Nutrients and tillage interactions in rice fallow cowpea (*Vigna unguiculata* L. Walp.) production

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DECLARATION

I hereby declare that this thesis entitled **"Nutrients and tillage interactions in rice fallow cowpea (*Vigna unguiculata* L. Walp.) production"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **"Nutrients and tillage interactions in rice fallow cowpea (*Vigna unguiculata* L. Walp.) production"** is a bonafide record of research work done independently by **Ms. Vandana G. Pai (2015-21-025)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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Symbols / Notations and Abbreviations

CD	-	Critical difference
Chl a	-	Chlorophyll a
Chl b	-	Chlorophyll b
CRD	-	Completely Randomized Design
CT	-	Conventional Tillage
cfu	-	Colony forming units
DAP	-	Diammonium phosphate
dS/m	-	Deci Siemen per meter
DAS	-	Days after sowing
DMP	-	Dry matter production
EC	-	Electrical conductivity
et al.	-	Co-workers
Fig.	-	Figure
g/cc	-	Grams per cubic centimeter
GOK	-	Government of Kerala
GOI	-	Government of India
ha	-	Hectares
HYV	-	High Yielding Varieties
KAU	-	Kerala Agricultural University
LAI	-	Leaf Area Index
mM	-	Millimolar
Mg m^{-3}	-	Mega gram per cubic meter
MOP	-	Muriate of potash
MT	-	Minimum tillage
nos	-	Numbers
OPSTAT	-	Online agriculture data analysis tool

POP	-	Package of practices
RDF	-	Recommended dose of fertilizers
RBD	-	Randomized block design
SOC	-	Soil organic carbon
TDMP	-	Total dry matter production
Total Chl	-	Total chlorophyll content
ZT	-	Zero tillage

Introduction

I. INTRODUCTION

India is the largest pulse producing country and contributes 25% of the global pulse production. India produces 22.95 million tons of pulses from a total area of 29.5 million ha with an average productivity of 779 kg/ha which is much lower compared to other pulse producing countries, (GOI, 2017). United Nation declared 2016 as International Year of Pulses to increase awareness about nutritional significance of pulses and to enhance pulse production and also to sustain soil health as pulses are good at symbiotic nitrogen fixation. Pulses also have wide range of adaptability especially due to short duration, lesser input demand, and drought tolerance. Pulses are termed as "smart food" because of their nutritional qualities.

Though pulses play an important role in improving soil health, often they are cultivated under low input conditions, mainly on marginal and sub-marginal lands, or as catch crop under rainfed condition leading to low crop productivity (Choudhary, 2013). Unavailability of quality seed and other inputs in time, inadequate fertilizer application, as well as non-adoption of scientific crop management practices are the reasons for low productivity of these crops.

Under the present scenario of climate change, increasing cost of inputs, lack of availability of labour and fluctuating prices, achieving sustainability in pulse production for ensuring food/nutritional security is a matter of concern. The major factors which indicate the non-sustainability of production systems include soil erosion, depleting soil organic matter content, intensive tillage induced problems, soil salinity, secondary and micro-nutrients deficiencies, mono-cropping related problems *etc*. This calls for adoption of conservation agricultural technologies.

Conservation agriculture involves resource saving technologies aimed at increasing agricultural production and productivity, maintaining the present natural resource base. Minimum soil disturbance, permanent soil cover with stubbles, cover crops, and crop rotations involving legumes, are the key to this concept so that higher productivity can be achieved through minimum environmental harm. It provides an opportunity to the farmers for reducing the production cost along with reducing the nutrient and water loss leading to more profit.

The availability of Ca and Mg is very low in Kerala soils due to leaching under heavy rainfall. About 80 per cent of Kerala soils are deficient in available Ca and Mg (Rajasekharan *et al.,* 2013). Intense rainfall leads to leaching of the basic nutrients to deeper layers. Farmers usually skip organic manure application, which aggravates secondary and micro nutrient deficiencies. Although liming of the soil can meet the crop requirement of calcium, demand for magnesium and sulphur have to be met through fertilizers in the case of deficient soils. Magnesium sulphate is a common source of Mg and S used to correct secondary nutrients deficiencies. Earlier research reports indicate that the secondary nutrient requirement of crops is almost similar to the phosphorus demand.

In Kerala, pulses are mainly cultivated as a *rabi* or summer crop especially in summer rice fallows. The area under pulses showed a drastic decline in the past few decades. The total area under pulses was 37,485 ha in 1975-76, which had drastically declined to 3764 ha by 2015-16, 1738 ha by 2016-17, and 1992 ha by 2017-18, (GOK, 2019). Cowpea is the major pulse crop cultivated in Kerala. High labour charges, scarcity of labour together with conversion of paddy fields for non-agricultural uses are the main reasons for declining trend in pulses production of the state.

In rice fallow crop production, usually tillage is undertaken for the raising of succeeding crop which is labour and energy intensive. Compared to conventional tillage, minimum and zero tillage requires less energy and labour. Tillage, nutrient management and weed management are the major components which decide the total cost of cultivation. The declining area under pulses cultivation together with soil constraints calls for evolving sustainable crop management technologies in rice fallow pulse production. Under these circumstances a study on effect of various conservation tillage practices and secondary nutrient application in rice fallow cowpea production was planned with the following objectives

- To assess the effect of various conservation tillage practices on growth and yield of cowpea
- To study the effect of secondary nutrients on cowpea
- To work out the economics of cowpea production under conservation tillage practices and secondary nutrient application

Review of Literature

II. REVIEW OF LITERATURE

Conservation agriculture is gaining importance world over due to increasing awareness about sustainable soil health management. Tillage-nutrient management and biodiversity conservation are given major thrust in this concept. The acidic soils of Kerala are inherently deficient in calcium, magnesium and sulphur; besides, heavy rainfall causes leaching of these nutrients to deeper layers making it unavailable for plant uptake. Although liming of the soil can meet the calcium requirement of the crop, magnesium and sulphur have to be supplied through fertilizers in case of deficiency. Apart from this, continuous tillage operations accelerate soil erosion causing leaching of nutrients. Proper nutrient management along with conservation tillage, can be adopted to ensure higher yield and to realize more returns. The literature on the response of pulses to potassium and secondary nutrient application under different tillage practices has been reviewed in this chapter.

Utilization of rice fallows for pulse production

In India, rice fallows in *rabi* account for 11.65 m ha area. Rather than leaving rice fields as fallow, it can be utilized for cultivation of short duration crops like pulses and oilseeds, which fits into the existing rice-based cropping system. In Kerala, current fallow land is 1.48 per cent of the total geographical area. The area under rice in winter season in Kerala accounts for 86710 ha (GOI, 2019). Rice fallows offer a potential site for various short duration crops like pulses which enhance soil fertility as well as assure additional income to farmers. Conservation tillage is a method of land preparation where crop residue is maintained on soil surface itself adopting either minimum tillage or zero tillage (Unger and McCall, 1980). Through conservation tillage, 30 per cent or more of the soil surface is covered by crop residues and are of four main types: mulch tillage, ridge tillage, zone tillage, and no-tillage (Carter, 2005). Apart from economic advantage, conservation tillage also has environmental importance compared to conventional tillage.

In order to adopt and practice zero tillage at a commercial or marginal level, farmers should have accessibility to no-till drill for the sowing of seeds, which either are not easily available or are costly at commercial scale, (Sanchez-Giron *et al*., 2004).

1. Effect of conservation tillage on growth and yield of various leguminous crops

One of the main objective of tillage is to loosen the soil for good aeration and root growth. Cook *et al*. (1995) and So and Ringrose-Voase (2000) reported that delaying sowing of legumes affected germination due to dryness and compactness of the soil. Nyakatawa and Reddy (2000), experimented cotton under conservation tillage and reported that compared to conventional tillage, under conservation tillage, the seedling count was 40- 50 per cent greater on the first and second day of seedling emergence. They also, found that seed germination, seedling emergence, dry matter and lint yield were enhanced significantly due to conservation tillage compared to conventional tillage and attributed this mainly to soil moisture reserves present under no-till system.

a. Seedling emergence

Baker and Saxton (2007) opined that poor seedling emergence is attributed to the unfavourable placement of seeds into the soil under no-till system, which either exposes seeds or will place it under crop residue. Ruhlemann and Schmidtke (2015) reported that under no-till system, seedling emergence of cover crops was affected by intensity of tillage and/or species. The poor yield and yield reduction under no-tillage were due to poor seedling emergence, higher weed infestation and decreased N mineralization (Ruhlemann and Schmidtke, 2015).

b. Growth

Akinyemi *et al*. (2003) observed that in cowpea raised under zero, ridge and flat tillage systems, in first season, statistically significant difference was observed in mean plant height of cowpea between the tillage systems, but this was non-significant in the second season. They also noticed that tillage had no significant effect on leaf area of cowpea. Henry and Chinedu (2014) studied the effect of tillage practices, P fertilizers and mulch on cowpea and found that, compared to un-mulched-untilled plots, mulching along with tillage resulted in higher dry matter accumulation in cowpea. Ruhlemann and Schmidtke (2015) in their study on cover crops observed that, although common vetch gave lower biomass, nitrogen fixation was higher under organic no-tillage system.

c. Root growth

Ball-Coelho *et al.* (1998) noted that the distribution of crop roots in different layers of soil can be affected by the type of tillage. As per the report by Pietola (2005) not adopting conventional tillage leads to an increase in soil density and impaired root growth. In a study on cowpea under various conservation tillage practices and mulching with weeds, significantly higher total root length was noticed under tilled soil with mulch either incorporated or surface applied, as compared to no-tilled no mulched plots, Ogban *et al.* (2008).

Muñoz-Romero *et al.* (2012) evaluated root growth of chickpea cultivated in continuous rotation with wheat using mini rhizotron, under zero tillage and conventional tillage systems and observed that, conventional tillage provided more favourable conditions for root development (0.34 mm/cM_3 versus 0.18 mm/cM_3) over no-tillage, and opined that it might be one reason for higher yields during the drier year, while in wetter years yields were similar under both tillage systems. They also reported that N content of the roots accounts for 15% of the total N extracted by the crop. However, they found that root: shoot biomass ratio has been increased under a no-tillage system in a drier year.

d. Yield

Akinyemi *et al*. (2003) observed that ridge tillage systems produced the highest yield and yield attributes of cowpea. Lopez-Bellido *et al*. (2003) studied faba bean-wheat in continuous rotation over 11 years and found that, no-tillage did not significantly influence seed yield of faba bean, however, in rainy seasons no-tillage was found lesser beneficial compared to conventional tillage. Soon and Arshad (2004) noted that no-tillage in legume-based cropping system could increase crop production over conventional tillage.

Hemmat and Eskandari (2004) studied winter wheat-chickpea cropping system under reduced tillage and no-tillage and found that yield of wheat was highest under minimum tillage, whereas chickpea yield was higher under no-tillage with or without residue. In case of chickpea, no-tillage system yielded significantly greater yield by 24-57 per cent compared to reduced, minimum or conventionally tilled plots; and they concluded that in wheat chickpea system traditional mouldboard ploughing can be replaced with conservation tillage. Cowpea yields noted in ridge tillage were higher than in conventional tillage in Nigeria as reported by Akinyemi *et al.* (2003) might be due to availability of sufficient rainfall and better moisture conservation and absorption occurring under ridges, and in yields of different crops in farmers filed in Kenya as reported by Miriti *et al*., 2005.

In India, Arya *et al*. (2005) conducted an experiment to understand the effect of tillage, fertilizers, and irrigation treatments on chickpea cultivated after rice, and reported that growth and yield attributes of chickpea were significantly higher under deep ploughing using spade, 30:60:40 kg NPK/ha, and 60 mm cumulative pan evaporation. Reicosky and Saxton (2007) noted that the major hurdle in adopting a no-till system for crop production is yield reduction during the transition time. Sanchez-Giron *et al*. (2007) evaluated various farms with wheat-forage legume cropping systems and found similarity in yields between three tillage systems, however, zero tillage produced more than reduced and conventional tillage systems in 6 of the 9 years under study.

Yau *et al.* (2010) conducted trial on conventional, minimum, and no-tillage in barley, chickpea, and safflower, and got similar yields in no-tillage and conventional tillage for chickpea and safflower, as compared to barley and they opined that the taproot system of chickpea and safflower may be more adapted to untilled conditions over the fibrous root system of barley. Aikins and Afuakwa (2012), found that compared to no-tillage and disc ploughing or harrowing alone, disc ploughing followed by disc harrowing produced lowest soil penetration resistance leading for best performance of cowpea.

Amanullah *et al.* (2015) studied the impact of varied tillage practices on green gram growth and yield, and concluded that, thorough ploughing led to early emergence (6 days), higher germination percentage, maximum plant height (66 cm), greater number of pods/plant (23), higher grain yield (402 kg/ha) as well as biological yield (2023 kg/ha) in dryland conditions. Comparing the effect of three tillage practices *i.e.* no-tillage, permanent bed, and conventional tillage in maize-legume crop rotations, Yadav *et al.* (2017) reported that there was a significant difference in stover yield with maximum values with maize-chickpea-S*esbania* cropping system under zero tillage.

In a study conducted on eight cropping sequences under two tillage practices by Das *et al.* (2018) noticed that in areas which received negligible winter rainfall, a yield increment up to 4 %-70 % for winter crops was observed under no-tillage over conventional tillage. According to Alarcón *et al.* (2018) legume yield under various tillage systems was not affected by the tillage, whereas both the highest and lowest yields in cereals were produced in no-tillage system.

The biomass production and grain yield of faba bean were significantly greater (30 % higher) in minimum tilled plots than ploughed in first year of study, while in the second year, total above-ground biomass and grain yield were comparable in minimum tillage and conventional tillage plots (Volpi *et al.*, 2018). Das *et al.* (2019) assessed effect of conservation tillage and four rice residue management practices on lentil in India, and reported that, under residual moisture, lentil can be successfully cultivated in rice fields by adopting reduced tillage by retaining 40 cm standing stubbles or by mulching, as it resulted in significant difference in growth and yield of lentil as well as soil properties and quality.

2. Effect of conservation tillage on nutrient content and uptake

Uptake by wheat differed significantly due to tillage practices and quantity of N fertilizers applied (Halvorson *et al*., 2001). Soon and Clayton (2002) studied the effect of long term tillage on wheat production and they observed that tillage and crop rotation interaction is non-significant in grain nutrient content. Soil available N status is greatly influenced by tillage practices, as it has an influence on soil C and N mineralization and further N utilization by crops Al-Kaisi and Licht (2004).

Soon and Arshad (2004) noted that in legume-based cropping system, no-tillage resulted in higher N uptake by crops as compared to conventional tillage. Among various cultivation practices, tillage and nutrient management practices affect the nutrient status, dynamics within the plant system as well as a soil system, which in turn together influenced the nutrient use efficiency of crops. In maize N and P uptake increased when N fertilizers were applied with tillage, but uptake was significantly influenced by seasonal variability than by tillage, as reported by Al-Kaisi and Kwaw-Mensah (2007). Dodwadia and Sharma (2012) observed no significant effect of tillage and sowing method on concentration of N, P and K in grain and stover of green gram. Tillage had no significant effect on uptake of N, P, and K during summer season but was significantly lower under zero tillage as compared to normal tillage in rainy season, and it was mainly due to lower yields obtained under no tillage than in conventional tillage (Dodwadia and Sharma 2012).

Muñoz-Romero *et al.* (2012) found that, in chickpea, in straw and roots, N uptake was higher under no tillage systems. Similar finding of higher uptake of N, P, and K uptake under zero tillage was also reported by Naresh *et al.* (2014).Findings of Gill (2013) suggested that in lentil, highest N, P, and K uptake was noticed under conventional tillage than that of zero and minimum tillage because of improved growth and yield attributes leading to more nutrient absorption by the crop. Alam *et al.*, 2014 reported that, N uptake by the crop decreased when conventional tillage is converted to conservation tillage. Yadav *et* al. (2016), reported that, in maize, zero tillage recorded maximum total (grain and stover) N, P and K uptake and protein content in grains and was low under conventional tillage, which was attributed to better root development and increased forage area for nutrient extraction, leading to enhanced nutrient content in maize crop.

3. Effect of conservation tillage on soil properties

a) Soil physical properties: For proper crop growth and to maintain soil quality, maintaining soil physical properties in optimal condition is important. Method of tillage profoundly affects soil physical properties and hence it is important to select a suitable type of tillage practices without compromising successful growth and yield of crops. Edwards *et al*. (1988) reported that, in conservation tillage, the soil suffers from lower aeration and lower oxygen levels as compared to conventional tillage.

In tillage experiments, soil bulk density is a frequently measured soil physical-quality parameter, Rasmussen (1999). Olaoye (2002) stated that penetration resistance measures the energy that a young seedling must exert in the soil to emerge from the soil. It indicates the resistance which rootlets of young seedlings should overcome in the struggle of seeking and absorbing nutrients and water present in the soil. He also noted that disc ploughing followed by disc harrowing resulted in lower bulk density over zero tillage plots in Nigeria.

Arya *et al*. (2005) observed that, compared to normal tillage, deep ploughing gave low bulk density while it increased water-holding capacity, pore space and expansion volume of the soil. Penetrometer resistance measurements of soil can be used to estimate and understand the need of tillage practices, which helps in effective rooting thus facilitating good water and nutrient uptake by plants (Veenstra *et al.*, 2006).

In a study conducted by Aikins and Afuakwa (2012) with four tillage practices (disc ploughing alone, disc ploughing followed by disc harrowing, disc harrowing alone and no-tillage), in cowpea cultivation, zero tillage offered significantly higher resistance to root penetration compared to tilled soil treatments. They also observed that adopting disc ploughing followed by disc harrowing resulted in the lowest bulk density and also the highest cowpea yield. Das *et al.* (2018) conducted a study on eight cropping sequences under two tillage practices in India and found that zero tillage recorded significant improvement in soil moisture content and infiltration rate over conventional tillage.

b) Soil chemical properties: Ball-Coelho *et al*. (1998) reported that methods of tillage followed in crop production can change nutrient distribution in various soil layers. Sharma and Acharya (2000) have noticed that short term conservation tillage had no significant effect on soil organic carbon content, however, they opined that practicing conservation tillage for a longer period may have a significant effect on many soil properties, including soil moisture conservation leading to higher crop productivity.

In maize production, Sharma *et al.* (2010) observed that tillage and weed management practices did not give significant difference on soil organic carbon and total nitrogen content of soil. Das *et al.* (2018) reported that zero tillage significantly improved chemical properties of soil such as soil organic carbon, available N-P-K, in a study on eight cropping sequences under two tillage practices.

Dorr de Quadros (2012) indicated that, under zero tillage system soil status of phosphorus, magnesium, organic carbon and total N were significantly higher. According to Ruhlemann and Schmidtke (2015), soil inorganic N resources were higher under zero-till system, and they concluded that legume cover cropping under no-till system is adoptable if and only if weed density is less or checked, and reduced tillage to raise legume cover crops is good if the density of weeds is severe.

c) Soil biological properties: Soon and Arshad (2004) noted enhanced soil microbial N in legume-based cropping system under no-tillage compared to conventional tillage, but had no effect on extractable soil inorganic N. Zero tillage helps in increasing soil microbial population and their activity, also increasing soil organic carbon, (Jain *et al*., 2007). Vian *et al.* (2009) compared four tillage systems such as mouldboard ploughing, shallow mouldboard ploughing, reduced tillage, and shallow soil tillage, in maize-based cropping system and found that, adoption of reduced tillage is best in organic farming, as it enhanced soil microbial biomass in the upper soil layers which was comparable to shallow mouldboard ploughing.

According to Dorr de Quadros (2012) in untilled soil, microbial diversity was higher and anaerobic bacteria (*clostridia*) found to dominate in no-tilled soil, whereas anaerobic methanogenic archaea, were only detected in zero tilled soil. Das *et al.* (2018) in a study on eight cropping sequences under two tillage practices reported that tillage systems and cropping sequences significantly influenced and gave higher values for soil microbial biomass carbon and dehydrogenase activity (34 % higher).

4. Effect of tillage on weed population

Bilalis *et al.* (2001) concluded that sowing of cover crops on zero tilled plots helps in decreasing population of annual weed species because germination of weed seeds from existing seed bank is not induced under no-tillage as observed under conventional tillage. Moonen and Barberi (2004) reported perennial weeds are favoured under no-till system. Chauhan and Johnson (2009) observed that the vertical distribution of weed seeds is affected significantly by tillage. According to Mishra and Singh (2009), compared to continuous no-tillage and conventional tillage, rotational tillage method reduced the seed density of *Echinochloa colona* significantly.

As per the reports of Chauhan and Johnson (2009) zero tillage, minimum tillage and conventional tillage affects emergence pattern of various weed species and they found that in both years of study seedling emergence of *Digitaria ciliaris, Echinochloa colona, Eleusine indica, Ageratum conyzoides, Eclipta prostrata,* and *Portulaca oleracea* were greater in zero tillage compared to conventional and minimum tillage where the emergence was similar and this attributed its effect on vertical seed distribution in soil. They also concluded that zero tillage favours germination of smallseeded weed species which requires light for its germination. Chauhan and Johnson (2009) reported that zero tillage, minimum tillage and conventional tillage affects emergence pattern of various weed species and *Digitaria ciliaris, Echinochloa colona, Eleusine indica, Ageratum conyzoides, Eclipta prostrata,* and *Portulaca oleracea* were greater in zero tillage compared to conventional and minimum tillage.

Amuri *et al*. (2010) studied the effect of residue management practices on weeds in wheat-soybean production and suggested that zero tillage with higher residue level suppressed many weed species. Yau *et al.* (2010) found that, every year among various tillage practices adopted in barley, safflower and chickpea cultivation, and no-tilled plots had similar weed density and weed dry weight/M_2 as noticed under conventional tillage. They also noted that, average weed infestation over years was found to be lower in conventional tillage and zero tillage than in minimum tilled plots. Takim and Fadayomi (2010) studied maize-cowpea cropping system under various tillage practices and found that, tractor ploughed and harrowed plots had 35-36 % of total weed seedlings emerged, which was significantly higher than the observations recorded in tractor ploughed, harrowed and ridged plots (28-30 %).

