	120.3^{D}
R1+C1	134.9^{A}	160.1^{B}	97.0^{A}	59.0^{A}	451.0^{A}

Table 13. Sulphur uptake (mg pot^{-1}) in the herbage of various fertilized treatments at four subsequent harvests. Values are means of replicates in a treatment. Within a column, treatments without similar letters are statistically different with 5% confidence interval (Tukeys test).

Treatments	S uptake (mg pot^{-1})				
	Harvest 1	Harvest 2	Harvest 3	Harvest 4	Total
C1	13.0^{B}	11.5^{B}	4.4^{CD}	2.4^{BC}	31.2^{B}
C2	18.3^{A}	14.2^{A}	4.4^{CD}	1.6^{C}	38.5^{A}
C0	6.0^{C}	9.7^{B}	6.4^{AB}	3.9^{A}	26.0^{C}
R1	2.1^{D}	5.1^{C}	2.6^{DE}	1.8^{C}	11.6^{E}
R2	1.9^{D}	3.6^{C}	2.2^{E}	1.8^{C}	9.5^{E}
1/2R2+1/5PK	5.4^{C}	6.2^{C}	3.2^{CDE}	2.1^{C}	16.9^{D}
R1+1/2P	6.8^{C}	9.7^{B}	4.9^{BC}	3.4^{AB}	24.9^{C}
R1+1/2K	2.1^{D}	5.0^{C}	2.6^{DE}	1.9^{C}	11.6^{E}
R1+C1	13.1^{B}	15.8^{A}	8.0^{A}	4.5^{A}	41.5^{A}

Table 14: Nutrients (K, P, Mg, Ca and S) concentration (g kg^{-1}) in the stolons at 4^{th} harvest. Values are means of replicates in a treatment. Within a column, treatments without similar letters are statistically different with 5% confidence interval (Tukeys test)

Treatments	Nutrient concentrations (g kg^{-1}) of herbages				
	K	P	Mg	Ca	S
C1	4.5^{C}	4.0^{A}	3.0^{AB}	3.8^{C}	0.8^{BC}
C2	4.9^{BC}	2.1^{B}	3.4^{A}	8.5^{BC}	0.6^{C}
C0	4.0^{C}	1.1^{BC}	3.5^{A}	11.7^{AB}	1.6^{A}
R1	13.5^{AB}	0.6^{C}	1.9^{B}	10.9^{AB}	1.6^{A}
R2	18.3^{A}	0.6^{C}	1.6^{B}	11.7^{AB}	1.3^{AB}
1/2R2+1/5PK	16.3^{A}	0.5^{C}	2.0^{AB}	11.2^{AB}	1.0^{BC}
R1+1/2P	16.7^{A}	0.7^{C}	1.9^{B}	12.5^{AB}	1.2^{AB}
R1+1/2K	16.2^{A}	0.6^{C}	1.6^{B}	11.4^{AB}	1.2^{AB}
R1+C1	20.5^{A}	0.8^{C}	2.2^{AB}	14.8^{A}	0.6^{C}

Table 15. Nutrient uptake (mg pot^{-1} in stolons collected after the fourth harvest Values are means of replicates in a treatment. Within a column, treatments without similar letters are statistically different with 5% confidence interval (Tukeys test).

	Nutrients uptake in stolons (mg pot^{-1})				
Treatments	K	P	Mg	Ca	S
C1	17.8^{C}	15.8^{A}	11.7^{B}	14.9^{D}	3.1^{BC}
C2	29.7^{BC}	12.3^{A}	19.0^{A}	49.7^{AB}	3.3^{AB}
C0	11.6^{C}	3.1^{B}	9.8^{B}	33.9^{BCD}	4.6^{A}
R1	17.1^{C}	0.7^{B}	2.4^{C}	14.1^{D}	2.1^{BCD}
R2	19.9^{BC}	0.7^{B}	1.9^{C}	13.3^{D}	1.6^{D}
1/2R2+1/5PK	39.6^{BC}	1.3^{B}	5.0^{C}	27.6^{CD}	2.5^{BCD}
R1+1/2P	47.9^{B}	1.9^{B}	5.2^{C}	35.8^{BC}	3.4^{AB}
R1+1/2K	25.5^{BC}	0.9^{B}	2.5^{C}	17.8^{CD}	1.8^{CD}
R1+C1	87.8^{A}	3.4^{B}	9.5^{B}	64.7^{A}	2.6^{BCD}