Ruhlemann and Schmidtke (2015) observed that intensive tillage using mouldboard plough though was an effective method for weed control, it adds a lot of residues leading to rapid humus decomposition and soil erosion. Shahzad *et al.* (2016) noticed that among various wheat-based cropping systems cultivated under different tillage practices, mungbean-wheat systems had more broadleaf weeds, whereas zero tillage recorded higher grassy and broadleaf weed density.

Perennial weeds like *Cirsium arvense* and *Sonchus arvensis* were found to be associated with reduced-tillage and zero-tillage practices, Thomas *et al.* (2017). The population of weeds like *Echinochloa colona* and *Digera arvensis* was observed to be lowest in zero tillage-raised bed types over a four-year study, (Sepat *et al*., 2017). Mei *et al*. (2018) studied maize-wheat-soybean/common vetch under tilled and untilled conditions either with or without stubble retention, and observed that, number of weed species and weed density in all three crops been affected by crop growth stage and tillage; however in common vetch fields, weed density steadily decreased in plots under no-tillage with and without stubble retention.

Based on the results of a nine-year study on tillage, Alarcón *et al.* (2018), found that, compared to various tillage systems (no-tillage, subsoil tillage and minimum tillage), inter-annual environmental variability mainly effected the weed species diversity, and the highest weed density was recorded in minimum tillage system in 2004 while in 2005, minimum tillage recorded lowest. However, tillage systems mainly effected the composition of weed communities and they also found that, none of the tillage systems gave consistent effects on weed community diversity or on crop yields.

Cirujeda *et al.,* 2011 opined that, even slight effects of tillage system on weed communities might lead to larger shifts in weed community composition in the long term. Yadav *et al*. (2018) reported that, among two types of tillage in rice field, conventional tillage with 100 per cent residue incorporation registered higher total weed density of 89-168 weeds/M_2 and biomass of 9.6–183 g/m^2 on dry weight basis over no-tillage with 100 per cent residue retention which recorded 75-161 weed/M_2 and 8-155 g/m^2 on dry weight basis.

5. Effect of potassium on various leguminous crops

a. Effect of potassium on physiology

Potassium plays a vital role in stomatal opening and closing, photosynthetic CO_2 fixation, partition and utilization of photosynthates in plants as well as immunity to plants. Cakmak *et al*. (1994) found that K deficiency affects phloem export of sucrose in bean plants and the reduction in sucrose export was in the range of 10-20 % compared to K sufficient plants and addition of K^+ to beans cultivated under optimal moisture regimes has been found to increase the movement of photosynthates to plant roots. Photosynthates moved from source to sink might be the root cause for the increase in the number of grains per pod as explained by Ali *et al.* (1996).

Application of potassium fertilizer also helps the plants to cope-up with water stress in plants. Arif *et al.* (2008) observed that potassium is involved in protein synthesis, and it also imparts pest and disease resistance to the crops. Sangakkara *et al.* (2000) reported that applying fertilizer K resulted in an increased photosynthetic rate in cowpea and green gram. Application of potash enhanced availability of other nutrients as well as increased the photosynthetic activity as reported by Samiullah and Khan (2003). Bukhsh *et al.* (2011) observed that K^+ activates enzymes in the plant system.

b. Effect of potassium on growth parameters of leguminous crops

Sangakkara *et al.* (2001), reported that K nutrient increased leaf area and shoot dry weights of cowpea and green gram. They also reported a significant increase in root growth of cowpea and green gram under K application with its impact greater in green gram grown under low soil moisture. According to Kudrali *et al.* (2002), highest dry matter was recorded in faba bean and chickpea fertilized with higher rate of potassium.

Asgar-Ali *et al.* (2007) experimented effect of potash on chickpea and found that, plants height and number of branches were higher with application of K @ 150 and 125 kg/ha and they concluded that, increase in potash level nevertheless, did not enhance height significantly.

Hatami *et al.* (2010) reported that application of potassium oxide on soybean in North Khorasan, Iran increased dry matter of plant. In another study, Hamid *et al.* (2010) reported that potassium has an impact on growth and yield of soybean as it increased plant dry matter, RGR, CGR, NAR, and LAI, while the number of grains per pod, and test weight, were affected only by cultivar. As per the reports of Hussain *et al.* (2011), two cultivars responded to various levels of potash, and significantly higher plant height (49.93 cm) was recorded with application of potassium @ 90 kg/ha, which was on par to K_2O @ 60 and 120 kg/ha. In black gram significant increase in plant height and the number of primary branches were observed with the application of K_2O @ 20 kg/ha over no potash, (Thesiya *et al*., 2013).

According to Fooladivanda *et al.* (2014) response of green gram to K fertilizer varied with variety. In green gram, Kumar *et al.* (2014) observed that application of potash @ 120 kg/ha gave higher plant height (52.5 cm), number of branches, and nodules per plant and it was on par with K @100, 80 and 60 kg/ha, and was minimum in control plot where potash was applied @ 20 kg/ha.

Rao *et al*. (2015) studied the effect of K_2SO_4 @ 1% sprayed at pod initiation stage and flowering stage of black gram raised on black cotton soils and recorded that, effect is significant on leaf area per plant (390.93 cm^2). Jadeja *et al.* (2016) found that in chickpea K @ 60 kg/ha and 80 kg/ha increased nodulation, primary and secondary branches, plant height (50.93 cm) and were statistically on par. Anjaly and Isaac (2018) found that in cowpea P, K, and Zn had a significant effect on nodulation.

c. Effect of potassium on yield and yield parameters of leguminous crops

According to Geetha and Varghese (2001), application of potassium @ 20 kg/ha produced maximum vegetable cowpea yield, however, there was no significant difference in yield parameters due to application of both N and K. Application of potassium @ 40 kg/ha doubled per plant pods and seeds per pod, Samiullah and Khan (2003). However, according to Oad *et al.* (2003), with increments in levels of potash there was no significant difference in pod number, test weight, and seed-index of green gram.

Asgar-Ali *et al.* (2007) found that in chickpea application of potash had a significant impact on yield parameters and yield, that it resulted in significantly higher number of grains per pod, test weight, seed yield (2341.25 kg/ha), and biological yield (5942.38 kg/ha) with K @ 150 kg/ha. K application in green gram lead to enhanced grain yield (Ali *et al.*, 2010). Hussain *et al.* (2011) reported that, application of K @ 90 kg/ha yielded maximum number of pods/plant (26.82), number of seeds per pod

(8.32), and maximum seed yield (753 kg/ha) of cowpea; Also 1000 seeds weight with application of K_2O @ 120 kg/ha which was statistically on par to K @ 90 kg/ha.

Fanaei *et al*. (2011) stated that potassium plays a vital role in increasing number of pods/plant and number of grains/pod thus increased grain yield. Results of application of K and Zn in cowpea indicated that, application of K_2O @ 60 kg/ha and Zn @ 40 kg/ha produced significantly higher grain yield and stover yield, Chavan *et al.* (2012).

Thesiya *et al*. (2013) carried out an experiment to understand the effect of potassium and sulphur on black gram under rainfed condition and found significant positive influence of K on various yield parameters and higher number of pods per plant, pod length, number of grains per pod, 100-grain weight, grain yield (9.17 q/ha) and straw yield (18.28 q/ha) was observed in application of K_2O @ 20 kg/ha, which was on par with K_2O @ 40 kg/ha. They also reported that combined application of 20 kg K_2O/ha and 30 kg S/ha resulted in significant increase in yield and yield attributes of black gram. Manjunatha *et al.* (2013) studied the residual effect of K and sulphur on cowpea through two different sources and reported that application of 150 % K recorded highest grain yield of cowpea (11.2 q/ha) which was on par to the application of K_2O @ 75 kg/ha as MOP along with bentonite and magnesium chloride.

Kumar *et al.* (2013) reported that in soybean, application of recommended dose of NPK along with a spray of 1% potassium sulphate registered the highest number of pods per plant. Kumar *et al.* (2014) stated that higher doses of potash gave higher seed weight in green gram as compared to lower levels of K. They also reported that increasing potassium levels up to 80 kg/ha significantly affected grain yield beyond which differences remained at par.

Fooladivanda *et al.* (2014) stated that in green gram cultivation, K applied @ 180 kg/ha, either under optimum irrigation conditions or under moisture stress lead to improved yield parameters while same level of K with no water stress gave 5% higher grain yield of 2093 kg/ha. Significantly higher 100-seed weight (23.57 g) and the number of pods per plant (109.75), and seed yield (2086 kg/ha) was observed by Jadeja *et al.* (2016), in chickpea under K and S nutrition.

d. Effect of potassium on quality of leguminous crops

Das, 1999 has reported a synergistic effect of potassium on nitrogen uptake thus enhancing protein synthesis. It also activates necessary enzymes. Therefore, protein content increased significantly with each increment in K levels. Asgar-Ali *et al.* (2007) found that, chickpea under no potassium fertilizer recorded lowest grain protein content compared to maximum grain protein content with K_2O applied @ 150 kg/ha.

Hussain *et al.* (2011) observed that in mungbean, grain protein content was higher (26.74 %) in application of potash @ 120 kg/ha compared to control (25.02 %). Chavan *et al.* (2012) observed that application of 60 kg K_2O/ha recorded higher grain protein content in cowpea compared to lower levels of K.

e. Effect of potassium on nutrient uptake by leguminous crop

Kurdali *et al.* (2002) observed that K fertilizer application significantly enhanced nitrogen content in faba bean and the lowest N content was noticed in plants grown under low water regime (45-50 % of field capacity) with no potash.

Singh *et al.* (2002) and Chavan *et al.* (2012) reported that higher K levels gave higher K content in grains over the lowest K levels and increased the uptake of nitrogen, phosphorus, potash and zinc by cowpea grain and stover. Thesiya *et al.* (2013) revealed that applying K @ 20 kg/ha resulted in higher nutrient uptake. Kumar *et al.* (2014) also observed that, higher doses of potassium resulted in higher N content in green gram seeds.

6. Effect on leguminous crops

a. Effect of secondary nutrients on the physiology of leguminous crops

According to Cakmak *et al.* (1994) Mg deficiency in bean crop adversely affected phloem export of amino acids. However, when the deficient plants were supplied with Mg for 12 hr during the dark or light phase, a rapid increase in sucrose export could be observed and with the supply of Mg for 24 hr and 48 hr, phloem export reached comparable rate with the control. These results reveal the importance of Mg in translocation of photosynthates from leaves to various sinks.

Kumawat *et al*. (2006) reported that chlorophyll content of green gram leaves increased significantly with application of sulphur @ 60 kg/ha. Norton *et al.* (2013) stated that the concentration of sulphur in plants is found to be the lowest among all macronutrients, and is needed in essential amino acids and protein synthesis. They also stated that, though crops assimilate sulfate and reduce it to amino acids, it is essential to pay attention to the crop needs for S in balanced crop nutrition, as its requirement of crops varies widely and concentration lies in the range of 0.1-1.0 % in plant dry matter.

Delfani *et al.* (2014) indicated that application of nano-Mg to black-eyed pea was harmful to the plasma membrane. Published results from Berab and Ghosh (2015) found that various levels and sources of sulphur significantly affected leaf chlorophyll content of green gram as sulphur is involved in the formation of chlorophyll. Khaitov (2018) reported that application of lower levels of Mg (@ 0.25 mM or no Mg) produced weak vascular tissue, which restrained water and nutrients uptake. Canizella *et al*. (2018) noticed that under Mg and Zn fertilization the chlorophyll content varied from 283.4 mg/m^2 to 329.7 mg/m^2 leaf area in four different cultivars of the soybean crop.

b. Effect of secondary nutrients on growth parameters of leguminous crops

In black gram Subramani and Solaimalai (2000) found that, seed treatment with ammonium molybdate @ 25 ppm along with foliar spray of 0.25 % $ZnSO_4$ at 50 % flowering stage, as well as foliar spray of 1 % DAP with 0.5 % urea and 0.5 % $MgSO_4$

resulted in significantly higher LAI, specific leaf weight, crop growth rate, relative growth rate, net assimilation rate and grain yield in both the seasons. Rady and Osman (2010) observed that foliar application of Mg EDTA @ 30 mg/L at 30 and 40 DAS gave tallest plants in beans with larger leaf area compared to that of control.

In lentil, Azizi *et al.* (2011) observed that soil application of magnesium sulphate resulted in taller plants. Howladar *et al*. (2014) practiced foliar application of Mg-EDTA @ 1mM in pea plants at 25 and 40 DAS and noticed a significant increase in dry matter, leaf area as well as plant height compared to control (no Mg application). Foliar spray of Mg @ 100 mg/L along with N, P, and K at vegetative stage of soybean resulted in taller plants over the control plots; whereas spraying at pod filling stage resulted in highest dry matter, (Mannan, 2014). Foliar spray of with $CaCl_2$ and $MgCl_2$ at green floral bud stage gave significantly higher plant height and higher leaf area in pigeon pea (Kaur *et al*. 2015).

Wijanarko and Taufiq (2016) found that in soybean, application of dolomite by mixing it to the soil within 20 cm depth resulted in 8 % higher plant height as compared to application on soil surface. Lakshmi *et al.* (2018) reported that dry matter of black gram increased significantly due to foliar application of 1 % each of $CaNO_3$, $MgNO_3$ and sulphur as well as with foliar application of 0.2 % $ZnSO_4$. Khaitov (2018) reported that 0.5 mM magnesium application along with rhizobium inoculation resulted in more vigorous shoot growth, and observed a significant increase in root nodule number, nodule weight and size, as well as nodulation index in soybean with increase in Mg supply.

c. Effect of secondary nutrients on yield and yield parameters of leguminous crops

Thalooth *et al*. (2006) carried out a study in green gram and found that foliar application of 50 ppm $MgSO_4$ resulted in higher seed index and higher seed yield under stressed condition. Costa and Rosolem (2007) in an experiment on soybean reported that liming equivalent to 2.25 t/ha in acid soil resulted in reduced exchangeable-Al which in turn increased soybean yield by about 20 % compared to plots with no liming. Azizi *et al.* (2011) in an experiment conducted on lentil cultivars observed that among soil and foliar application of magnesium sulphate, soil application produced maximum grain and biological yield. However, 100-seed weight, pod number per plant, were comparable in both foliar and soil application.

In pea plants, foliar spray of Mg EDTA @ 1mM at 25 DAS and 45 DAS produced the highest number of pods/plant, higher seeds per pod, 100 seed weight (17.3g), Howladar *et al*. (2014). In a study carried out by Mannan (2014) in soybean, observed that Mg spray along with N, P, and K @ 100 mg/L each, produced highest number of pods per plant (93 pods/plant) compared to control (85 pods/plant), higher seeds per pod, 100 seed weight (12.52 g). In faba bean, foliar spray of $MgSO_4$ @ 50 and 200 mM resulted in highest number of pods per plant (Neuhaus *et al.*, 2014). Application of nano-Mg significantly enhanced yield, number of pods per plant and 1000-seed weight of black-eyed pea, especially when applied along with 0.5 g/L either Fe or nano-Fe, (Delfani *et al.*, 2014).

Application of NPK and liming with lime @ 20 % of lime requirement and gypsum @ 50 kg/ha resulted in lower number of immature pods/plant and higher seed weight (66.48g) in groundnut, (Ghosh *et al*., 2015). According to Berab and Ghosh (2015), among various sulphur sources, magnesium sulphate was superior over single superphosphate and gypsum with regard to seed yield and seed quality parameters of green gram in West Bengal.

Kaur *et al.* (2015) stated that foliar application of $MgCl_2$ at green floral bud stage of pigeon pea produced comparable seed yield per plant to that of control. Wijanarko and Taufiq (2016) reported that application of calcium through dolomite to soybean in acidic soil increased pod numbers by 48-49 % compared to no liming. However, the significant difference in seed yield due to interaction of lime dose and methods of application suggested that lime required to produce optimum soybean yield depends on method of lime application. They found that applying lime @ equivalent to 10 % Al saturation, registered highest yield that too on mixing it with soil within 20 cm depth. Lakshmi *et al.* (2018) observed a significant increase in seed yield and haulm yield of black gram in application of recommended dose along with a foliar spray of $CaNO_3$, $MgNO_3$ and Sulphur (one per cent each) as well as a foliar application 0.2 % $ZnSO_4$. Venkatesh *et al*. (2018) reported that application of magnesium in green gram raised in acidic soil, resulted in enhanced dry matter yield and it increased with increase in rates of magnesium application over control.

d. Effect of secondary nutrients on quality of leguminous crops

Azizi *et al.* (2011) reported that foliar application of magnesium sulphate registered highest percentage of crude protein in grains of lentil. Various sources and levels of sulphur had a significant effect on protein content of green gram which ranged from 15 to 24 per cent, and found to increase with increasing sulphur levels, irrespective of sulphur source, Berab and Ghosh (2015). They also noticed that beyond a rate of 60 kg S/ha, per cent protein content decreased irrespective of sources. They also reported that highest protein content (24.0 %) was obtained with the application of single superphosphate @ 60 kg S/ha followed by magnesium sulphate and gypsum.

e. Effect of secondary nutrients on nutrient absorption by leguminous crops

Meena *et al.* (2007), found that in groundnut, Ca content of pods is less than that in haulm and it may be due to lower mobility of Ca. Rady and Osman (2010) observed that in bean plant a spray of Mg-EDTA @ 30 mg/L resulted in higher uptake of N, P, K, Ca, Mg, and Zn. Rady and Osman (2010) found that foliar application of magnesium had significant effect on magnesium and zinc uptake. According to the reports of Azizi *et al.* (2011) seed magnesium percentage was higher with application of magnesium sulphate both trough foliar and soil application. Along with NPK and micronutrients, pulses generally remove 3-10 kg of Ca, 1-5 kg of Mg and 1-3 kg S for producing one-ton biomass, Choudhary *et al.* (2014). Delfani *et al.* (2014) reported that in black-eyed pea application of nano-Mg increased the uptake of stem and leaf Mg, indicating that mobility and absorbance capability of nano-Mg is greater.

Berab and Ghosh (2015) studied effect of various doses and sources of sulphur on green gram and found that, irrespective of which source is used, total sulphur uptake by crop continued to enhance with the enhanced levels of sulphur, nonetheless the highest uptake was reported with magnesium sulphate. Application of 80 kg S/ha failed to register higher S uptake compared to 60 kg S/ha.

Lakshmi *et al.* (2018) stated that, in black gram, foliar application of secondary nutrients and zinc resulted in progressive and significant increase in nutrient uptake at all growth stages. Venkatesh *et al*. (2018) indicated that there is a positive and significant correlation between soil available Mg and plant magnesium content and plant uptake in green gram. Canizella *et al*. (2018) found that with increase in soil available Mg concentration, Zn uptake by soybean plants got reduced.

f. Effect of liming on soil properties under legume cultivation

Liming decreases the phytotoxic level of Al and reduces nutrient imbalance Belkacem and Nys (1997). When soil is acidic Al, Fe, as well as Mn toxicity, is a constraint. Venkatesh *et al*. (2002) conducted a study on acidic soil having a pH, 4.8

found that organic carbon content of the soil could be increased due to liming, FYM and P application. In a study conducted on soybean in acidic soil, the post-harvest analysis showed an increase in soil pH, soil, organic carbon as well as available NPK, Ca and Mg due to surface application and incorporation of lime into 20 cm depth, Wijanarko and Taufiq (2016).

7. Effect of tillage and nutrients on economics

Conservation tillage to be attractive to farmers, should assure higher net economic benefit over traditional tillage practices either by reducing cost of production, increasing yield or more net income or less risk (Zentner *et al*., 2004). Akinyemi *et al*. (2003) found that there is economic benefit by raising cowpea under ridge tillage system over zero and flat tillage systems with the highest benefit: cost ratio of 3.8 in first season. Buman *et al.* (2004) noticed that in crop production of maize and soybean under long-term varying tillage practices, profit from maize under no-tillage and strip-tillage was highest in four out of five years and for soybean also, the five-year average profit was highest under no-tillage, narrow-row system. Blaise *et al.* (2005) conducted experiment by strip intercropping cotton and red gram under various tillage and fertilizer combinations and reported that, although, conservation tillage had maximum productivity, because of higher costs of herbicide, the marginal B: C ratio obtained was lower than treatment where only application of recommended dose of fertilizers was adopted.

Yedukondalu *et al*. (2007) concluded that soil application of $MgSO_4$ @ 50 kg/ha along with recommended dose of fertilizers resulted in higher B: C ratio (4.87) in soybean. Economic analysis of experiment on potassium fertilization in legumes resulted in higher net returns compared to no potassium application. Sanchez-Giron *et al*. (2007) evaluated various farm holdings ranging from 100 to 1600 ha for assessing economics of chisel ploughing and zero tillage systems compared to mouldboard ploughing for rainfed winter wheat with forage legume production and reported that zero tillage is most profitable system for farms with an area of 400 ha or more, while up to 400 ha chisel ploughing gave economic benefits than that of zero tillage, and in all farm sizes highest total cost was recorded for mouldboard tillage.

According to Asgar *et al.* (2007), application of K @150 kg/ha gave higher net returns of Rs.49431 per ha which was 76.23 % higher compared to control, followed by net returns recorded in application of K_2O @ 125 kg/ha. Kumar *et al*. (2013) found that in soybean, foliar application of potassium sulphate with recommended dose at both flowering and pod formation stages gave higher gross returns, net returns and B: C ratio.

Yadav *et al.* (2017) compared three tillage practices such as no-tillage, permanent bed, and conventional tillage in maize-legume cropping systems, and reported that effect of interaction between tillage and crop rotations was significant on net returns and B: C ratio and these parameters were recorded highest in maize-chickpea-S*esbania* rotations under zero tillage. Lakshmi *et al.* (2018) stated that, in black gram, combined foliar spray of secondary nutrients with 0.2 per cent $ZnSO_4$ at 25 and 45 DAS along with recommended dose of NPK fertilizers resulted in highest gross returns, net returns, and B: C ratio.

Materials and Methods

III. MATERIALS AND METHODS

Present study entitled "Nutrients and tillage interactions in rice fallow cowpea (*Vigna unguiculata* Walp L.) production" was conducted at Department of Agronomy, College of Horticulture, Vellanikkara, Thrissur, during 2016 to 2019. There were two experiments, a pot culture study and a field experiment. The details of the materials used and methods adopted during the course of the study are described in this chapter.

3.1 Location

The experiments were conducted at the Agronomy fields at College of Horticulture, Vellanikkara. The latitude and longitude of the study area is 10^0 31'N and of 76^0 13'E and the altitude is 40 m above MSL.

3.2 Climate and weather

The experimental site enjoys typical tropical humid climate with an average annual rainfall of ~3000mm and the maximum and minimum temperature are 32^0C and 24^0C respectively.

During the pot culture study period the area received a total rainfall of 301.1 mm. The mean maximum and minimum temperatures were 32.7^0C and 23.7^0C respectively, **Fig. 1**. In the second experiment during 2017, there was a rainfall of 320.5 mm. The mean maximum and minimum temperature were 34.2^0C and 22.5^0C respectively. While, in the next year (2018), rainfall of 491.5 mm was received and the mean maximum and minimum temperature were 34.1^0C and 26.2^0C respectively. Wind velocity and relative humidity recorded were 4 km/hr and 65.1% respectively. Data on weather parameters recorded during the cropping period are furnished in **Appendix I** and **Fig. 2 & 3.**

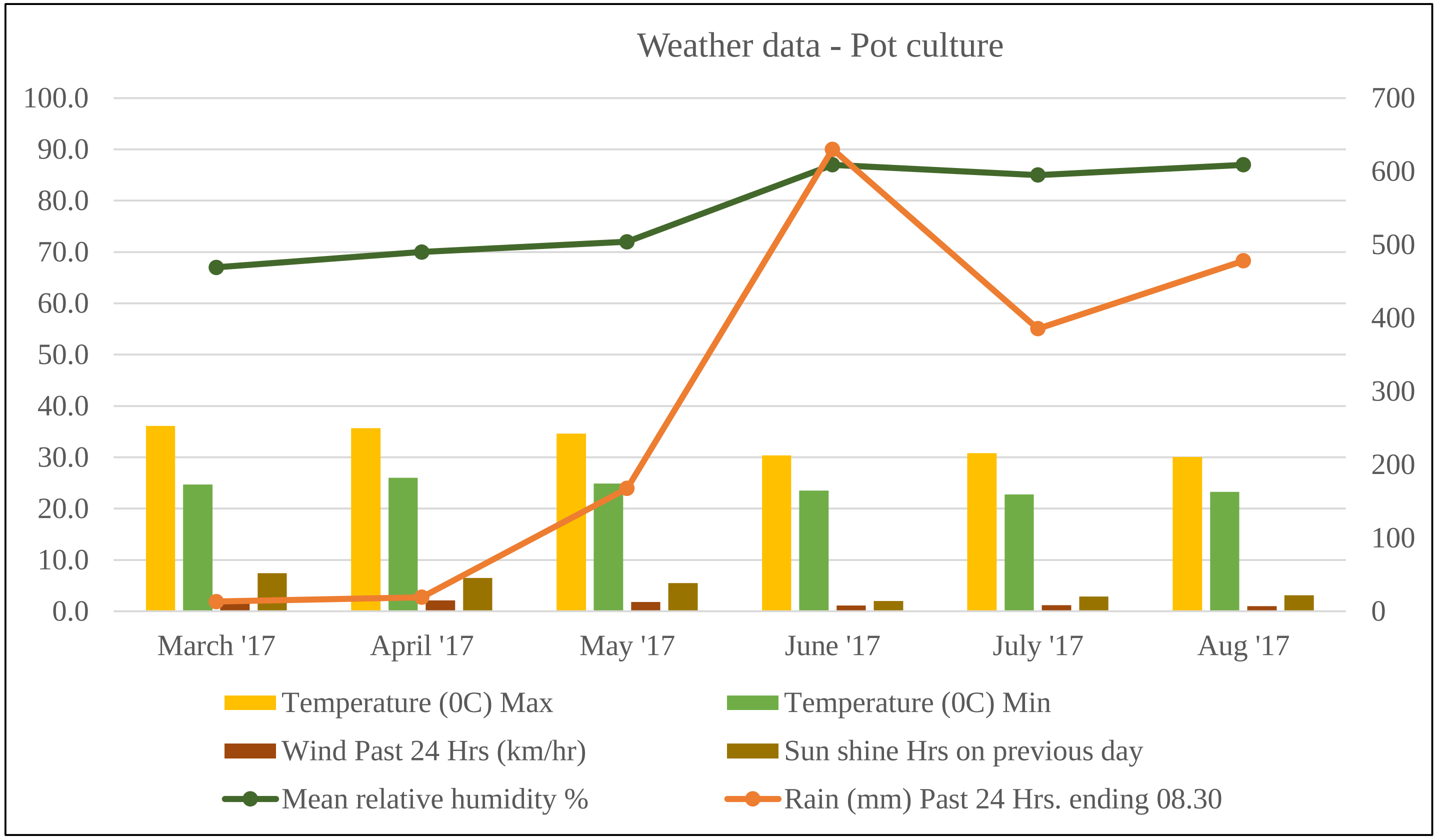


Fig. 1. Weather data during the crop period March 2017-August 2017

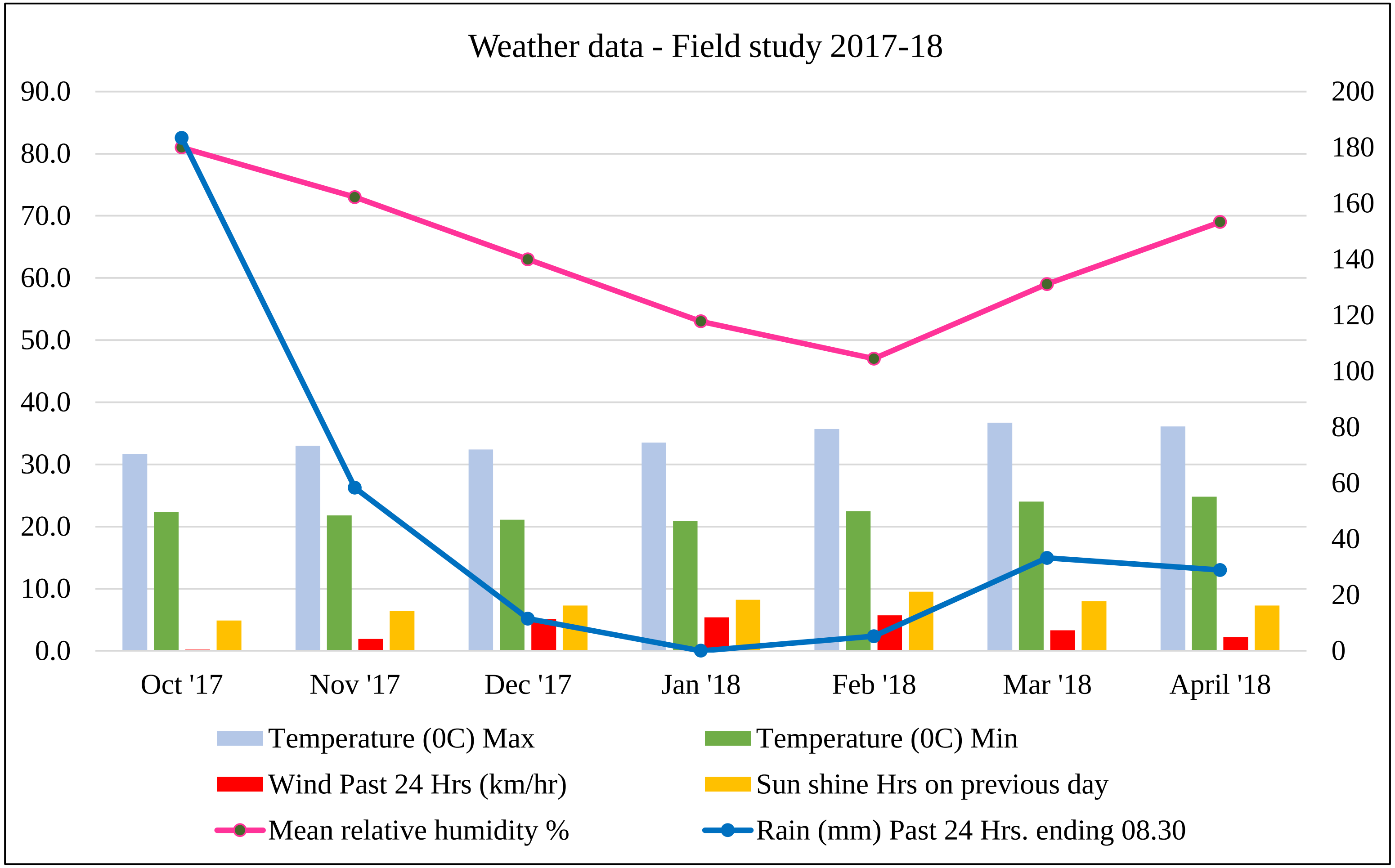


Fig. 2. Weather data during the crop period October 2017-April 2018

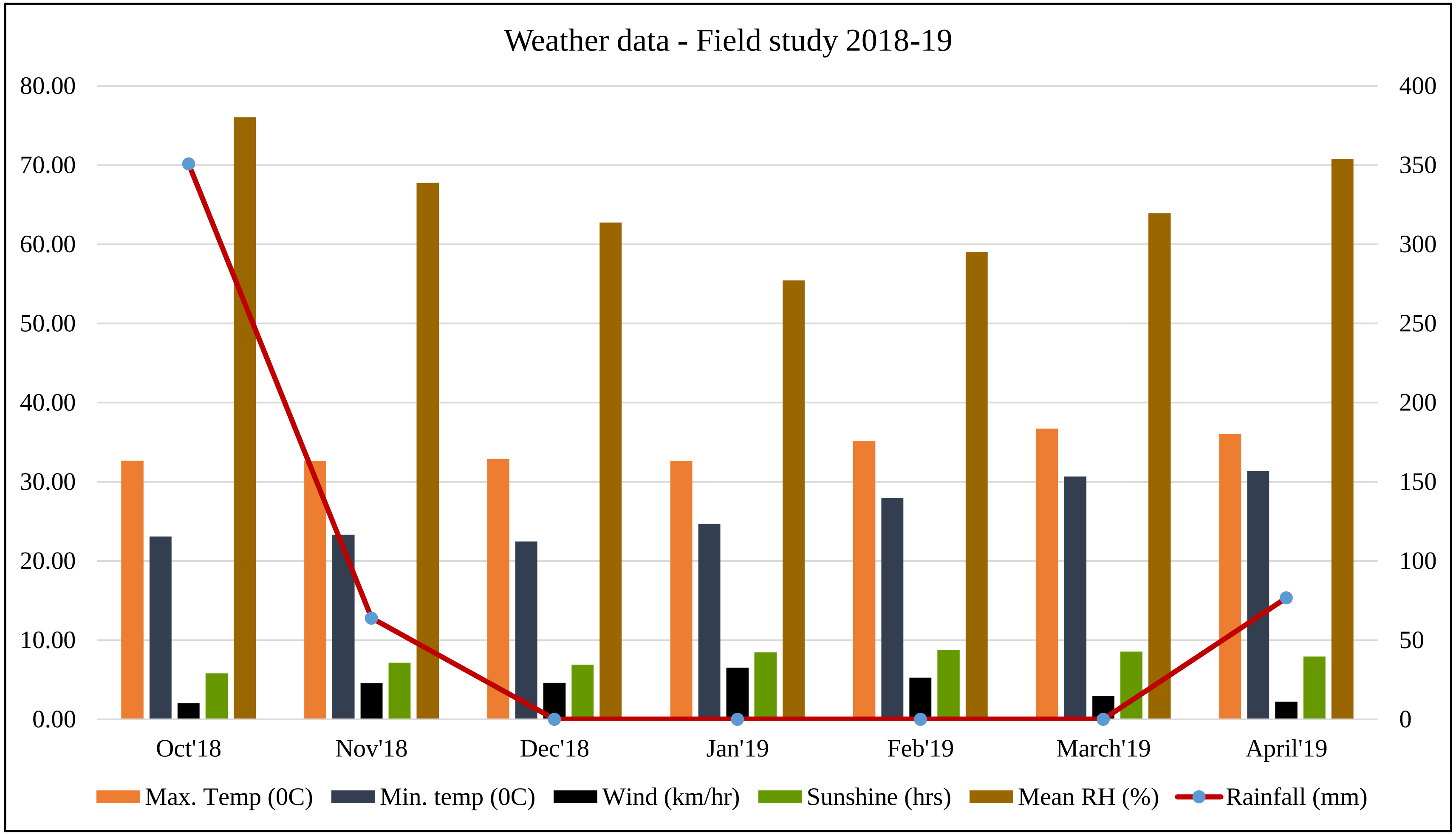


Fig. 3. Weather data during the crop period October 2018-April 2019

3.3 Soil

The texture of the soil of the experimental field was sandy loam. The physico-chemical and biological properties of the soil are given in **Table.1**

Table 1: Soil properties before experiment

Particulars	Field study	Methodology
A. Mechanical properties		
Sand (%)	68.81	Robinson's International Pipette method (Piper, 1966)
Silt (%)	16.32	
Clay (%)	14.87	
Textural class	Sandy loam	
B. Physical properties		
Bulk density (g/cM3)	1.40	Core Sampler Method (Michael, 2009)
Particle density (g/cM3)	2.60	
Porosity (%)	43.0	

Table 2: Microbial status of the soil before experiment

Particulars	Field study		Methodology
	2017	2018	
Total fungi (cfu/g)	2.7×10^4	2.9×10^4	Pour plate method (Agarwal and Hasija, 1986).
Total bacteria (cfu/g)	4×10^5	5×10^5	
Total actinomycetes (cfu/g)	0	0	
Rhizobium colony (cfu/g)	0	0	
Biological nitrogen fixers (cfu/g)	2×10^4	3×10^4	

Table 3: Soil chemical properties before experiment

Particulars	Pot culture	Field study		Methodology
		2017	2018	
pH	4.51	4.70	4.95	Soil water suspension (1:2.5) Jackson, 1958
EC (dS/m)	0.13	0.13	0.03	Soil water suspension (1:2.5) and read in EC meter, Jackson, 1958
Organic carbon (%)	1.4	1.0	1.1	Walkley and Black Method,1934
Available N (kg/ha)	401.5	412.1	369.6	Alkaline permanganate method, Subbiah and Asija, 1956
Available P (kg/ha)	20.30	3.98	3.77	Bray extractant-Ascorbic acid reductant method (Watnabe and Olsen, 1965)
Available K (kg/ha)	320.0	107.2	135.7	Neutral normal ammonium acetate extractant Flame photometry (Jackson,1958)
Available Ca (mg/kg)	1053.4	256.4	252.4	Atomic Absorption Spectrophotometer (Sims and Johnoson,1991)
Available Mg (mg/ kg)	61.2	65.4	60.6	
Available S (mg/ kg)	5.2	4.6	5.0	$CaCl_2$ extract-turbidimetry method (Chesin and Yien, 1951)
Available Fe (mg/kg)	45.0	51.6	49.1	Atomic Absorption Spectrophotometer (Sims and Johnoson,1991)
Available Mn (mg/ kg)	7.5	1.0	0.8	
Available Zn (mg/ kg)	3.3	0.98	0.95	
Available Cu (mg/ kg)	1.0	1.1	1.1	
Available B (mg/kg)	0.10	0.15	0.12	Hot water soluble boron (Tandon,1993)

3.4 Cropping history of experimental site

The experiment was conducted in a low land in which *mundakan* rice cultivation was taken up before laying out the experiment.

3.5 Season

For pot culture study the crop was raised during March-July in 2017 and field experiment was carried out during November 2017-April 2018 and October 2018-April 2019.

3.6 Variety

A semi trailing dual purpose high yielding cowpea variety Anaswara was chosen as test crop for the experiment. Anaswara is a high yielding variety with broad triangular green leaves, light green petiole, stem, and pods. Pods are medium-long while grains are bold, seed coat cream and the 100 seed weight is 16 g. Its fresh pod yield potential was reported up to 12.5 t/ha. Plants have semi-determinate growth habit. The total crop duration is about four months. This HYV released by KAU is recommended for cultivation in Central Kerala.

3.7 Experiment-I: Response of cowpea to varying doses of K and Mg

The design was completely randomized design (CRD), with 14 treatments and three replications **(Fig. 4)**. Treatment details are as follows.

T_1 - K_2O 10 kg/ha + $MgSO_4$ 40 kg/ha

T_2 - K_2O 10 kg/ha + $MgSO_4$ 60 kg/ha

T_3 - K_2O 10 kg/ha + $MgSO_4$ 80 kg/ha

T_4 - K_2O 10 kg/ha + $MgSO_4$ 100 kg/ha

T_5 - K_2O 20 kg/ha + $MgSO_4$ 40 kg/ha

T_6 - K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha

T_7 - K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha

T_8 - K_2O 20 kg/ha + $MgSO_4$ 100 kg/ha

T_9 - K_2O 40 kg/ha + $MgSO_4$ 40 kg/ha

T_{10} - K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha

T_{11} - K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha

T_{12} - K_2O 40 kg/ha + $MgSO_4$ 100 kg/ha

T_{13} - K_2O 10 kg/ha + No $MgSO_4$ (POP)

T_{14} - Soil test based nutrient application (control)

Lime and Organic manure were applied to all treatments. Whereas N and P_2O_5 were applied as per POP recommendations to treatments T_1 to T_{12}. Lime was applied @ 140 kg/ha CaO (equivalent of $CaCO_3$ @ 250 kg/ha as soil application). Urea was applied @ 18 kg/ha and DAP @ 65 kg/ha uniformly to all treatments except T_{14}. In T_{14}, N @ 15.6 kg/ha, P_2O_5 @ 21.3 kg/ha, K_2O @ 3.7 kg/ha, Calcium through liming, $MgSO_4$ @ 80 kg/ha, Zn @ 25 kg/ha was applied.

Fig. 4. Layout plan of pot culture

N

Design: CRD

R-I	R-II	R-III
T_1	T_{11}	T_3
T_6	T_2	T_{13}
T_{12}	T_8	T_{10}
T_{11}	T_7	T_4
T_2	T_{14}	T_{12}
T_9	T_{12}	T_1
T_5	T_4	T_{14}
T_7	T_{13}	T_9
T_{13}	T_6	T_2
T_4	T_5	T_{11}
T_3	T_{10}	T_6
T_{10}	T_9	T_5
T_8	T_3	T_7
T_{14}	T_1	T_8

Plate 1. General view of the pot culture study

3.8 Experiment-II: Response of cowpea to conservation tillage and nutrients

To study the effect of nutrients and tillage on growth and yield of cowpea the field experiments were conducted during November 2017–April 2018 and October 2018-April 2019. The experiment was laid out in factorial RBD with two factors tillage and nutrients. Factorial combination of three tillage treatments and best five nutrient treatments (S_1 to S_5), **(Fig. 5)**, replicated thrice. Size of the sub-plot was 25.2 m^2 and main plot was 126 m^2.

Factor-I: *Tillage*

M_1 - Herbicide based zero tillage

M_2 - Minimum tillage (Strip tillage along rows)

M_3 - Conventional tillage

Factor-II: *Nutrient management*

S_1 - Soil test based nutrient application

S_2 - K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha

S_3 - K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha

S_4 - K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha

S_5 - K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha

For the treatment, herbicide based zero tillage (M_1) glyphosate was sprayed @ 0.82 kg/ha two week before sowing cowpea. For minimum tillage plots (M_2) soil was tilled in strips. For conventional tillage plots (M_3) soil was ploughed twice and formed ridges and furrows, 30 cm apart and dibbled the seeds in 15 cm apart in furrows.

3.9 Land preparation, manuring, irrigation, liming, and fertilizer application

a. Pot culture

Potting mixture was prepared by mixing sand, soil and manure in 1:1:1 ratio and filled in pots @ 10 kg per pot. Then top layer was mixed with Pseudomonas and Trichoderma @ 20 g each per pot. Based on soil pH, lime was applied @ 2 g/kg

Fig. 5. Layout plan of field study

Design: Factorial RBD (2017-2019)

Plate 2. Rice fallow before layout of the experiment

Plate 3. General view of the field

soil 15 days before sowing. One week after sowing, magnesium sulphate was applied and seedlings were thinned retaining one healthy plant per pot. Micronutrient spray was given (KAU vegetable mixture in treatment T_{14}). Weeding was carried out at 15 DAS and 30 DAS.

Pods were harvested when the pods were turn yellow colour. Pod and grain yield were recorded.

b. Field experiment

Tillage was done according to the treatments. FYM @ 20 t/ha was applied uniformly to all plots and incorporated. Subsequently lime was applied based on soil pH status. Basal dose of fertilizers, such as DAP, MOP were applied 15 days later, and seeds were dibbled at a spacing of 30 cm x 15 cm. One week later $MgSO_4$ was applied as per the treatments. Half of the total nitrogen requirement was top dressed at 15 DAS through urea.

Irrigation

Initially, a pre sowing irrigation was done. After sowing, crop was irrigated daily till germination and seedling establishment. Later on, twice a week till third harvest and weekly once thereafter.

After-cultivation

Gap filling was completed within 10 DAS. Thinning was done 15 DAS to obtain optimum plant population. Plots were kept weed free till 30 DAS, through manual weeding done at 15 DAS and 30 DAS.

Plant protection

Aphids and pod borer were the major pests in the plot. Minor incidence of anthracnose disease was also observed.

Plate 4. Glyphosate spray in zero tillage

Plate 5. Minimum tillage (tilling along the strips)

Plate 6. Conventional tillage (two ploughings & ridges)

Plate 7. Sowing cowpea seeds

Plate 8. Gap filling after two weeks

Plate 9. Germination under zero tillage system

Plate 10. Germination under minimum tillage system

Plate 11. Germination under conventional tillage

Plate 12. General view of the field under germination

Plate 13. Advisory committee visit to the field

Plate 14. Crop at harvesting stage under minimum tillage

For aphids and pod bugs spray of (Thiamethoxam) Actara 25 WG @ 5 g/ 20 L was sprayed. Pests were effectively controlled with a spray of Flubendamide @ 25 g /ha (Fame 480 SC, 2 ml/10L).

Harvesting

The crop was harvested when the pods turned yellow and dry. Yield was recorded separately in each picking and pods were sundried and threshed to separate the grains. The produce was then cleaned, dried again and grain weight for each sub-plots were recorded. Weight of pods and grains were expressed in t/ha.

3.10 Observations

A. Growth parameters

For pot culture study, observation on each plant was recorded on plant height, number of branches at 30 DAS, 60 DAS, and 90 DAS.

In field study, five plants were randomly tagged in each sub-plots and measurement of growth parameters like plant height, number of branches were taken at 30 DAS, 45 DAS, and 60 DAS. In case of field experiment parameters like root spread, root weight, number of nodules, root-shoot ratio at harvest were also recorded.

a. Plant height

Plant height was taken from ground level to growing tip of plants at 30 DAS, 45 DAS, and 60 DAS and the mean height was expressed in cm.

b. Number of branches

Total number of primary branches was counted 30 DAS, 45 DAS, and 60 DAS and the mean was recorded.

c. Number of nodules per plant

At harvest three plants were carefully uprooted and root was properly washed and nodules were counted.

d. Days to flowering

Number of days attained for 50 % flowering of the plant population was recorded.

e. Root: shoot ratio

From each plot three plants were randomly selected after final harvest. The roots and corresponding shoots of three randomly selected plants were separated and washed thoroughly. Shade dried and oven dried at 80^0C for 24-48 hours till consistent weight was obtained. Dry weight of the root and shoot was recorded and root: shoot ratio was calculated as follows.

$$\text{Root: shoot ratio} = \frac{\text{Dry weight of root}}{\text{Dry weight of shoot}}$$

f. Root length

Three randomly selected plants were carefully pulled out and washed thoroughly. The length of roots was measured from base of the plant to the tip of longest root and the mean value was expressed in cm.

g. Root weight

The roots of the uprooted plants were dried and weight was recorded. This was expressed in grams /plant.

h. Root spread

From the measured root length and breadth spread was calculated and expressed as cm^2.

i. Dry matter production

Three plants from each plots were uprooted at 15 days interval, cleaned and shade dried. Samples were then oven dried (60^0C $\pm$ 5^0C) for 24-48 hours till constant weight was attained. The dry weight was recorded and expressed in kg /ha.

j. Leaf area per plant

Leaf area was measured using leaf area meter. Fully open leaflets were separated and reading was taken immediately. Area thus obtained was multiplied with total number of leaves per plant and the mean was expressed in cm^2.

k. Leaf area index

Leaf area index (LAI) was expressed as ratio of leaf area to the unit land area.

$$\text{Leaf area index} = \frac{\text{Leaf area}}{\text{Land area}}$$

l. Chlorophyll content

Chlorophyll content of leaves were measured at active growth stage (60 DAS) using the formula given below (Yoshida *et al*., 1972). From each sub-plot third fully opened leaf of tagged plant was plucked. Reading was taken using spectrophotometer at 663 nm and 645 nm. The chlorophyll content is expressed in mg/g.

$$\text{Chl a (mg/g)} = \frac{(12.7 \text{ x OD at } 663) - (2.69 \text{ x OD at } 645) \text{ x } 25}{1000 \text{ x } 0.2}$$

$$\text{Chl b (mg/g)} = \frac{(22.9 \text{ x OD at } 645) - (4.68 \text{ x OD at } 663) \text{ x } 25}{1000 \text{ x } 0.2}$$

$$\text{Total Chl (mg/g)} = \frac{(8.02 \text{ x OD at } 663) + (20.2 \text{ x OD at } 645) \text{ x } 25}{1000 \text{ x } 0.2}$$

C. Yield and yield parameters

In pot study, each plant was harvested and the pods were dried and yield attributes, pod yield and grain yield were recorded.

In field study, from sub-plots five pods were randomly selected and yield attributes were measured. Pod weight and grain yield from net plot area was also recorded.

a. Pod length and weight

Length and weight of randomly selected dried pods (10 numbers) were measured and the mean was calculated.

b. Number of grains per pod

Grains in randomly selected pods (10 numbers) were counted and expressed as numbers per pod.

c. Test weight of grains

Hundred grains were randomly selected from each treatment and weighed, then expressed in grams (g).

d. Grain yield

Pods from each treatment was threshed manually. Grain yield was expressed as g /plant in the case of pot culture experiment.

In field experiment, pod yield, grain weight and haulm weight per plot were recorded treatment wise for each picking and the total yield was expressed in kg /ha.

D. Observations on weeds

A quadrat of size 50 cm x 50 cm was placed randomly in each sub-plot on 30 DAS and 60 DAS. Weeds were carefully uprooted and cleaned thoroughly and species wise weed count was recorded and expressed in nos. / plot. Collected weeds were shade dried, and oven dried at 60^0C $\pm$ 5^0C and dry weight was recorded and expressed in g/m^2.

E. Pest and disease incidence

Infestation of aphids and pod borer were noticed in both the experiments.

F. Soil analysis

In case of pot culture, before preparing potting mixture, soil sample was collected for analyzing of initial nutrient status. After harvest soil samples were collected from pots treatment wise for analysis. In case of field experiment, at the time of land preparation, soil samples were collected for analysis.

Physico-chemical properties like, bulk density, particle density, porosity, pH, EC, available N, P, K, Ca, Mg, S, Cu, Mn, Fe, and Zn.

For microbial studies, soil was collected from rhizosphere of plant and under each treatment composite samples were used. Enumeration of microbial population was done using serial dilution and pour plate method (Agarwal and Hasija, 1986).

Enumeration of total microbial count was done with different suitable media as shown below. Suitable sterile media was poured (15-20 ml) on corresponding plates with 1ml of corresponding dilution and the plates were sealed properly to incubate at room temperature. The colony counts were counted as and when they appeared (bacteria: 2-3 days, fungi: 5-7 days, actinomycetes 5-14 days.) on the plates.

Table 4. Media used for microbial analysis

Microbial population	Media used
Total bacteria	Nutrient Agar medium
Total fungi	Rose Bengal Agar medium
Total actinomycetes	Kenknight & Munaier’s medium
Rhizobium	Yeast Extract Mannitol Agar medium

G. Plant analysis

Plant samples collected were shade dried and oven dried at 80^{0}C to a constant weight. Powdered samples of the respective plant parts were used for estimation of N, P, K, Ca, Mg, S, and micronutrients (Cu, Fe, Zn, Mn) using standard procedures (Jackson, 1958)

Nutrient uptake by plants were calculated by summing product of plant nutrient content and dry matter production. The nutrient uptake is expressed in kg/ha.

Table 5. Methods used for plant analysis

Parameter	Methodology used
Total N content	Microkjeldal digestion and distillation method (Jackson, 1958)
Total P content	Vanadomolybdophosphoric yellow colour method (Piper, 1966)
Total K content	Flame photometry (Piper, 1966)
Total S content	Turbidimetric method (Williams and Steinbergs, 1959) [Spectronic 20 spectrophotometer]
Total Ca content	Atomic Absorption Spectrophotometer (AAS)
Total Mg content	Atomic Absorption Spectrophotometer (AAS)
Micronutrients (Cu, Zn, Fe, Mn) content	Atomic Absorption Spectrophotometer (AAS)

b. Crude protein

The nitrogen content in grains was estimated by Microkjeldal digestion and distillation method suggested by Jackson (1958). The nitrogen content so obtained was multiplied with a factor 6.25 to get crude protein which was expressed as percentage.

H. Economics

Gross expenditure was computed by adding the prevailing labour charges and input costs and expressed in Rupees /ha. The prevailing market price of grain was used for calculation of gross returns, net returns, and B: C ratio.

3.11 Statistical analysis

The data were statistically analyzed using the statistical package OPSTAT (Sheoran *et al.*, 1998). Pooled analysis was done for the two year data for interpretation of results.

Results

IV. RESULTS

An experiment entitled "Nutrients and tillage interactions in rice fallow cowpea production" was conducted during 2017-2019 at College of Horticulture, Vellanikkara. The study consisted of two experiments. First experiment was a pot culture study to find out best dose of potassium and magnesium sulphate for cowpea. Five best treatments from the pot culture study were carried to second experiment. The second experiment was a field trial to study the interaction effect of tillage and nutrients (K and Mg) on growth and yield of cowpea. Results obtained from the experiments are furnished below.

4.1 Nutrient management for increasing productivity of cowpea (Pot culture study)

4.1.1 Growth Parameters

Effect of application of various levels of K and Mg on growth parameters of grain cowpea are presented in the following tables **(Table 6-9)**. Observations on plant height and number of branches were taken at 30 DAS, 60 DAS and 90 DAS.

A. Plant height

Nutrient application was found to bring about significant influence on plant height at 60 and 90 days after sowing **(Table 6)**. At 30 DAS, the treatment differences were non-significant and plant height was in the range of 23-35 cm.

The data shows that, application of K_2O @ 40 kg/ha with $MgSO_4$ @ 40 and 100 kg/ha resulted in taller plants. At 60 DAS, significantly higher values of plant height were found in application of K: $MgSO_4$ @ 40:40 kg/ha (T_9), which was statistically at par to application of K: $MgSO_4$ @ 40:100 kg/ha (T_{12}). This trend was observed at 90 DAS also.

At 60 DAS, lower values for plant height was observed with application of K: $MgSO_4$ @ 10:40 (T_1), 10:80 (T_3), 10:100 (T_4), 20:40 (T_5), and 20:80 (T_7) kg/ha. At 90 DAS, treatments K: $MgSO_4$ @ 10:40 (T_1), and 10:80 (T_3), kg/ha recorded lower and comparable plant height.

B. Number of branches

Data pertaining to number of branches at various stages is represented in **Table 7**. On an average, plants produced 4 branches at 30 DAS, 11 branches at 60 DAS and 13 branches at 90 DAS.

At 30 DAS and 90 DAS, significant difference in number of branches was not observed. However at 60 DAS there was a significant difference in number of branches and crop under POP based treatment (K_2O @ 10 kg/ha and no magnesium sulphate) registered higher number of branches *i.e.* 12.7 which was on par with application of K: $MgSO_4$ @ 10:60 (T_2), 20:40 (T_5), 20:60 (T_6), 20:100 (T_8), 40:40 (T_9), 40:80 (T_{11}), 40:100 (T_{12}) kg/ha as well as to soil test based nutrition (T_{14}). Least number of branches were noted with application of K: $MgSO_4$ @ 20:80 kg/ha (T_7) which was on par to treatments K: $MgSO_4$ @ 10:40 (T_1) and 10:100 (T_4) kg/ha.

C. Days to flowering

Days to 50% flowering was not significantly influenced by K and $MgSO_4$ application and the plants flowered by 43 DAS **(Table 8)**.

D. Chlorophyll content

Chlorophyll-a, chlorophyll-b, and total chlorophyll contents were estimated at active vegetative growth stage of the crop (45 DAS). Application of various levels of potassium and magnesium had significant variation in chlorophyll a and total chlorophyll contents **(Table 9)**. However, in chlorophyll-b no significant variation was observed.

Highest content of chlorophyll-a (1.31 mg/g) was registered with application of K: $MgSO_4$ @ 20:60 kg/ha (T_6). Higher total chlorophyll content was registered in soil test based nutrition (T_{14}) which was on par with K: $MgSO_4$ applied @ 20:60 kg/ha (T_6). It could be noted that, magnesium sulphate @ 60 and 80 kg/ha along with various levels of potassium resulted in higher total chlorophyll content.

Lower contents of chlorophyll a and total chlorophyll was noticed in application of K: $MgSO_4$ @ 20:100 kg/ha (T_8). With regard to chlorophyll a content T_8 was on par to treatments such as T_5, T_7, T_9, T_{11} and T_{12}. While with respect to total chlorophyll content, T_8 was on par to T_1, T_2, T_5, T_9, T_{11}, T_{12}, and T_{13}.

E. Total dry matter production

Perusal of data reveals that, dry matter production was effected by K and Mg nutrition **(Table 8)**. Significantly higher dry matter production (44.0 g/plant) was recorded under application of K: $MgSO_4$ @ 40:100 kg/ha (T_{12}) which was on par with dry matter recorded in soil test based application (T_{14}).

It could be noted that, there was a gradual increase in dry matter production of cowpea with each increment of magnesium sulphate applied along with potassium @ 10 and 20 kg/ha. Lowest dry matter production (25.5 g/plant) was recorded in POP based nutrient application (K_2O @ 10 kg/ha and no $MgSO_4$).

F. Number of nodules per plant

Observation on number of root nodules was taken at harvest. Significant effect on nodulation was noted with application of K and $MgSO_4$ doses **(Table 8)**. Highest number of nodules (201 nos) was observed in plants treated with K: $MgSO_4$ @ 40:100 kg/ha (T_{12}), followed by K: $MgSO_4$ @ 40:60 kg/ha (T_{10}). Least count was noted in plants supplied with K: $MgSO_4$ @ 10:40 (T_1) and 10:60 (T_2) kg/ha.

Table 6. Effect of K and $MgSO_4$ application on plant height of cowpea

Treatments	Plant height (cm)		
	30DAS	60DAS	90DAS
T_1 - K_2O 10 kg/ha + $MgSO_4$ 40 kg/ha	25.2	63.6^{h}	77.6^{f}
T_2 - K_2O 10 kg/ha + $MgSO_4$ 60 kg/ha	29.1	74.1^{fg}	84.7^{de}
T_3 - K_2O 10 kg/ha + $MgSO_4$ 80 kg/ha	27.0	67.7^{h}	81.8^{ef}
T_4 - K_2O 10 kg/ha + $MgSO_4$ 100 kg/ha	27.2	65.4^{h}	90.1^{d}
T_5 - K_2O 20 kg/ha + $MgSO_4$ 40 kg/ha	28.4	63.5^{h}	100.8^{c}
T_6 - K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	25.6	96.5^{d}	101.6^{c}
T_7 - K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	27.7	68.7^{gh}	100.4^{c}
T_8 - K_2O 20 kg/ha + $MgSO_4$ 100 kg/ha	30.5	77.3^{f}	104.9^{c}
T_9 - K_2O 40 kg/ha + $MgSO_4$ 40 kg/ha	31.8	118.9^{a}	120.8^{a}
T_{10} - K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	31.2	109.5^{bc}	113.6^{b}
T_{11} - K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	33.7	106.9^{c}	112.7^{b}
T_{12} - K_2O 40 kg/ha + $MgSO_4$ 100 kg/ha	31.9	113.9^{ab}	118.4^{ab}
T_{13} - K_2O 10 kg/ha + No $MgSO_4$ (POP)	25.7	84.9^{e}	88.8^{d}
T_{14} - Soil test based recommendations	34.6	108.6^{bc}	113.1^{b}
CD (0.05)	**NS**	**6.0**	**6.3**

Table 7. Effect of K and $MgSO_4$ application on number of branches of cowpea

Treatments	No. of branches		
	30DAS	60DAS	90DAS
T_1 - K_2O 10 kg/ha + $MgSO_4$ 40 kg/ha	3.5	10.0[de]	13.0
T_2 - K_2O 10 kg/ha + $MgSO_4$ 60 kg/ha	3.7	11.8[abc]	13.0
T_3 - K_2O 10 kg/ha + $MgSO_4$ 80 kg/ha	4.2	10.8[cd]	12.5
T_4 - K_2O 10 kg/ha + $MgSO_4$ 100 kg/ha	4.0	10.0[de]	12.7
T_5 - K_2O 20 kg/ha + $MgSO_4$ 40 kg/ha	3.5	11.5[abc]	12.8
T_6 - K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	3.5	11.3[bc]	13.2
T_7 - K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	3.5	9.5[e]	12.8
T_8 - K_2O 20 kg/ha + $MgSO_4$ 100 kg/ha	3.5	12.0[abc]	11.7
T_9 - K_2O 40 kg/ha + $MgSO_4$ 40 kg/ha	3.2	12.5[a]	12.7
T_{10} - K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	3.7	11.3[abc]	13.0
T_{11} - K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	2.8	12.5[a]	12.5
T_{12} - K_2O 40 kg/ha + $MgSO_4$ 100 kg/ha	3.7	11.8[abc]	13.2
T_{13} - K_2O 10 kg/ha + No $MgSO_4$ (POP)	4.0	12.7[a]	12.5
T_{14} - Soil test based recommendations	3.0	12.0[abc]	12.8
CD (0.05)	**NS**	**1.2**	**NS**

Table 8: Effect of K and $MgSO_4$ application on days to flowering, nodulation and dry matter production of cowpea

Treatments	Days to 50% flowering (days)	No. of nodules per plant	DMP at harvest (g/plant)
T_1 - K_2O 10 kg/ha + $MgSO_4$ 40 kg/ha	42.6	106^{i}	27.3^{f}
T_2 - K_2O 10 kg/ha + $MgSO_4$ 60 kg/ha	42.2	107^{i}	27.3^{f}
T_3 - K_2O 10 kg/ha + $MgSO_4$ 80 kg/ha	43.0	130^{fg}	37.3^{bcd}
T_4 - K_2O 10 kg/ha + $MgSO_4$ 100 kg/ha	42.6	151^{c}	37.3^{bcd}
T_5 - K_2O 20 kg/ha + $MgSO_4$ 40 kg/ha	42.1	149^{cd}	34.7^{e}
T_6 - K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	42.8	140^{e}	34.7^{e}
T_7 - K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	42.5	125^{fgh}	35.8^{de}
T_8 - K_2O 20 kg/ha + $MgSO_4$ 100 kg/ha	42.5	132^{f}	36.2^{cde}
T_9 - K_2O 40 kg/ha + $MgSO_4$ 40 kg/ha	42.4	142^{de}	38.5^{b}
T_{10} - K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	42.2	190^{b}	37.8^{b}
T_{11} - K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	42.6	121^{h}	37.5^{b}
T_{12} - K_2O 40 kg/ha + $MgSO_4$ 100 kg/ha	42.4	201^{a}	44.0^{a}
T_{13} - K_2O 10 kg/ha + No $MgSO_4$ (POP)	42.4	123^{gh}	25.5^{g}
T_{14} - Soil test based recommendations	42.0	132^{f}	43.0^{a}
CD (0.05)	**NS**	**7.7**	**1.5**

Table 9. Effect of K and $MgSO_4$ application on leaf chlorophyll content of cowpea at active vegetative growth stage

Treatments	Chlorophyll (mg/g)		
	a	b	Total
T_1 - K_2O 10 kg/ha + $MgSO_4$ 40 kg/ha	1.18^{cd}	0.30	1.34^{ef}
T_2 - K_2O 10 kg/ha + $MgSO_4$ 60 kg/ha	1.19^{cd}	0.32	1.37^{ef}
T_3 - K_2O 10 kg/ha + $MgSO_4$ 80 kg/ha	1.16^{cde}	0.34	1.48^{cde}
T_4 - K_2O 10 kg/ha + $MgSO_4$ 100 kg/ha	1.15^{cdef}	0.30	1.47^{cde}
T_5 - K_2O 20 kg/ha + $MgSO_4$ 40 kg/ha	1.05^{ef}	0.29	1.39^{def}
T_6 - K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	1.31^{b}	0.36	1.65^{ab}
T_7 - K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	1.09^{def}	0.41	1.52^{bcd}
T_8 - K_2O 20 kg/ha + $MgSO_4$ 100 kg/ha	1.03^{f}	0.29	1.30^{f}
T_9 - K_2O 40 kg/ha + $MgSO_4$ 40 kg/ha	1.08^{def}	0.33	1.36^{ef}
T_{10} - K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	1.26^{bc}	0.35	1.57^{bc}
T_{11} - K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	1.13^{def}	0.30	1.34^{ef}
T_{12} - K_2O 40 kg/ha + $MgSO_4$ 100 kg/ha	1.06^{ef}	0.36	1.40^{def}
T_{13} - K_2O 10 kg/ha + No $MgSO_4$ (POP)	1.08^{def}	0.30	1.35^{ef}
T_{14} - Soil test based recommendations	1.45^{a}	0.38	1.79^{a}
CD (0.05)	**0.12**	**NS**	**0.15**

4.1.2 Yield and yield parameters

Effect of K and Mg nutrition on yield and yield parameters of grain cowpea is furnished in **Table 10.** Significant difference in yield was observed with differential levels of K and $MgSO_4$ application. Soil test based nutrient application resulted in significantly higher values for yield parameter as reflected in dry matter production. In general, higher dose of potash with higher dose of magnesium sulphate resulted in higher values of yield and yield parameters.

A. Total number of pods per plant

Treatment effect on total number of pods per plant was significant. Treatments which received higher doses of potash resulted in higher number of pods per plant. Application of K: $MgSO_4$ @ 40:60 kg/ha (T_{10}) recorded higher number of pods (14 nos), which was statistically comparable to application of K_2O @ 20 kg/ha along with Mg @ 40, 60, and 80 kg/ha, as well as to K_2O @ 40 kg/ha along with $MgSO_4$ @ 40, 80, and 100 kg/ha.

B. Grains per pod

Effect of various levels of potassium and magnesium application on grains per pod was not significant. The average number of grains per pod recorded was 16.

C. 100 seed weight

Influence of various levels of K and Mg found to be significant with respect to test weight. Application of potassium @ 20 and 40 kg/ha along with 40, 60 and 80 kg/ha magnesium sulphate, and soil test based nutrient application resulted in higher 100 seed weight of cowpea **(Table 10)**.

Application of K: $MgSO_4$ @ 40:60 kg/ha (T_{10}) resulted in significantly higher test weight (21.5 g) and it was on par to soil test based nutrition (T_{14}), as well as to application of K and Mg @ 20:40 (T_5), 20:60 (T_6), 20:80 (T_7), and 40:80 (T_{11}) kg/ha and POP recommendation (T_{13}). K: $MgSO_4$ @ 10:100 (T_4), 10:80 (T_3), 10:60 (T_2), 10:40 (T_1) kg/ha registered lower values for test weight.

Table 10: Effect of K and $MgSO_4$ application on yield and yield parameters of cowpea

Treatments	No. of pods/plant	Average pod weight (g)	No. of grains/ pod	100 seed weight (g)	Pod length (cm)	Grain yield/plant (g)
T_1 - K_2O 10 kg/ha + $MgSO_4$ 40 kg/ha	10.3^{bc}	2.4	15.1	18.2^{cde}	26.9	20.9^{e}
T_2 - K_2O 10 kg/ha + $MgSO_4$ 60 kg/ha	10.4^{bc}	2.5	13.7	17.9^{de}	25.2	21.4^{e}
T_3 - K_2O 10 kg/ha + $MgSO_4$ 80 kg/ha	10.4^{bc}	2.5	15.4	17.2^{e}	26.6	20.9^{e}
T_4 - K_2O 10 kg/ha + $MgSO_4$ 100 kg/ha	11.0^{bc}	2.6	15.5	17.2^{e}	25.1	22.2^{e}
T_5 - K_2O 20 kg/ha + $MgSO_4$ 40 kg/ha	11.5^{bc}	2.3	14.3	20.5^{ab}	26.4	26.1^{d}
T_6 - K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	12.3^{ab}	3.0	15.7	20.2^{ab}	28.3	36.0^{b}
T_7 - K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	12.3^{ab}	3.0	15.8	20.5^{ab}	25.3	34.4^{b}
T_8 - K_2O 20 kg/ha + $MgSO_4$ 100 kg/ha	12.0^{b}	3.1	16.7	18.3^{cde}	28.1	35.1^{b}
T_9 - K_2O 40 kg/ha + $MgSO_4$ 40 kg/ha	12.3^{ab}	2.9	15.3	19.6^{bc}	25.2	30.3^{c}
T_{10} - K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	14.0^{a}	3.3	15.8	21.2^{a}	29.5	40.3^{a}
T_{11} - K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	13.7^{ab}	3.5	16.5	20.5^{ab}	26.3	40.2^{a}
T_{12} - K_2O 40 kg/ha + $MgSO_4$ 100 kg/ha	13.5^{ab}	3.6	16.6	19.4^{bcd}	26.4	37.4^{ab}
T_{13}- K_2O 10 kg/ha + No $MgSO_4$ (POP)	10.0^{c}	2.4	14.3	18.0^{de}	24.7	21.8^{e}
T_{14}- Soil test based recommendations	12.0^{b}	3.0	16.7	20.2^{ab}	26.1	35.0^{b}
CD (0.05)	**1.7**	**NS**	**NS**	**1.7**	**NS**	**3.0**

D. Pod length

No significant difference was observed in pod length due to application of potassium and magnesium doses **(Table 10)**. Longest pods (29.5 cm) were noted in plants supplied with K: $MgSO_4$ @ 40: 60 kg/ha (T_{10}). Application of K_2O @ 10 kg/ha along with magnesium sulphate @ 60 and 100 kg/ha resulted in lower values. Average pod length recorded was 26.7 cm.

E. Pod weight

Data on average pod weight is furnished in **Table 10.** K and $MgSO_4$ doses failed to bring about significant effect on average pod weight. Average pod weight recorded was 3g.

F. Total grain yield

Data pertaining to total grain yield per plant is furnished in **Table 10.** Significant influence of K and Mg levels was noticed on grain yield of cowpea. Higher grain yield per plant was recorded in application of potassium @ 40 kg/ha along with $MgSO_4$ @ 60, 80, and 100 kg/ha which were statistically on par to each other.

Application of K_2O @ 10 kg/ha along with $MgSO_4$ @ 40, 60, 80 and 100 kg/ha resulted in lower grain yield and were on par to each other. Application of NPK @ 20: 30: 10 kg/ha without magnesium sulphate application (POP) also failed to produce good grain yield.

Table 11: Effect of K and $MgSO_4$ application on crude protein content in grains and primary nutrients content of cowpea

Treatments	Protein content %	N%		P%		K%	
		30DAS	Harvest	30DAS	Harvest	30DAS	Harvest
T_1 - K_2O 10 kg/ha + $MgSO_4$ 40 kg/ha	20.4^{e}	2.1	1.8	0.31	0.27	2.0	1.4
T_2 - K_2O 10 kg/ha + $MgSO_4$ 60 kg/ha	21.5^{e}	2.0	1.7	0.32	0.25	1.8	1.4
T_3 - K_2O 10 kg/ha + $MgSO_4$ 80 kg/ha	23.6^{cd}	2.2	1.8	0.34	0.26	1.9	1.3
T_4 - K_2O 10 kg/ha + $MgSO_4$ 100 kg/ha	23.5^{d}	2.3	1.9	0.33	0.28	1.8	1.3
T_5 - K_2O 20 kg/ha + $MgSO_4$ 40 kg/ha	24.7^{bcd}	2.2	1.8	0.36	0.26	2.1	1.7
T_6 - K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	25.2^{b}	2.4	2.1	0.33	0.27	2.4	1.7
T_7 - K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	27.0^{a}	2.6	2.3	0.34	0.27	2.5	1.8
T_8 - K_2O 20 kg/ha + $MgSO_4$ 100 kg/ha	26.3^{ab}	2.6	2.2	0.35	0.29	2.4	1.8
T_9 - K_2O 40 kg/ha + $MgSO_4$ 40 kg/ha	26.0^{ab}	2.3	2.0	0.33	0.26	2.5	1.7
T_{10} - K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	25.2^{bc}	2.4	2.0	0.32	0.28	2.4	1.8
T_{11} - K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	24.7^{bcd}	2.3	2.2	0.32	0.25	2.6	1.8
T_{12} - K_2O 40 kg/ha + $MgSO_4$ 100 kg/ha	24.7^{bcd}	2.4	1.8	0.35	0.27	2.5	1.8
T_{13} - K_2O 10 kg/ha + No $MgSO_4$ (POP)	23.4^{d}	2.0	1.7	0.30	0.26	1.9	1.3
T_{14} - Soil test based recommendations	23.5^{d}	2.6	2.4	0.32	0.29	2.6	1.5
CD (0.05)	**1.7**	**0.2**	**0.3**	**NS**	**NS**	**0.2**	**0.1**

4.1.3 Crude protein content

Grain N content ranged from 3.3% to 4.3%. Significant affect due to K and Mg doses could be observed with regard to crude protein **(Table 11)**.

Application of K_2O @ 20 kg/ha along with $MgSO_4$ @ 80 kg/ha (T_7) recorded higher protein content. It was on par to K: $MgSO_4$ applied @ 20:100 (T_8) and 40:40 (T_9) kg/ha. Application of K and Mg @ 10:40 and 10:60 kg/ha registered lower protein content.

4.1.4 Plant nutrient content

Plant samples were collected at 30 DAS and at harvest (90 DAS) to estimate primary, secondary and micro nutrient content (**Table 11 and 12**).

A. Primary nutrients

a. Nitrogen content

Influence of potash and magnesium levels was significant with respect to nitrogen content at 30 DAS and 90 DAS (**Table 11)**. At 30 DAS, significantly higher nitrogen content (2.6%) was observed with application of K: $MgSO_4$ @ 20:100 kg/ha (T_8). It was on par to the treatments such as soil test based nutrition (K: $MgSO_4$ @ 10.6:80 kg/ha), K: $MgSO_4$ applied @ 20:80 (T_7) and 40:60 (T_{10}) kg/ha. Lowest N content (2.0%) was observed in POP based management where NPK was applied @ 20:30:10 kg/ha with no magnesium.

At harvest, application of nutrients according to soil test results (T_{14}) resulted in higher N content in plant. It was on par to application of K: $MgSO_4$ @ 20:60 (T_6), 20:80 (T_7), 20:100 (T_8), and 40:80 (T_{11}) kg/ha. Application of nutrients as per POP recommendations resulted in lower N content (1.7%) which showed parity to K: $MgSO_4$ @ 10:60 (T_2) and 20:40 (T_5) kg/ha.

b. Phosphorus content

In cowpea, phosphorus content was not influenced by various levels K and Mg (**Table 11**). Values observed were on an average 0.33% at 30 DAS and 0.27% at harvest.

c. Potassium content

Potassium content estimated at 30 DAS shows significant difference **(Table 11).** Nutrient application based on soil test results, (K_2O @ 10.6 kg/ha and Mg @ 80 kg/ha) recorded highest K content (2.63 %) in plants. It was on par to treatments such as T_7, T_9, T_{10}, T_{11}, and T_{12} where K_2O was applied @ 20 and 40 kg/ha, along with higher levels of $MgSO_4$ (60, 80 and 100 kg/ha). Application of K and Mg @ 10:60 kg/ha resulted in lowest value for K content and it was on par to treatments like T_1, T_2, T_3, and T_{13} where Potassium was applied @ 10 kg/ha.

At harvest, plant K content varied from 1.28 % to 1.82 %. Although, statistically significant difference was observed in data, many treatments were on par. Treatments such as T_6, T_7, T_8, T_9, T_{10}, T_{11}, and T_{12}, were superior with respect to plant K content (1.69 % to 1.82 %) which in turn was statistically on par to T_5 (K: $MgSO_4$ @ 20:40 kg/ha). Whereas, treatments such as T_1, T_2, T_3, T_4 as well as T_{13}, recorded inferior values (1.28 % to 1.40 %).

B. Secondary nutrients

a. Calcium

Calcium content in plants at 30 DAS and at harvest (90 DAS) is furnished in **Table 12.** At both stages, no significant difference was noticed in plant calcium content and on an average the content was 1.66 % at 30 DAS and 0.84 % at harvest.

b. Magnesium

Magnesium content in plant differed significantly in both stages of crop growth **(Table 12)**. At 30 DAS, treatment consisting of higher level of K and Mg (T_{12}) recorded highest magnesium content (1 %). Followed by treatments T_7, T_8, and T_{11} which received higher levels of magnesium (80 and 100 kg/ha) along with higher levels of K (20 and 40 kg/ha). Lowest Mg content was recorded in POP based management where K @ 10 kg/ha with no magnesium sulphate was supplied to plants. Although, treatments influence on magnesium content was statistically significant, many treatments were comparable to each other.

At harvest, application of K: $MgSO_4$ @ 20:100 kg/ha (T_8) registered highest plant Mg content (1.1%) which was on par with K: $MgSO_4$ @ 40:100 kg/ha (T_{12}). Treatments consisting of highest level of magnesium sulphate (100 kg/ha) along with higher levels of potash (20 and 40 kg/ha) registered higher values of magnesium content. Treatments with lower levels of K and Mg (T_2, T_3, and T_{13}) recorded inferior values for plant Mg content. POP based nutrient management practice (T_{13}) where no magnesium sulphate is supplied, recorded the lowest value.

c. Sulphur

Significant difference in plant sulphur content was observed and the data is furnished in **Table 12**. At 30 DAS, the highest content was recorded in K: $MgSO_4$ @ 20:60 kg/ha (T_6). It was on par to sulphur content recorded (0.73% to 0.77%) in T_1, T_2, and T_5 which received K_2O @ 10 and 20 kg/ha along with Mg @ 40 and 60 kg/ha. Lowest content was observed in POP based management (T_{13}, K @ 10 kg/ha with no $MgSO_4$). It showed parity to treatment such as T_3, and T_4.

At harvest also, sulphur content differed significantly. Application of K: $MgSO_4$ @ 40:80 kg/ha (T_{12}) recorded highest S content (0.76%). It was followed by application of NPK according to soil test results (K: $MgSO_4$ @ 10.6:80 kg/ha) and treatments such as T_3, T_4, T_7, T_8, and T_{11} where Mg was applied @ 80 and 100 kg/ha with various levels of K. As observed at 30 DAS, the lowest S content was noticed in POP based nutrition where K was applied @ 40 kg/ha with no $MgSO_4$ (T_{13}).

C. Micronutrients

Iron, manganese, zinc and copper were estimated in plant samples at 30 DAS and 90 DAS **(Table 13)**, but significant difference was not observed. In general, micronutrient content was more at 30 DAS compared to harvest stage. In case of iron, the content was 0.13% and 0.07% at 30 DAS and 90 DAS respectively. Corresponding values for manganese content recorded were 0.03% and 0.01% respectively. Zinc and Copper content was low and the average Zn content at both stages were 0.01%. Copper content recorded at 30 DAS and at harvest was 0.002% and 0.001% respectively.

Table 12. Effect of K and $MgSO_4$ application on secondary nutrient content (%) of cowpea

Treatments	Ca %		Mg %		S %	
	30DAS	Harvest	30DAS	Harvest	30DAS	Harvest
T_1 - K_2O 10 kg/ha + $MgSO_4$ 40 kg/ha	1.59	0.72	0.78	0.58	0.76	0.49
T_2 - K_2O 10 kg/ha + $MgSO_4$ 60 kg/ha	1.63	0.75	0.72	0.62	0.74	0.50
T_3 - K_2O 10 kg/ha + $MgSO_4$ 80 kg/ha	1.66	0.84	0.76	0.72	0.51	0.61
T_4 - K_2O 10 kg/ha + $MgSO_4$ 100 kg/ha	1.65	0.83	0.83	0.92	0.52	0.65
T_5 - K_2O 20 kg/ha + $MgSO_4$ 40 kg/ha	1.63	0.86	0.80	0.68	0.73	0.47
T_6 - K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	1.68	0.95	0.81	0.76	0.78	0.50
T_7 - K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	1.77	0.95	0.86	0.90	0.55	0.63
T_8 - K_2O 20 kg/ha + $MgSO_4$ 100 kg/ha	1.71	0.95	0.90	1.06	0.56	0.66
T_9 - K_2O 40 kg/ha + $MgSO_4$ 40 kg/ha	1.64	0.71	0.82	0.61	0.62	0.49
T_{10} - K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	1.63	0.70	0.86	0.67	0.60	0.52
T_{11} - K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	1.69	0.82	0.91	0.79	0.55	0.64
T_{12} - K_2O 40 kg/ha + $MgSO_4$ 100 kg/ha	1.66	0.91	1.01	1.03	0.57	0.76
T_{13} - K2O 10 kg/ha + No MgSO4 (POP)	1.62	0.76	0.68	0.56	0.48	0.43
T_{14} - Soil test based recommendations	1.66	0.95	0.90	0.88	0.63	0.69
CD (0.05)	**NS**	**NS**	**0.09**	**0.10**	**0.06**	**0.06**

Table 13. Effect of K and $MgSO_4$ application on micronutrient content (%) in cowpea

Treatments	Fe %		Mn %		Zn %		Cu %	
	30DAS	Harvest	30DAS	Harvest	30DAS	Harvest	30DAS	Harvest
T_1 - K_2O 10 kg/ha + $MgSO_4$ 40 kg/ha	0.12	0.05	0.03	0.01	0.009	0.007	0.001	0.001
T_2 - K_2O 10 kg/ha + $MgSO_4$ 60 kg/ha	0.12	0.06	0.03	0.01	0.010	0.009	0.001	0.001
T_3 - K_2O 10 kg/ha + $MgSO_4$ 80 kg/ha	0.13	0.05	0.02	0.01	0.008	0.008	0.002	0.002
T_4 - K_2O 10 kg/ha + $MgSO_4$ 100 kg/ha	0.13	0.07	0.03	0.02	0.009	0.007	0.003	0.002
T_5 - K_2O 20 kg/ha + $MgSO_4$ 40 kg/ha	0.13	0.07	0.03	0.01	0.009	0.008	0.002	0.001
T_6 - K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	0.13	0.07	0.03	0.02	0.010	0.009	0.001	0.001
T_7 - K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.13	0.08	0.03	0.02	0.011	0.007	0.003	0.001
T_8 - K_2O 20 kg/ha + $MgSO_4$ 100 kg/ha	0.13	0.08	0.03	0.01	0.011	0.009	0.001	0.001
T_9 - K_2O 40 kg/ha + $MgSO_4$ 40 kg/ha	0.14	0.07	0.03	0.01	0.009	0.007	0.002	0.001
T_{10} - K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.14	0.08	0.03	0.01	0.010	0.007	0.003	0.001
T_{11} - K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.13	0.07	0.02	0.01	0.011	0.008	0.003	0.001
T_{12} - K_2O 40 kg/ha + $MgSO_4$ 100 kg/ha	0.14	0.09	0.03	0.02	0.010	0.009	0.002	0.002
T_{13} - K_2O 10 kg/ha + No $MgSO_4$ (POP)	0.12	0.06	0.02	0.01	0.008	0.007	0.002	0.001
T_{14} - Soil test based recommendations	0.14	0.11	0.04	0.02	0.012	0.013	0.004	0.002
CD (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

4.1.5 Plant nutrient uptake

Uptake of primary nutrients such as calcium, magnesium, and sulphur recorded at 30 DAS and 90 DAS (at harvest) is furnished in **Table 14.**

A. Uptake of primary nutrients

a. Nitrogen uptake

Nitrogen uptake was significantly affected due to K and $MgSO_4$ doses at harvest while no significant difference was observed at 30 DAS **(Table 14).** At harvest, soil test based nutrient management (T_{14}) recorded highest uptake (1.0 g/plant) compared to all the other treatments. Also, the treatments which received higher levels of K and Mg recorded superior values for N uptake while, lower levels of K and Mg recorded lower uptake. POP based NPK application with no magnesium (T_{13}) resulted in lowest N uptake of 0.4 g/plant at harvest.

b. Phosphorus uptake

Phosphorus uptake at both 30 DAS and 90 DAS was not significantly influenced by K and $MgSO_4$ application **(Table 14)** and average P uptake at 30 DAS was 0.01 g/plant and 0.1 g/plant at harvest.

c. Potassium uptake

Potassium uptake estimated at 30 DAS and 90 DAS resulted in significant difference only at harvest stage. At initial stage, treatments had no significant effect on potassium uptake **(Table 14).** At harvest application of K_2O @ 40 kg/ha along with 80 and 100 kg/ha $MgSO_4$ (T_{12}) recorded higher potassium uptake. It was on par to treatments T_{10} and T_{11} which received K: $MgSO_4$ @ 40:60 (T_{10}) and 40:80 (T_{11}) kg/ha which recorded an uptake of 0.67 g/plant and 0.66 g/plant respectively. Again, POP based NPK application with no magnesium recorded lowest uptake (0.34 g/plant). It was on par to application of K: $MgSO_4$ @ 10:40 (T_1) and 10:60 (T_2) kg/ha.

Table 14: Effect of K and $MgSO_4$ application on primary nutrients uptake (g/plant) by cowpea

Treatments	N		P		K	
	30DAS	Harvest	30DAS	Harvest	30DAS	Harvest
T_1 - K_2O 10 kg/ha + $MgSO_4$ 40 kg/ha	0.09	0.49	0.01	0.07	0.08	0.38
T_2 - K_2O 10 kg/ha + $MgSO_4$ 60 kg/ha	0.09	0.46	0.01	0.07	0.08	0.37
T_3 - K_2O 10 kg/ha + $MgSO_4$ 80 kg/ha	0.10	0.67	0.01	0.10	0.08	0.49
T_4 - K_2O 10 kg/ha + $MgSO_4$ 100 kg/ha	0.10	0.72	0.01	0.10	0.08	0.48
T_5 - K_2O 20 kg/ha + $MgSO_4$ 40 kg/ha	0.10	0.63	0.02	0.09	0.09	0.57
T_6 - K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	0.11	0.73	0.01	0.09	0.11	0.59
T_7 - K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.12	0.81	0.02	0.10	0.11	0.64
T_8 - K_2O 20 kg/ha + $MgSO_4$ 100 kg/ha	0.12	0.80	0.02	0.11	0.10	0.66
T_9 - K_2O 40 kg/ha + $MgSO_4$ 40 kg/ha	0.10	0.76	0.01	0.10	0.11	0.65
T_{10} - K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.11	0.77	0.01	0.11	0.11	0.67
T_{11} - K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.11	0.83	0.01	0.09	0.12	0.66
T_{12} - K_2O 40 kg/ha + $MgSO_4$ 100 kg/ha	0.11	0.80	0.02	0.12	0.12	0.69
T_{13} - K_2O 10kg/ha + No $MgSO_4$ (POP)	0.08	0.43	0.01	0.07	0.08	0.34
T_{14} - Soil test based recommendations	0.11	0.90	0.02	0.13	0.13	0.65
CD (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

B. Uptake of secondary nutrients

Uptake of secondary nutrients such as calcium, magnesium, and sulphur recorded at 30 DAS and 90 DAS (at harvest) is furnished in **Table 15.**

a. Calcium uptake

Calcium uptake at harvest showed significant affect due to various K and $MgSO_4$ doses. However, significant influence was not observed in calcium uptake at 30 DAS **(Table 15).**

Calcium uptake recorded highest (0.49 g/plant) in soil test based nutrient management, where K: $MgSO_4$ was applied @ 10.6:80 kg/ha (T_{14}) and it was superior to all the other treatments. It was followed by K: $MgSO_4$ @ 40:100 kg/ha (T_{12}) which in turn was on par to T_7, and T_8, where, K_2O @ 20 kg/ha along with $MgSO_4$ @ 80 and 100 kg/ha was applied.

It could be noted that, treatments which received lower doses of potassium with lower or no magnesium sulphate resulted in lower uptake values. Lowest uptake (0.20 g/plant) was observed under application of K: $MgSO_4$ @ 10:40 (T_1), 10:60 (T_2) kg/ha as well as to POP based nutrient application (T_{13}).

b. Magnesium uptake

Effect of K and Mg application on Magnesium uptake was significant at harvest. But no significant effect on Mg uptake was observed at 30 DAS **(Table 15)**.

At harvest application of K: $MgSO_4$ @ 40:100 kg/ha (T_{12}) recorded highest Mg uptake (0.45 g/plant). Followed by soil test based nutrition (T_{14}) where K: $MgSO_4$ @ 10.6:80 kg/ha was applied, which in turn showed parity to soil test based nutrition (T_{14}), as well as to T_4 and T_8 which received K @ 10 and 20 kg/ha along with $MgSO_4$ @ 100 kg/ha. POP based NPK application with no magnesium resulted in lowest Mg uptake (0.14 g/plant) which was on par to application of K: $MgSO_4$ @ 10:40 kg/ha (T_1) and 10:60 kg/ha (T_2). At harvest application of higher levels of

Table 15: Effect of K and $MgSO_4$ application on secondary nutrients uptake (g/plant) by cowpea

Treatments	Ca		Mg		S	
	30DAS	Harvest	30DAS	Harvest	30DAS	Harvest
T_1 - K_2O 10 kg/ha + $MgSO_4$ 40 kg/ha	0.07	0.20	0.03	0.16	0.03	0.13
T_2 - K_2O 10 kg/ha + $MgSO_4$ 60 kg/ha	0.07	0.20	0.03	0.17	0.03	0.14
T_3 - K_2O 10 kg/ha + $MgSO_4$ 80 kg/ha	0.07	0.31	0.03	0.27	0.02	0.23
T_4 - K_2O 10 kg/ha + $MgSO_4$ 100 kg/ha	0.07	0.31	0.04	0.34	0.02	0.24
T_5 - K_2O 20 kg/ha + $MgSO_4$ 40 kg/ha	0.07	0.30	0.04	0.24	0.03	0.16
T_6 - K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	0.08	0.34	0.04	0.26	0.03	0.17
T_7 - K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.08	0.37	0.04	0.32	0.02	0.23
T_8 - K_2O 20 kg/ha + $MgSO_4$ 100 kg/ha	0.07	0.40	0.04	0.38	0.02	0.24
T_9 - K_2O 40 kg/ha + $MgSO_4$ 40 kg/ha	0.07	0.25	0.04	0.23	0.03	0.19
T_{10} - K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.07	0.26	0.04	0.25	0.03	0.20
T_{11} - K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.08	0.31	0.04	0.30	0.03	0.24
T_{12} - K_2O 40 kg/ha + $MgSO_4$ 100 kg/ha	0.08	0.40	0.05	0.45	0.03	0.33
T_{13} - K_2O 10kg/ha + No $MgSO_4$ (POP)	0.06	0.20	0.03	0.14	0.02	0.11
T_{14} - Soil test based recommendations	0.08	0.49	0.04	0.38	0.03	0.30
CD (0.05)	**NS**	**0.06**	**NS**	**0.04**	**NS**	**0.03**

$MgSO_4$ and K resulted in higher uptake of Mg whereas lower values were registered with lower doses.

c. Sulphur uptake

Sulphur uptake at both stages was not effected significantly due to application of various levels of K and Mg **(Table 15)**. The average sulphur uptake was 0.03 g/plant at 30 DAS and 0.21 g/plant at harvest

4.1.6 Soil chemical properties

Soil samples collected from each pot were analyzed for pH, EC, organic carbon, primary, secondary and micro nutrients.

A. pH

There was no significant difference in soil pH due to various treatments imposed and it ranged between 5-5.6 **(Table 16)**. However, an increase of soil pH for post-harvest analysis of soil was observed compared to that of pre sowing pH status of 4.5.

B. EC

Though statistically significant difference in electrical conductivity of soil was observed, many treatments registered comparable values **(Table 16)**. Electrical conductivity of 1.28 dS/m was recorded before the experiment whereas after the experiment the average EC was 1.40 dS/m.

Application of K: $MgSO_4$ @ 20:60 kg/ha (T_6) registered higher soil E.C. of 1.54 dS/m and it was on par to treatments where K: $MgSO_4$ was applied @ 20:40 (T_5), 10:40 (T_1), 10:60 (T_2), 10:100 (T_4), 40:100 (T_{12}), 10:80 (T_3), 40:80 (T_{11}), and soil test based nutrition (T_{14}). The E.C. ranged from 1.21 dS/m to 1.39 dS/m in other treatments.

C. Organic carbon

It could be noted that, organic carbon content was not significantly influenced by K and Mg doses **(Table 16)**. A slight reduction in organic carbon content of soil to 0.9 % compared to initial soil value of 1.4 % was observed.

D. Primary nutrients

a. Available nitrogen

In post-harvest analysis of soil significant difference in available nitrogen was observed **(Table 16)**. It could be noted that, higher levels of K (K_2O @ 20 and 40 kg/ha) along with higher levels of $MgSO_4$ (*i.e.* 80 and 100 kg/ha) resulted in higher available nitrogen content. Application of K: $MgSO_4$ @ 20:80 kg/ha (T_7), 20:100 kg/ha (T_8), and 40:100 kg/ha (T_{12}) registered higher as well as comparable values for soil available nitrogen. This was followed by K: $MgSO_4$ @ 40:80 kg/ha (T_{11}), 40:60 kg/ha (T_{10}) and soil test based treatment (T_{14}) where magnesium sulphate was applied @ 80 kg/ha. Lowest content was noted in K: $MgSO_4$ applied @ 10:40 kg/ha (T_1), which was on par to treatments like T_2, T_3, T_4, T_5 and T_{13}.

b. Available phosphorous

Data analyzed shows that treatments imposed have no significant effect on available phosphorus content of soil **(Table 16)**. The available phosphorus ranged from 23 kg/ha to 28 kg/ha.

c. Available potassium

Available potassium content of soil resulted in significant difference **(Table 16)**. Adoption of soil test based nutrient application (T_{14}) resulted in significantly higher values and it was on par to the treatments which received K: $MgSO_4$ @ 20:80 (T_7) and 20:40 (T_5) kg/ha. Lowest available potassium (149.1 kg/ha) was recorded under application of K: $MgSO_4$ @ 10:40 kg/ha (T_1). This was on par to K: $MgSO_4$ @ 10:60 kg/ha (T_2), as well to those treatments where K_2O @ 40 kg/ha along with various levels of magnesium sulphate (*i.e.* 40, 60, 80, and 100 kg/ha) was applied.

Table 16: Effect of K and $MgSO_4$ application on post-harvest soil chemical properties

Treatments	pH	E.C	Organic carbon	Available N	Available P	Available K
		dS/m	%	kg/ha		
T_1 - K_2O 10 kg/ha + $MgSO_4$ 40 kg/ha	5.0	0.147	0.8	165.3^{e}	25.3	149.1^{e}
T_2 - K_2O 10 kg/ha + $MgSO_4$ 60 kg/ha	5.2	0.145	0.8	166.5^{e}	23.7	151.3^{de}
T_3 - K_2O 10 kg/ha + $MgSO_4$ 80 kg/ha	5.1	0.141	0.8	176.9^{de}	25.7	157.3^{cde}
T_4 - K_2O 10 kg/ha + $MgSO_4$ 100 kg/ha	5.0	0.143	0.8	167.7^{e}	24.5	165.2^{bcd}
T_5 - K_2O 20 kg/ha + $MgSO_4$ 40 kg/ha	5.3	0.150	0.9	176.5^{de}	25.1	176.5^{ab}
T_6 - K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	5.2	0.154	0.9	189.6^{cd}	25.7	172.9^{b}
T_7 - K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	5.6	0.139	0.8	217.6^{a}	24.9	177.0^{ab}
T_8 - K_2O 20 kg/ha + $MgSO_4$ 100 kg/ha	5.5	0.135	0.8	210.9^{ab}	25.2	170.7^{bc}
T_9 - K_2O 40 kg/ha + $MgSO_4$ 40 kg/ha	5.0	0.121	0.8	189.4^{cd}	24.4	155.1^{de}
T_{10} -K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	5.0	0.122	0.8	199.3^{bc}	26.5	154.9^{de}
T_{11} -K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	5.1	0.140	0.9	201.2^{bc}	27.2	152.9^{de}
T_{12} -K_2O 40 kg/ha + $MgSO_4$ 100 kg/ha	5.1	0.141	0.9	203.3^{abc}	27.5	153.8^{de}
T_{13} -K_2O 10 kg/ha + No MgSO4 (POP)	5.0	0.136	0.8	165.7^{e}	23.2	157.1^{cde}
T_{14} -Soil test based recommendations	5.6	0.148	0.8	197.9^{bc}	26.5	188.4^{a}
CD (0.05)	**NS**	**NS**	**NS**	**16.3**	**NS**	**14.3**

E. Secondary nutrients

a. Calcium

Available calcium resulted in significant difference due to various K and Mg doses **(Table 17)**. Perusal of data shows that the values ranged from 243 kg/ha to 278 mg/kg which is higher than the available calcium content recorded in pre-sown soil (217.3 mg/kg). Highest calcium (276.5 mg/kg) was noticed in application of soil test based nutrient management (T_{14}). It was on par to application of K_2O @ 20 and 40 kg/ha with higher levels of magnesium sulphate *i.e.* T_7, T_8, T_{11}, and T_{12}.

b. Magnesium

Application of K and $MgSO_4$ was found to bring about significant difference in available magnesium content in soil **(Table 17)**. The treatments T_1 to T_8 (K_2O @ 10 and 20 kg/ha along with $MgSO_4$ @ 40, 60, 80, and 100 kg/ha) recorded higher values for available magnesium. Highest available magnesium (86.7 mg/kg) in soil was recorded under application of K: $MgSO_4$ @ 20: 100 kg/ha (T_8). However, treatments which received higher dose of potash along with various levels of magnesium recorded inferior values. Meanwhile, POP based recommendations (T_{13}) where no magnesium sulphate was given recorded lowest available magnesium (61.7 mg/kg) which was on par to application of K: $MgSO_4$ @ 40:40 (T_9) and 40:60 (T_{10}) kg/ha. It could be noted that, post-harvest available magnesium recorded after crop harvest was higher than the available magnesium content in pre-sown soil (61.2 mg/kg).

c. Sulphur

Application of various K and Mg doses significantly effected available sulphur **(Table 17)**. Soil test based nutrition (K: $MgSO_4$ @ 10.6: 80 kg/ha) recorded higher sulphur content of 20.9 mg/kg. Application of K_2O @ 10 and 20 kg/ha along with various levels of $MgSO_4$ resulted in higher available sulphur content while, K_2O @ 40 kg/ha along with different levels of $MgSO_4$ registered lower content. Lowest available sulphur (12.1 mg/kg) was recorded in POP based NPK application with no $MgSO_4$. However, the values were higher than the available sulphur content in pre-sown soil (5.5 mg/kg).

F. Micronutrients

Although significant difference was observed in iron content of soil in post-harvest analysis, no significant effect in manganese, zinc, and copper content was observed **(Table 17)**. Higher iron content (60.6 mg/kg) was recorded with application of K: $MgSO_4$ @ 40:100 kg/ha (T_{12}) which was on par to K: $MgSO_4$ @ 40:80 kg/ha (T_{11}). Followed by application of K: $MgSO_4$ @ 40:60 kg/ha (T_9). Higher values were noted with higher levels of K with various levels Mg. Lower levels of potash applied with various levels of magnesium sulphate recorded lower values for available iron content. The least iron content recorded in K_2O applied @ 10 kg/ha with magnesium @ 40 kg/ha. POP based management also registered lower values.

It could be noted that, the manganese content decreased from initial status of 15 mg/kg to 8.8 mg/kg after harvest of the crop. Zinc content in soil also decreased from 6.7 mg/kg to 5.0 mg/kg and the treatment differences were non-significant. Copper content also decreased from 1.06 mg/kg to 0.91 mg/kg after harvest of the crop.

Table 17: Effect of K and $MgSO_4$ application on post-harvest soil chemical properties

Treatments	Ca	Mg	S	Fe	Mn	Zn	Cu
	mg/kg of soil						
T_1 - K_2O 10 kg/ha + $MgSO_4$ 40 kg/ha	250.7	79.2	14.1	43.4	7.1	3.2	0.7
T_2 - K_2O 10 kg/ha + $MgSO_4$ 60 kg/ha	246.1	80.7	15.3	45.1	7.5	4.0	0.7
T_3 - K_2O 10 kg/ha + $MgSO_4$ 80 kg/ha	253.2	80.4	15.6	44.4	8.0	3.5	0.8
T_4 - K_2O 10 kg/ha + $MgSO_4$ 100 kg/ha	245.9	79.3	16.0	44.6	7.9	3.4	0.7
T_5 - K_2O 20 kg/ha + $MgSO_4$ 40 kg/ha	260.1	79.9	16.5	46.3	7.2	4.1	0.8
T_6 - K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	243.0	81.8	17.6	46.2	7.1	3.6	0.8
T_7 - K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	273.7	85.4	19.0	47.9	8.0	3.3	0.8
T_8 - K_2O 20 kg/ha + $MgSO_4$ 100 kg/ha	264.2	86.7	18.7	48.1	8.0	3.2	0.8
T_9 - K_2O 40 kg/ha + $MgSO_4$ 40 kg/ha	258.1	62.7	14.5	54.3	7.6	4.0	0.8
T_{10} -K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	260.5	65.2	14.1	53.8	7.4	4.2	0.8
T_{11} -K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	263.1	74.4	14.8	59.0	8.1	4.0	0.9
T_{12} -K_2O 40 kg/ha + $MgSO_4$ 100 kg/ha	264.7	76.5	14.9	60.6	7.9	4.1	0.9
T_{13} -K_2O 10 kg/ha + No MgSO4 (POP)	254.9	61.7	12.1	45.3	7.0	3.0	0.8
T_{14} -Soil test based recommendations	276.5	83.1	20.9	51.4	8.1	3.6	0.9
CD (0.05)	**15.7**	**8.0**	**1.7**	**4.9**	**NS**	**NS**	**NS**

4.2 Effect of tillage practices and soil application of potassium with secondary nutrients on cowpea

The experiment was laid out during the period November 2017- April 2018 and October 2018- April 2019 in rice fallow and the results are furnished below.

4.2.1 Growth parameters

A. Germination

Germination per cent was noted one week after sowing in both the years and found to have significant difference due to various tillage practices **(Table 18)**.

There was significant difference in germination of cowpea seeds due to tillage practices like normal tillage, minimum tillage and zero tillage and all the three practices differed significantly from each other. The highest germination percentage was observed in conventional tillage (CT) with seed germination of 78.7 % and 79.7 % in first and second year respectively. It was followed by minimum tillage (MT) with a seed germination of 55.8 % and 60.8 % in first and second year respectively, whereas in zero tillage (ZT) only 44.7 % and 43.2 % were recorded.

Pooled analysis of data showed that germination percentage recorded under CT was 79.2 % and was highest. It was followed by MT (58.3 %). The lowest germination percentage was observed under zero tillage (44 %).

Influence of various doses of K and $MgSO_4$ was found to be non-significant with respect to germination percentage. In both years of study, same trend was observed. The germination percentage ranged between 58-61 % in first year and 62-65 % in the second year. Interaction effect of nutrients and various tillage practices was also non-significant.

Table 18. Effect of tillage and nutrients on germination percentage (%) of cowpea

Treatment	2017	2018	Pooled
Tillage			
M_1- Zero tillage (ZT)	44.7[c]	43.2[c]	44.0[c]
M_2- Minimum tillage (MT)	55.8[b]	60.8[b]	58.3[b]
M_3- Conventional tillage (CT)	78.7[a]	79.7[a]	79.2[a]
C.D (0.05)	**2.67**	**3.3**	**3.0**
SE(m)	**0.92**	**1.12**	**0.93**
Nutrients			
S_1- Soil test based recommendations	59.8	62.5	61.2
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	57.5	58.9	58.2
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	59.7	64.9	62.3
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	60.9	61.7	61.3
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	60.9	58.2	59.5
C.D (0.05)	**NS**	**NS**	**NS**
SE(m)	**1.19**	**1.45**	**1.10**
Interaction			
M_1S_1: ZT + Soil test based	46.7	51.4	49.0
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	44.7	41.4	43.0
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	52.4	49.4	50.9
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	44.2	38.5	41.4
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	35.7	35.4	35.5
M_2S_1: MT + Soil test based	48.9	54.3	51.6
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	43.1	58.2	50.7
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	63.8	60.8	62.3
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	55.3	68.2	61.8
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	68.1	62.4	65.2
M_3S_1: CT + Soil test based	84.0	81.7	82.8
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	84.7	77.0	80.9
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	63.0	84.3	73.7
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	83.1	78.4	80.7
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	78.8	76.9	77.9
C.D (0.05)	**NS**	**NS**	**NS**
SE(m)	**2.05**	**2.51**	**2.47**

B. Plant height

No significant variation in plant height at any of the growth stages was observed due to different tillage practices such as conventional tillage, minimum tillage and zero tillage **(Table 19)**.

Influence of various level of K and $MgSO_4$ and effect of interaction was also found to be non-significant with regard to plant height, and average plant height at 30 DAS, 45 DAS and 60 DAS was 27.1 cm, 39.4 cm, and 49.6 cm respectively, during first year. The corresponding values in the second year of study were 38.1 cm, 45.9 cm, and 61 cm, respectively.

C. Number of branches

No significant variation could be observed due to various tillage systems and K-$MgSO_4$ doses on number of branches of cowpea at 30 DAS **(Table 20)**.

However, at later stages treatments varied significantly with regard to number of branches. At 45 DAS, highest number of branches was recorded under minimum tillage system (9.0) in 2017, followed by zero tillage and conventional tillage which were at par. However in 2018 zero tillage (M_1) resulted in highest number of branches (5.3) followed by minimum tillage and conventional tillage which were on par with each other. At 60 DAS, minimum tillage resulted in highest number of branches followed by zero tillage (M_1) and conventional tillage (M_3) during 2017, in the following year higher number of branches (14) were observed under minimum tillage (M_2) which were at par to branches recorded under zero tillage system (13). Least number noticed during 2017 and 2018 was under conventional tillage.

Perusal of pooled data revealed that, at 45 DAS, zero tillage and minimum tillage produced more number of branches. At 60 DAS minimum tillage registered highest number of branches (14), which was followed by number of branches recorded under ZT (12). The lowest number of branches were recorded under conventional tillage at both these stages of growth.

Table 19. Effect of tillage and nutrients on plant height (cm) of cowpea

	2017			2018		
Treatments	**30DAS**	**45DAS**	**60DAS**	**30DAS**	**45DAS**	**60DAS**
Tillage						
M_1- Zero tillage (ZT)	25.4	37.7	47.5	36.9	44.8	59.1
M_2- Minimum tillage (MT)	28.1	42.3	52.9	37.2	46.0	66.0
M_3- Conventional tillage (CT)	27.7	38.3	48.4	40.2	46.9	57.9
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.73**	**0.45**	**0.49**	**0.35**	**0.42**	**0.67**
Nutrients						
S_1- Soil test based recommendations	27.2	38.0	48.8	39.2	46.1	59.9
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	27.6	41.2	50.3	36.9	43.5	54.6
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	27.4	39.7	50.1	37.3	45.8	60.1
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	26.2	37.9	47.5	37.4	45.3	65.1
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	26.9	40.4	51.4	39.7	48.8	65.2
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.94**	**0.59**	**0.64**	**0.45**	**0.54**	**0.85**
Interaction						
M_1S_1: ZT + Soil test based	25.6	36.8	46.7	39.1	47.1	66.0
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	26.2	38.1	48.2	31.8	43.6	53.0
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	26.2	38.0	48.8	36.3	46.7	62.4
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	23.3	36.9	44.6	38.2	43.3	53.7
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	26.0	38.6	48.9	38.9	43.1	60.3
M_2S_1: MT + Soil test based	28.1	41.1	51.3	37.2	44.0	58.0
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	27.7	43.4	51.6	38.3	44.1	56.0
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	27.6	43.0	52.8	38.2	45.9	66.6
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	28.9	41.8	51.5	36.8	47.5	74.8
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	28.1	42.4	52.2	35.7	48.7	74.4
M_3S_1: CT + Soil test based	28.1	35.9	49.3	41.4	47.3	55.7
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	29.0	42.3	50.7	40.6	42.7	54.8
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	28.6	38.0	50.4	37.4	45.0	51.2
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	26.2	35.0	48.0	37.1	44.9	67.0
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	26.7	40.2	49.1	44.4	54.5	60.9
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**1.62**	**1.01**	**1.10**	**0.77**	**0.93**	**1.47**

Table 20. Effect of tillage and nutrients on number of branches of cowpea

	30DAS		45DAS			60DAS		
Tillage	**2017**	**2018**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
M_1- Zero tillage (ZT)	5.6	3.8	7.0[b]	5.3[a]	10 (6.2)[a]	12[b]	13[a]	12[b]
M_2- Minimum tillage (MT)	6.2	2.9	9.0[a]	4.8[b]	9 (6.8)[a]	14[a]	14[a]	14[a]
M_3- Conventional tillage (CT)	6.0	2.6	6.5[b]	4.6[b]	8 (5.6)[b]	10[b]	10[b]	10[c]
C.D (0.05)	**NS**	**NS**	**1.0**	**0.7**	**1.0**	**1.6**	**1.7**	**1.0**
SE(m)	**0.09**	**0.05**	**0.34**	**0.10**	**0.19**	**0.54**	**0.58**	**0.31**
S_1- Soil test based recommendations	6.1	3.1	7.0	5.0	9 (6.0)	11	12	12
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	6.1	3.6	8.1	4.7	9 (6.4)	12	13	12
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	5.8	2.9	7.8	4.7	9 (6.3)	12	12	12
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	5.7	3.6	8.1	5.2	10 (6.6)	12	13	12
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	5.7	2.9	6.9	4.9	9 (5.8)	12	11	12
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.12**	**0.10**	**0.44**	**0.13**	**0.25**	**0.70**	**0.75**	0.40
M_1S_1: ZT + Soil test based	5.9	4.4	6.3	5.3	9 (5.8)	10	13	12
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	5.4	3.2	8.3	5.0	10 (6.7)	12	13	13
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	5.6	3.8	7.5	5.1	9 (6.3)	12	13	12
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	5.3	4.2	8.0	5.2	10 (6.6)	12	13	13
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	5.5	3.3	5.1	6.0	10 (5.5)	11	10	11
M_2S_1: MT + Soil test based	6.8	2.8	8.5	5.2	10 (6.8)	14	14	14
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	6.3	3.8	8.6	4.3	9 (6.5)	14	14	14
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	5.6	2.4	8.6	4.4	9 (6.5)	14	14	14
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	6.3	2.8	9.2	5.9	11 (7.7)	14	14	14
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	5.8	3.0	8.6	4.2	9 (6.4)	14	14	14
M_3S_1: CT + Soil test based	5.7	2.2	6.4	4.5	8 (5.4)	10	10	10
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	7.0	3.6	7.2	4.8	9 (6.0)	10	11	10
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	6.2	1.0	7.3	4.7	9 (6.0)	10	10	10
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	5.4	3.8	6.1	4.4	8 (5.3)	10	11	10
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	5.6	2.4	6.2	4.5	8 (5.3)	10	10	10
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.21**	**0.10**	**0.77**	**0.22**	**0.42**	**1.21**	**1.29**	**0.69**

*R (weighted MSE) transformed values, original values in parentheses. In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

However, effect of various K and $MgSO_4$ doses as well as interaction between tillage and nutrient was non-significant on number of branches during both the years of study.

D. Leaf area index

Leaf area index recorded at active growth stage of cowpea (45 DAS) differed significantly due to various tillage, K and $MgSO_4$ doses and their interaction, **(Table 21).**

In both 2017 and 2018 highest LAI was registered under zero tillage (6.3 and 6.7 respectively). It was followed by minimum tillage, which resulted in LAI values of 5.3 and 5.1 respectively. Meanwhile, plants under conventional tillage system (M_3) registered significantly lower leaf area indices (3.1 and 2.9 respectively).

In 2017, application of K: $MgSO_4$ @ 40:80 kg/ha (S_5) resulted in higher leaf area index (8.1), which was at par to application of K: $MgSO_4$ @ 40:60 kg/ha (S_4), while, soil test based nutrition registered lowest LAI (5.8). In second year, highest LAI (9.6) was observed in application of K: $MgSO_4$ @ 40:80 kg/ha (S_5), followed by K: $MgSO_4$ @ 40:60 kg/ha (S_4). However lower values were noted in S_1, S_2, and S_3.

Interaction of various tillage and K-Mg doses also had significant effect on LAI of cowpea in both years. Higher LAI was recorded in crop raised under ZT with K: $MgSO_4$ @ 40:80 kg/ha (M_1S_5) which showed parity to MT with K: $MgSO_4$ @ 40:60 kg/ha (M_2S_4) in first year. Same treatment, *i.e.* ZT with K: $MgSO_4$ @ 40:80 kg/ha (M_1S_5) recorded highest LAI in the following year. It was followed by K: $MgSO_4$ @ 40:60 kg/ha under zero tillage (M_1S_4) which in turn showed parity to M_2S_5. During both years, conventional tillage along with various nutrient treatments resulted in lower values for LAI.

Pooling of data showed that among types of tillage systems, highest LAI was registered with zero tillage. It was followed by LAI recorded under MT. The tillage system to record lowest LAI was conventional tillage.

Application of K: $MgSO_4$ @ 40:80 kg/ha registered highest LAI, whereas the lowest values were recorded with soil test based nutrition where K: $MgSO_4$ was applied @ 12:80 kg/ha. Interaction effect was also significant and application of K: $MgSO_4$ @ 40:80 kg/ha under zero tillage registered highest LAI. Conventional tillage practices along with various nutrient combinations registered lower LAI and were at par with each other.

E. Chlorophyll content

Data pertaining effect of various tillage, K-Mg doses and their interaction on chlorophyll a, b, total chlorophyll content and chlorophyll a/b ratio are furnished in **Table 22**.

Various tillage practices had no significant influence on chlorophyll a, b, a/b ratio, and total chlorophyll content during both years. Average chlorophyll a contents in 2017 and 2018 were 1.03 mg/g and 0.99 mg/g respectively, while, average chlorophyll b contents in corresponding years were 0.27 mg/g and 0.26 mg/g respectively. In 2017 total chlorophyll content and chlorophyll a/b ratio were 1.34 mg/g and 3.92 respectively, while in following year it was 1.23 mg/g and 3.96 respectively.

Data showed that various levels of K and $MgSO_4$ had significant influence on content of chlorophyll a and total chlorophyll. In 2017, K: $MgSO_4$ @ 20:60 kg/ha (S_2) resulted in higher chlorophyll a (1.13 mg/g) and total chlorophyll content (1.44 mg/g), while no significant change was observed in chlorophyll b and a/b ratio. This was on par to S_1, S_3 and S_5. Application of K: $MgSO_4$ @ 40:60 kg/ha produced lowest content of chlorophyll a and total chlorophyll (0.99 mg/g and 1.22 mg/g).

Table 21. Effect of tillage and nutrients on LAI of cowpea on 45 DAS

Treatment	**LAI**		
Tillage	**2017**	**2018**	**Pooled**
M_1- Zero tillage (ZT)	6.3^{a}	6.7^{a}	6.3^{a}
M_2- Minimum tillage (MT)	5.3^{b}	5.1^{b}	5.0^{b}
M_3- Conventional tillage (CT)	3.1^{c}	2.9^{c}	3.2^{c}
C.D (0.05)	**0.7**	**0.7**	**0.6**
SE(m)	**0.20**	**0.19**	**0.21**
Nutrients			
S_1- Soil test based recommendations	5.8^{c}	6.3^{c}	6.0^{d}
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	6.4^{bc}	6.7^{c}	6.6^{c}
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	6.9^{b}	6.8^{c}	6.9^{c}
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	7.4^{ab}	8.3^{b}	7.9^{b}
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	8.1^{a}	9.6^{a}	8.8^{a}
C.D (0.05)	**1.0**	**0.9**	**0.8**
SE(m)	**0.27**	**0.30**	**0.31**
Interaction			
M_1S_1: ZT + Soil test based	7.1^{de}	6.0^{de}	6.6^{c}
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	6.7^{def}	5.5^{e}	6.1^{cd}
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	8.1^{bc}	7.4^{cd}	8.2^{b}
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	5.8^{bcde}	8.3^{b}	8.4^{b}
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	9.6^{a}	9.8^{a}	9.4^{a}
M_2S_1: MT + Soil test based	6.4^{f}	4.7^{fg}	6.1^{e}
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	6.5^{cde}	6.9^{e}	8.2^{cd}
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	6.3^{ef}	5.2^{f}	6.8^{de}
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	7.2^{ab}	7.5^{e}	7.4^{bc}
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	8.2^{bcd}	9.6^{bc}	7.4^{b}
M_3S_1: CT + Soil test based	3.0^{g}	3.0^{h}	3.4^{f}
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	3.1^{g}	2.9^{h}	3.4^{f}
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	3.4^{g}	2.6^{h}	3.5^{f}
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	3.2^{g}	3.4^{gh}	3.8^{f}
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	3.3^{g}	3.3^{h}	3.3^{f}
C.D (0.05)	**0.8**	**0.7**	**0.7**
SE(m)	**0.45**	**0.48**	**0.49**

However, in 2018, it was observed that K: $MgSO_4$ @ 40:80 kg/ha resulted in higher values for chlorophyll-a (1.08 mg/g) and total chlorophyll (1.34 mg/g) content. It was on par to K: $MgSO_4$ @ 20:80 kg/ha (S_2). This was against the trend noticed in first year. However, chlorophyll a and total chlorophyll content was lowest in plants (0.86 mg/g and 0.99 mg/g) which received in K: $MgSO_4$ @ 20:80 kg/ha (S_3).

Interactions between tillage and nutrients were found to be significant with respect to chlorophyll a and total content, while chlorophyll b and a/b ratio were not affected. Higher chlorophyll a (1.29 mg/g) and total chlorophyll content (1.62 mg/g) were recorded in zero tillage with soil test based nutrient application (M_1S_1) which was on par with chlorophyll content of cowpea grown under conventional tillage with application of K: $MgSO_4$ @ 20:60 kg/ha (M_3S_2). Significantly lower values were noted in CT with K: $MgSO_4$ @ 40:60 kg/ha (M_3S_4).

It could be observed that during second year, interaction effect was significant with respect to chlorophyll a, total chlorophyll content and a/b ratio. However no significant difference was noted in chlorophyll b content. Higher chlorophyll content (1.19 mg/g) was noticed under CT with application of K: $MgSO_4$ @ 20:60 kg/ha (M_3S_2) as well as 40:80 kg/ha (M_3S_5). Which were on par to CT with K: $MgSO_4$ @ 40:60 kg/ha (M_3S_4) and MT with K: $MgSO_4$ @ 40:80 kg/ha (M_2S_5) and ZT with soil test based nutrient management (M_1S_1).

From the pooled data it is clear that tillage did not influence chlorophyll content significantly. In nutrient treatments, application of K: $MgSO_4$ @ 20:60, 40:80 kg/ha and 12:80 kg/ha (soil test based) registered higher chlorophyll a content. Whereas, application of K: $MgSO_4$ @ 20:60 and 40:80 kg/ha resulted in higher total chlorophyll content. Interaction of ZT with soil test based nutrition and CT with of K: $MgSO_4$ @ 20:60 kg/ha (M_3S_2) produced higher chlorophyll a content while, higher total chlorophyll content (1.58 mg/g) was registered with M_3S_2 which was on par with M_1S_1 (1.49 mg/g).

Table 22. Effect of tillage and nutrients on chlorophyll content (mg/kg) of cowpea on 60 DAS

Treatment	**Chlorophyll a**			**Chlorophyll b**		**Total chlorophyll**			**Chlorophyll a/b**	
Tillage	**2017**	**2018**	**Pooled**	**2017**	**2018**	**2017**	**2018**	**Pooled**	**2017**	**2018**
M_1- Zero tillage (ZT)	1.06	0.98	14.3 (1.06)	0.31	0.25	1.34	1.20	1.28	3.76	3.95
M_2- Minimum tillage (MT)	1.01	0.94	12.9 (0.98)	0.26	0.23	1.26	1.22	1.24	3.95	4.21
M_3- Conventional tillage (CT)	1.04	1.01	13.7 (1.04)	0.26	0.29	1.29	1.25	1.32	4.10	3.71
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.02**	**0.02**	**0.17**	**0.01**	**0.01**	**0.02**	**0.02**	**0.02**	**0.06**	**0.05**
S_1- Soil test based recommendations	1.07^{a}	1.01^{ab}	13.7 (1.04)^{a}	0.27	0.27	1.34^{a}	1.27^{a}	1.29^{b}	3.91	3.84
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	1.13^{a}	1.02^{ab}	14.3 (1.07)^{a}	0.31	0.26	1.44^{a}	1.27^{a}	1.34^{a}	3.70	3.80
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	1.07^{a}	0.86^{c}	13.0 (0.96)^{b}	0.27	0.22	1.34^{a}	0.99^{b}	1.17^{d}	3.92	4.13
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.99^{b}	0.97^{b}	12.9 (0.98)^{b}	0.24	0.25	1.22^{b}	1.29^{a}	1.26^{c}	4.24	4.23
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	1.08^{a}	1.08^{a}	14.3 (1.08)^{a}	0.28	0.28	1.35^{a}	1.32^{a}	1.34^{a}	3.91	3.78
C.D (0.05)	**0.07**	**0.09**	**0.60**	**NS**	**NS**	**0.08**	**0.08**	**0.1**	**NS**	**NS**
SE(m)	**0.02**	**0.03**	**0.22**	**0.01**	**0.01**	**0.03**	**0.03**	**0.02**	**0.08**	**0.06**
M_1S_1: ZT + Soil test based	1.29^{a}	1.08^{ab}	15.9 (1.19)^{a}	0.33	0.28	1.62^{a}	1.36^{cde}	1.49^{ab}	3.90	3.98^{de}
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	1.13^{bc}	0.99^{bcde}	14.1 (1.06)^{cd}	0.31	0.26	1.44^{bc}	1.24^{def}	1.34^{cd}	3.67	3.93^{de}
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	1.10^{bc}	0.87^{ef}	13.3 (0.99)^{defg}	0.29	0.20	1.39^{bcde}	0.77^{h}	1.08^{i}	3.82	4.35^{b}
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	1.13^{bc}	0.91^{cdef}	13.8 (1.02)^{cdef}	0.29	0.25	1.42^{bcd}	1.17^{f}	1.29^{de}	3.86	3.91^{ef}
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	1.12^{bc}	1.01^{bcde}	14.2 (1.07)^{cd}	0.31	0.26	1.43^{bc}	1.03^{g}	1.23^{efg}	3.57	3.58^{gh}
M_2S_1: MT + Soil test based	0.97^{defg}	0.96^{bcdef}	12.7 (0.97)^{fg}	0.24	0.25	1.21^{efgh}	1.27^{def}	1.24^{efg}	4.03	3.91^{de}
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	1.05^{cde}	0.88^{ef}	12.9 (0.96)^{efg}	0.29	0.19	1.35^{cde}	0.92^{g}	1.13^{hi}	3.58	3.88^{efg}
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	1.02^{cdef}	0.90^{def}	12.8 (0.96)^{efg}	0.26	0.26	1.28^{defg}	1.24^{ef}	1.26^{def}	3.98	4.22^{bcd}
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.94^{efg}	0.93^{bcdef}	12.3 (0.94)^{g}	0.22	0.20	1.16^{gh}	1.26^{def}	1.21^{efgh}	4.20	4.71^{a}
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	1.05^{cde}	1.05^{abcd}	13.8 (1.05)^{cde}	0.27	0.24	1.32^{cdef}	1.37^{cd}	1.35^{cd}	3.85	4.29^{bc}
M_3S_1: CT + Soil test based	0.94^{fg}	0.98^{bcdef}	12.6 (0.96)^{g}	0.25	0.29	1.19^{fgh}	1.17^{f}	1.18^{fgh}	3.78	3.64f^{gh}
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	1.21^{ab}	1.19^{a}	15.8 (1.20)^{ab}	0.31	0.34	1.52^{ab}	1.63^{a}	1.58^{a}	3.85	3.57^{gh}
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	1.08^{c}	0.82^{f}	12.8 (0.95)^{efg}	0.27	0.20	1.35^{cde}	0.97^{g}	1.16^{ghi}	3.98	3.83^{efg}
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.89^{g}	1.07^{abc}	12.7 (0.98)^{g}	0.19	0.28	1.08^{h}	1.45^{bc}	1.26^{def}	4.31	4.07^{cde}
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	1.07^{cd}	1.19^{a}	14.7 (1.13)^{bc}	0.25	0.35	1.31^{cdef}	1.55^{ab}	1.43^{bc}	4.30	3.42^{h}
C.D (0.05)	**0.11**	**0.16**	**1.1**	**NS**	**NS**	**0.14**	**0.14**	**0.1**	**NS**	**0.29**
SE(m)	**0.04**	**0.05**	**0.38**	**0.01**	**0.02**	**0.05**	**0.05**	**0.04**	**0.14**	**0.10**

*R (weighted MSE) transformed values, original values in parentheses. In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

F. Days to 50 % flowering

Early flowering was observed in conventional tillage plots where 50% of plants attained flowering in 45 days during 2017. In minimum tillage and zero tillage, it took 48 days and they differed statistically **(Table 23)**. However, it was observed that, influence of K-$MgSO_4$ doses and interaction effect were non-significant with respect to earliness in flowering. In all the treatments 50 % flowering was attained in 47 days after sowing.

The same trend was observed in the next year also and conventional tillage resulted in early flowering, *i.e*. on 46th day after sowing. However, both zero tillage and minimum tillage condition resulted in delayed flowering (46-49 days to reach 50 % flowering). Potassium and magnesium sulphate doses and their interaction with tillage had no significant effect on days taken to reach 50 % flowering in cowpea.

G. Total dry matter production (TDMP)

Total dry matter production was recorded at 15 days interval of crop growth in 2017 and 2018. Various tillage systems, K and $MgSO_4$ doses and interaction had significant effect on total dry matter production of cowpea during both years (**Table 24, 25 and 26**). It could be noted that during first year, under various tillage practices dry matter production gradually increased until 60 DAS. While, in second year there was an increase in dry matter production till 75 DAS.

During the period of study conventional tillage (CT) registered highest dry matter production at 15 DAS, 30 DAS, 45 DAS, and 60 DAS, and the values recorded in 2017 were 48.7, 384.9, 2287.5, and 2799.6 kg/ha respectively. Corresponding values in the second year were 52.4, 788.4, 1125.4, and 3593.9 kg/ha. Conventional tillage was followed by minimum tillage (MT) and zero tillage (ZT). However, in later stages of crop growth a change in this trend was observed. At 75 DAS and 90 DAS, dry matter produced was highest under minimum tillage, followed by ZT and CT

Table 23. Effect of tillage and nutrients on days to 50% flowering of cowpea

Tillage	**2017**	**2018**
M_1- Zero tillage (ZT)	48[a]	49[a]
M_2- Minimum tillage (MT)	48[a]	48[a]
M_3- Conventional tillage (CT)	45[b]	46[b]
C.D (0.05)	**1.0**	**1.0**
SE(m)	**0.37**	**0.47**
Nutrients		
S_1- Soil test based recommendations	47	47
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	47	47
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	47	48
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	47	47
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	47	47
C.D (0.05)	**NS**	**NS**
SE(m)	**0.48**	**0.61**
Interaction		
M_1S_1: ZT + Soil test based	49	48
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	47	48
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	48	49
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	49	49
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	48	48
M_2S_1: MT + Soil test based	47	47
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	49	49
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	47	47
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	48	47
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	48	48
M_3S_1: CT + Soil test based	45	45
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	45	46
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	44	46
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	44	46
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	44	45
C.D (0.05)	**NS**	**NS**
SE(m)	**0.82**	**1.05**

during 2017. In 2018, again highest dry matter was produced under CT followed by MT and ZT at 75 DAS. At 90 DAS CT recorded highest dry matter and dry matter under MT and ZT were at par. In both years, lowest TDMP was noted in zero tillage (ZT) till 60 DAS. It could be also noted that lower dry matter content was consistently observed in zero tillage system and this trend was changed in later stages of crop growth.

Influence of K and $MgSO_4$ doses was found to be significant with respect to total dry matter production of cowpea throughout the crop growth stages in first year, while in the following year, significant variation due to nutrient levels was noticed in all growth stages except at 30 DAS, where nutrient doses failed to bring about significant effect on dry matter production.

In 2017, at 15 DAS, K: $MgSO_4$ @ 40:60 kg/ha (S_4) registered higher dry matter production (42.2 kg/ha) and it was at par with application of K: $MgSO_4$ @ 20:60 kg/ha (S_2). At 30 DAS, K: $MgSO_4$ @ 20:60 kg/ha (S_2) registered highest dry matter production (323 kg/ha, while at 45 DAS, K: $MgSO_4$ @ 20:80 kg/ha (S_3) registered higher dry matter which was on par with S_4 and S_5. At 60 DAS, again S_4 registered higher dry matter content (2667.2 kg/ha) which showed parity to S_3 and S_5. At 75 and 90 days after sowing also, S_4 resulted in higher dry matter production. At 90 DAS, it was at par with soil test based nutrition (S_1). At 15 DAS, lower dry matter was recorded in S_1, S_3, and S_5, while at 30 DAS, application of K: $MgSO_4$ @ 40:80 kg/ha (S_5) recorded lowest dry matter (250.4 kg/ha). Application of K: $MgSO_4$ @ 20:60 kg/ha (S_2) recorded lowest dry matter (1557.2 kg/ha) at 45 DAS and it was at par with S_1. S_2, S_3, and S_5 registered lowest dry matter production of cowpea at 75 DAS, and S_2 and S_3 were inferior at 90 DAS.

In second year, at 15 DAS soil test based nutrient application (S_1) recorded higher dry matter content in crop and it showed parity to S_2, S_3, and S_4. At 30 DAS, treatments failed to create significant effect on dry matter production. At 45 DAS application of K: $MgSO_4$ @ 40: 80 kg/ha (S_5) registered higher total dry matter content (910.2 kg/ha) which was at par with S_1, S_3, and S_4. However, application of K: $MgSO_4$

@ 40: 60 kg/ha (S_4) resulted in higher total dry matter content (3145 kg/ha) in cowpea at 60 DAS and was on par to dry matter produced in S_1 and S_5 (2965.2 and 2956.9 kg/ha respectively). At 75 DAS, application of K: $MgSO_4$ @ 20: 60 kg/ha (S_2) was observed to produce higher dry matter (3614.2 kg/ha) which was at par to S_3. However at 90 DAS, soil test based nutrient application (S_1) produced highest dry matter content of 2519 kg/ha.

Lowest total dry matter recorded at 15 DAS (31.4 kg/ha) resulted with the application of K: $MgSO_4$ @ 40:80 kg/ha. At 45 and 60 DAS the lowest dry matter was registered with application of K: $MgSO_4$ @ 20:60 kg/ha (S_2) *i.e.* 739.2 kg/ha and 2273.2 kg/ha respectively, while at 75 and 90 DAS application of K: $MgSO_4$ @ 40: 80 kg/ha (S_5) produced lowest dry matter.

In first year of study, among various treatment combinations, higher dry matter content (62.2 kg/ha) was recorded under CT with K: $MgSO_4$ @ 20:60 kg/ha (M_3S_2) at 15 DAS. It was on par to CT with K: $MgSO_4$ @ 40:60 kg/ha (M_3S_4). At 30 DAS, CT along with K: $MgSO_4$ @ 20:60 kg/ha (M_3S_2) resulted in significantly higher dry matter of 498.6 kg/ha. This was followed by dry matter recorded (411.2 kg/ha) under CT with K: $MgSO_4$ @ 40:60 kg/ha (M_3S_4). At 45 DAS, CT along with K: $MgSO_4$ @ 40:80 kg/ha (M_3S_5) produced higher dry matter (2632.1 kg/ha) and it showed parity with M_2S_3, M_3S_2, and M_3S_4. At 60 DAS also, CT along with K: $MgSO_4$ @ 40:80 kg/ha (M_3S_5) recorded higher dry matter (3421.7 kg/ha) which was on par to CT with soil test based nutrition (M_3S_1), and ZT + K: $MgSO_4$ @ 20:80 kg/ha (M_1S_3), and MT + K: $MgSO_4$ @ 40:60 kg/ha (M_2S_4). At 75 DAS, minimum tillage along with K: $MgSO_4$ @ 40:60 kg/ha recorded higher dry matter of 3715.9 kg/ha and was on par to dry matter produced (3476.3 kg/ha) in M_2S_5. At 90 DAS also M_2S_4 resulted in significantly higher dry matter production (2410.2 kg/ha). In 2018, higher dry matter content (60.1 kg/ha) was recorded with application of soil test based nutrition under conventional tillage (M_3S_1) at 15 DAS, and it was on par to dry matter produced (54.9 kg/ha) in K: $MgSO_4$ @ 40:60 kg/ha under conventional tillage (M_3S_4). Conventional tillage along with K: $MgSO_4$ @ 12.8:80 kg/ha (M_3S_1) resulted in higher dry matter of 1008.8 kg/ha at 30 DAS and 1306.3 kg/ha at 45 DAS, and was on par to dry matter produced in M_3S_5

(995.8 kg/ha at 30 DAS and 1274.6 kg/ha at 45 DAS). At 60 DAS, conventional tillage along with K: $MgSO_4$ @ 40:80 kg/ha (M_3S_5) recorded higher dry matter (3820.7 kg/ha) which was on par to dry matter produced in conventional tillage with K: $MgSO_4$ @ 40:60 kg/ha (M_3S_4) and 20:80 kg/ha (M_3S_2). At 75 DAS, conventional tillage with K: $MgSO_4$ @ 20:80 kg/ha (M_3S_3) resulted in higher dry matter production of 4446.6 kg/ha and was on par to M_3S_2 (4261.6 kg/ha) and M_3S_1 (4107.4 kg/ha). At 90 DAS also, M_3S_1 resulted in higher dry matter production (3028.7 kg/ha) and it was on par to M_3S_2 (2742.4 kg/ha).

At 15 DAS, lower dry matter content was observed under ZT system along with K: $MgSO_4$ applied @ 20:60 kg/ha (M_1S_2), 20:80 kg/ha (M_1S_3) and 40:80 kg/ha (M_1S_5) as well as to MT along with K: $MgSO_4$ applied @ 12.8:80 kg/ha and (M_2S_1), and 20:60 kg/ha (M_2S_2) in 2017. However, in 2018, lower dry matter content was registered under ZT system along with K: $MgSO_4$ applied @ 40:60 kg/ha (M_1S_4) and 40:80 kg/ha (M_1S_5). In 2017, lowest dry matter produced at 30 DAS (102.6 kg/ha) was registered under zero tillage along with K: $MgSO_4$ 40:80 kg/ha (M_1S_5). Corresponding values in the next year were recorded under MT along with soil test based nutrition (M_2S_1) which was on par to MT along with K: $MgSO_4$ 20:60 (M_2S_2), ZT along with K: $MgSO_4$ @ 20:60 (M_1S_5) and 40:60 kg/ha (M_1S_4). However, at 45 DAS lower dry matter (962.5 kg/ha) was recorded in application of K: $MgSO_4$ @ 20:60 kg/ha under MT (M_2S_2) which was on par with application of K: $MgSO_4$ @ 40:80 kg/ha and soil test based recommendations under ZT system (M_1S_5) during 2017. In 2018, adoption of M_1S_5 resulted in lower dry matter production of cowpea (446.4 kg/ha), and it was at par with application of K: $MgSO_4$ @ 40:60 kg/ha and soil test based recommendations under ZT system (M_1S_4). It could be noted that at every stage of crop growth, interaction between zero tillage and various nutrient doses produced lower values for dry matter production.

Pooled analysis revealed that tillage had significant influence on dry matter production throughout the growth stages. Among various tillage practices, compared to conservation tillage systems (ZT and MT), higher dry matter was produced was under conventional tillage practice at 75 DAS, highest dry matter was produced under minimum tillage (3240 kg/ha). However, at 90 DAS, both minimum and conventional tillage resulted in higher dry matter (2043 kg/ha and 2085 kg/ha respectively). At every stage of growth the lowest dry matter was registered under zero tillage system.

At 15 DAS, higher dry matter production was registered with K: $MgSO_4$ @ 20:60 (S_2), 20:80 (S_3) and 40:60 (S_4) kg/ha which were on par to each other. The lowest dry matter at this stage (33.7 kg/ha) was noticed with application of K @ 40 kg/ha with $MgSO_4$ @ 80 kg/ha (S_5). Nutrient combinations failed to produce significant effect on dry matter production at 30 DAS and at 45 DAS. At 60 DAS highest dry matter production (2906.1 kg/ha) was noticed with the application of K: $MgSO_4$ @ 40:60 kg/ha (S_4) and the lowest content (2232.6 kg/ha) was noticed under K: $MgSO_4$ @ 20:60 kg/ha (S_2). Nutrient treatments S_2, S_3 and S_4 resulted in higher dry matter production (3033 kg/ha, 2974.3 kg/ha and 3025 kg/ha respectively) at 75 DAS. At 90 DAS, S_1 and S_4 registered higher dry matter production and they were at par. The treatment which received lower dose of potash (20 kg/ha) with higher level of Mg (80 kg/ha) produced lowest dry matter at 90 DAS.

At 15 DAS, CT with 20:60 (M_3S_2) and 40:60 (M_3S_4) kg/ha recorded higher dry matter production and it was on par with M_3S_4. The lowest dry matter (19 kg/ha) was noted under ZT with 40:80 kg/ha (M_1S_5). Conventional tillage with soil test based nutrition and conventional tillage with K: $MgSO_4$ @ 20:60 kg/ha recorded higher dry matter (689 kg/ha and 593 kg/ha respectively) at 30 DAS. At 45 DAS and 60 DAS, M_3S_1 and M_3S_5 registered higher dry matter production. At 75 DAS and 90 DAS, higher dry matter production (3996 kg/ha and 2461 kg/ha respectively) was noticed under MT along with K-$MgSO_4$ @ 40:60 kg/ha (M_2S_4). At 75 DAS, soil test based nutrition under conventional tillage (M_3S_1) also produced higher dry matter (2510 kg/ha). Results indicated that, dry matter production increased gradually till 75 DAS and declined at later stage due to senescence of leaves.

Table 24. Effect of tillage and nutrients on total dry matter production (kg/ha) of cowpea at 15 DAS and 30 DAS

	15 DAS			30 DAS		
Tillage	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
M_1- Zero tillage (ZT)	27.9[c]	22.4[c]	25.1[c]	191.7[c]	459.2[c]	5.6 (326)[c]
M_2- Minimum tillage (MT)	34.3[b]	35.6[b]	35.0[b]	274.5[b]	593.7[b]	7.7 (434)[b]
M_3- Conventional tillage (CT)	48.7[a]	52.4[a]	50.6[a]	384.9[a]	788.4[a]	10.6 (587)[a]
C.D (0.05)	**3.2**	**2.8**	**2.5**	**21.9**	**73.4**	**0.6**
SE(m)	**1.10**	**0.97**	**0.85**	**7.52**	**25.2**	**0.19**
S_1- Soil test based recommendations	32.2[c]	40.4[a]	36.3[b]	280.6[b]	597.8	7.9 (439)
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	38.3[ab]	36.9[a]	37.6[ab]	323.0[a]	555.3	8.4 (439)
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	36.2[bc]	38.2[a]	37.2[ab]	283.9[b]	652.0	8.2 (468)
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	42.2[a]	37.0[a]	39.6[a]	280.6[b]	594.4	7.9 (438)
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	35.9[bc]	31.4[b]	33.7[c]	250.4[c]	669.2	7.7 (460)
C.D (0.05)	**4.1**	**3.6**	**3.2**	**28.3**	**NS**	**NS**
SE(m)	**1.42**	**1.25**	**1.09**	**9.70**	**32.5**	**0.25**
M_1S_1: ZT + Soil test based	31.1[def]	29.7[f]	30.4[gh]	200.0[i]	480.1[efg]	5.9 (340)[fg]
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	23.9[g]	23.3[g]	23.6[ij]	217.2[hi]	513.6[ef]	6.4 (365)[f]
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	28.1[efg]	27.8[fg]	27.9[hi]	266.1[g]	607.3[cde]	7.7 (437)[de]
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	32.4[cdef]	16.8[h]	24.6[i]	172.5[i]	363.7[fgh]	4.8 (268)[g]
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	23.9[g]	14.2[h]	19.0[j]	102.6[j]	331.1[gh]	3.5 (217)[h]
M_2S_1: MT + Soil test based	26.1[fg]	31.5[ef]	28.8[ghi]	272.2[efg]	304.7[h]	6.2 (289)[f]
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	28.8[efg]	36.1[de]	32.5[fgh]	253.2[gh]	464.5[efgh]	6.7 (359)[ef]
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	46.8[b]	39.3[d]	43.1[cd]	269.2[fg]	812.3[b]	8.8 (541)[cd]
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	33.2[cde]	39.2[d]	36.2[ef]	258.1[gh]	706.2[bc]	8.0 (482)[cd]
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	36.3[cd]	32.0[ef]	34.2[fg]	319.9[de]	680.8[bcd]	9.0 (500)[c]
M_3S_1: CT + Soil test based	39.3[c]	60.1[a]	49.7[b]	369.7[bc]	1008.8[a]	12.1 (689)[a]
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	62.2[a]	51.3[bc]	56.8[a]	498.6[a]	687.9[bcd]	11.5 (593)[ab]
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	33.7[cde]	47.5[c]	40.6[de]	316.3[def]	536.2[de]	8.2 (426)[cd]
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	61.0[a]	54.9[ab]	57.9[a]	411.2[b]	713.4[bc]	10.7 (562)[b]
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	47.5[b]	48.1[c]	47.8[bc]	328.7[cd]	995.8[a]	10.7 (662)[b]
C.D (0. 05)	**7.2**	**6.3**	**5.5**	**48.9**	**164.0**	**1.3**
SE(m)	**2.46**	**2.17**	**1.89**	**16.81**	**56.33**	**0.43**

*R (weighted MSE) transformed values, original values in parentheses. In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

Table 25. Effect of tillage and nutrients on total dry matter production (kg/ha) of cowpea at 45 DAS and 60 DAS

	45 DAS			60 DAS		
Tillage	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
M_1- Zero tillage (ZT)	1394.9[c]	600.5[c]	7.7 (998)[c]	2099.7[c]	2099.9[c]	2099.8[c]
M_2- Minimum tillage (MT)	1618.9[b]	819.8[b]	9.7 (1219)[b]	2408.5[b]	2840.4[b]	2624.5[b]
M_3- Conventional tillage (CT)	2287.5[a]	1125.4[a]	13.5 (1707)[a]	2799.6[a]	3593.9[a]	3196.7[a]
C.D (0.05)	**139.9**	**57.9**	**0.5**	**174.3**	**170.4**	**97.9**
SE(m)	**48.05**	**19.9**	**0.18**	**59.87**	**58.50**	**33.63**
S_1- Soil test based recommendations	1702.1[bc]	846.1[a]	10.1 (1274)	2255.2[b]	2965.2[ab]	2610.3[c]
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	1557.2[c]	739.2[b]	9.0 (1148)	2192.2[b]	2273.2[c]	2232.6[d]
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	1902.3[a]	851.7[a]	10.6 (1377)	2617.6[a]	2883.4[b]	2750.5[b]
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	1784.3[ab]	895.6[a]	10.6 (1340)	2667.2[a]	3145.0[a]	2906.1[a]
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	1889.6[a]	910.2[a]	11.0 (1400)	2447.3[ab]	2956.9[ab]	2702.0[b]
C.D (0.05)	**180.6**	**74.8**	**NS**	**225.0**	**220.0**	**126.4**
SE(m)	**62.03**	**25.7**	**0.23**	**77.29**	**75.60**	**43.41**
M_1S_1: ZT + Soil test based	1565.4[cde]	687.7[d]	8.7 (1127)[f]	1724.0[de]	2735.9[e]	2230.0[f]
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	1322.0[ef]	621.8[de]	7.6 (972)[fg]	2050.8[cd]	1204.6[h]	1627.7[g]
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	1456.0[def]	689.9[d]	8.4 (1073)[f]	3066.4[a]	2460.6[efg]	2763.5[d]
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	1454.0[def]	556.5[ef]	7.5 (1005)[fg]	2222.3[bc]	2246.7[g]	2234.5[f]
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	1177.5[fg]	446.4[f]	6.1 (812)[h]	1434.5[e]	1851.8[h]	1643.2[g]
M_2S_1: MT + Soil test based	1285.5[ef]	544.3[ef]	7.0 (915)[gh]	1779.2[de]	2636.2[ef]	2207.7[f]
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	962.5[g]	608.0[de]	6.5 (785)[gh]	1972.3[cd]	2351.9[fg]	2162.1[f]
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	2564.4[ab]	887.9[c]	12.7 (1726)[cd]	2489.3[b]	2584.1[efg]	2536.7[cd]
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	1423.2[def]	1049.1[b]	10.6 (1236)[e]	3316.6[a]	3431.6[bcd]	3374.1[e]
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	1859.3[c]	1009.6[b]	11.5 (1434)[de]	2485.2[b]	3198.2[d]	2841.7[d]
M_3S_1: CT + Soil test based	2255.5[b]	1306.3[a]	14.5 (1781)[ab]	3262.7[a]	3523.6[abcd]	3393.1[a]
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	2387.2[ab]	987.8[bc]	12.8 (1688)[c]	2553.3[b]	3262.9[cd]	2908.1[cd]
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	1687.3[cd]	977.2[bc]	10.9 (1332)[e]	2297.0[bc]	3605.5[abc]	2951.3[cd]
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	2475.7[ab]	1081.2[b]	13.7 (1778)[bc]	2463.1[b]	3756.6[ab]	3109.8[c]
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	2632.1[a]	1274.6[a]	15.3 (1953)[a]	3421.7[a]	3820.7[a]	3621.2[a]
C.D (0.05)	**312.8**	**129.5**	**1.2**	**389.8**	**381.0**	**218.9**
SE(m)	**107.43**	**44.5**	**040**	**133.86**	**130.90**	**75.19**

*R (weighted MSE) transformed values, original values in parentheses. In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

Table 26. Effect of tillage and nutrients on total dry matter production (kg/ha) of cowpea at 75 DAS and 90 DAS

Treatments	**75 DAS**			**90 DAS**		
Tillage	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
M_1- Zero tillage (ZT)	2314.2^b	2401.8^c	9.0 (2358)^c	1727.4^b	2058.2^b	13.3 (1893)^b
M_2- Minimum tillage (MT)	3191.8^a	3287.2^b	12.4 (3240)^a	2048.4^a	2037.8^b	14.7 (2043)^a
M_3- Conventional tillage (CT)	2001.5^c	3950.6^a	10.5 (2976)^b	1614.1^c	2556.4^a	14.1 (2085)^a
C.D (0.05)	**159.4**	**256.7**	**0.5**	**80.5**	**146.5**	**0.7**
SE(m)	**54.7**	**88.2**	**0.2**	**27.7**	**50.3**	**0.2**
S_1- Soil test based recommendations	2019.0^d	3186.9^b	9.4 (2603)^b	1995.8^a	2519.0^a	15.6 (2258)^a
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	2451.3^c	3614.2^a	11.1 (3033)^a	1655.4^c	2334.1^b	13.7 (1995)^b
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	2641.2^{bc}	3307.5^{ab}	11.1 (2974.3)^a	1645.6^c	2113.2^c	12.7 (1880)^c
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	2883.1^a	3167.2^b	11.5 (3025)^a	1944.0^a	2193.8^{bc}	14.7 (2069)^a
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	2517.9^c	2790.1^c	10.0 (2654)^b	1838.9^b	1927.0^c	13.5 (1883)^b
C.D (0.05)	**205.7**	**331.4**	**0.7**	**104.0**	**189.0**	**0.9**
SE(m)	**70.7**	**113.8**	**0.2**	**35.7**	**64.9**	**0.3**
M_1S_1: ZT + Soil test based	1704.8^g	2334.1^d	7.4 (2019)^h	1886.0^{bc}	2844.3^{ab}	16.1 (2365)^{bc}
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	2629.2^c	3083.8^c	10.7 (2857)^{def}	1565.0^{ef}	2106.7^f	12.7 (1836)^{fg}
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	2572.1^{cd}	3307.0^c	10.9 (2940)^{de}	1477.0^f	1975.7^{fg}	12.0 (1726)^g
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	2594.9^c	1673.3^e	8.6 (2134)^g	1852.9^{bcd}	1773.6^{gh}	13.2 (1813)^{efg}
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	2069.8^{ef}	1610.7^e	7.2 (1840)^h	1856.3^{bcd}	1590.6^h	12.7 (1723)^{fg}
M_2S_1: MT + Soil test based	2595.6^c	3119.1^c	10.7 (2857)^{def}	2010.0^b	1684.4^{gh}	13.7 (1847)^{def}
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	3051.2^b	3497.2^c	12.3 (3274)^{bc}	1993.4^b	2154.2^f	14.8 (1979)^{cd}
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	3120.2^b	2168.8^{de}	10.5 (2645)^{ef}	1803.5^{bc}	2236.6^{ef}	14.2 (2138)^{def}
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	3715.9^a	4276.9^a	15.0 (3996)^a	2410.2^a	2512.0^{cde}	17.7 (2461)^a
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	3476.3^a	3373.8^c	13.1 (3425)^b	1978.8^{bc}	1602.1^h	13.4 (1791)^{efg}
M_3S_1: CT + Soil test based	1756.7^{fg}	4107.4^{ab}	10.2 (2932)^{ef}	1991.3^b	3028.7^a	17.1 (2510)^a
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	1673.7^g	4261.6^a	10.2 (2968)^{ef}	1407.8^f	2742.4^{abc}	13.6 (2075)^{def}
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	2231.1^{cd}	4446.6^a	11.8 (3339)^{cd}	1420.6^f	2127.7^f	12.1 (1774)^g
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	2338.4^{cde}	3551.3^{bc}	10.7 (2945)^{def}	1568.9^{ef}	2295.0^{def}	13.2 (1932)^{efg}
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	2007.8^{efg}	3385.8^c	9.7 (2697)^{fg}	1681.7^{de}	2588.0^{bcd}	14.5 (2135)^{de}
C.D (0.05)	**356.3**	**574.0**	**1.1**	**180.1**	**327.5**	**1.5**
SE(m)	**122.4**	**197.1**	**0.4**	**61.8**	**112.5**	**0.5**

*R (weighted MSE) transformed values, original values in parentheses. In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

H. Number of root nodules

Various tillage practices and potassium and magnesium sulphate doses failed to create significant variation in number of root nodules per plant during both years **(Table 27)**. Average number of nodules noticed was very low in both years and it ranged from 5 to 26 nodules/plant.

I. Root length

Root length of cowpea varied significantly due to various tillage and nutrient doses and the trend observed was same during both 2017 and 2018 **(Table 27)**. It could be noted that length of roots decreased with increasing intensity of tillage.

During first year, zero tillage (M_1) resulted in longest roots (32.1 cm) followed by minimum tillage (M_2) and conventional tillage (23.5 cm). In the following year, zero tillage (ZT) resulted in longest roots (44.8 cm) which was on par to the root length observed under MT conditions (44.0 cm). In both years the shortest roots were observed under CT conditions.

Among K and Mg levels K: $MgSO_4$ @ 40:60 kg/ha (S_4) resulted in longer roots (30 cm) which was on par with soil test based nutrient application (S_1) and K: $MgSO_4$ @ 20:80 kg/ha (S_3). Application of K: $MgSO_4$ @ 40:80 kg/ha (S_5) produced shorter roots (25.7 cm) during 2017. In 2018 longest roots (47.3 cm) was recorded in K: $MgSO_4$ @ 20:60 kg/ha (S_2). It was on par to the application of K: $MgSO_4$ @ 20:80 kg/ha *i.e.* S_3 (46.3 cm).

Interaction effect was also significant. In 2017, ZT along with soil test based nutrient application (M_1S_1) produced longer roots (38.8 cm) which was on par with K: $MgSO_4$ @ 40:60 kg/ha under zero tillage conditions (M_1S_4). In 2018, application of K: $MgSO_4$ @ 20:80 kg/ha under MT (M_2S_3) resulted in higher root length (55.2 cm) and it was at par with M_1S_4, *i.e.* application of K: $MgSO_4$ @ 40:60 kg/ha under zero tillage (54.9 cm). Shortest roots (32.7 cm) was noticed under conventional tillage along with higher levels of K (40 kg/ha) with $MgSO_4$ (60 and 80 kg/ha).

Pooled analysis of data revealed that cowpea roots were longest under no tillage (38.5 cm), followed by minimum tillage (36.5 cm) and the shortest roots were noticed under conventional tillage. Application of K: $MgSO_4$ @ 20:60 (S_2), 20:80 (S_3) and 40:60 (S_4) kg/ha produced longer roots. Interaction of ZT with K: $MgSO_4$ @ 40:80 kg/ha (M_1S_4) and MT with K: $MgSO_4$ @ 20:80 kg/ha (M_2S_3) resulted in longest roots. Application of K: $MgSO_4$ @ 40:80 kg/ha in conventional tillage registered shortest roots.

J. Root spread

Significant variation in root spread due to different types of tillage, K-$MgSO_4$ doses and their interaction was observed during both years **(Table 27)**. Among various tillage practices, no-tillage (M_1) recorded largest root spread (1552 cm^2 and 3206 cm^2) during both years. Conventional tillage resulted in lowest root spread.

In both years, among various K and $MgSO_4$ doses, larger root spread was recorded under soil test based nutrition (1501 cm^2 and 2883 cm^2 respectively) and K: $MgSO_4$ @ 40:60 kg/ha (1374 cm^2 and 2858 cm^2). In 2018, these treatments were on par with root spread recorded (2923 cm^2) in K: $MgSO_4$ @ 20:80 kg/ha (S_3). Except S_1

Table 27. Effect of tillage and nutrients on root length (cm), number of root nodules, and root spread (cm^2) of cowpea

Treatments	Root length			Nodules		Root spread		
Tillage	**2017**	**2018**	**Pooled**	**2017**	**2018**	**2017**	**2018**	**Pooled**
M_1- Zero tillage (ZT)	32.1^{a}	44.8^{a}	38.5^{a}	19	19	1552^{a}	3206^{a}	$13.8\ (2379)^{a}$
M_2- Minimum tillage (MT)	29.0^{b}	44.0^{a}	36.5^{b}	14	16	1320^{b}	2326^{c}	$10.4\ (1823)^{b}$
M_3- Conventional tillage (CT)	23.5^{c}	42.6^{b}	33.0^{c}	12	13	952^{c}	2507^{b}	$10.2\ (1730)^{b}$
C.D (0.05)	**1.6**	**1.2**	**1.1**	**NS**	**NS**	**184**	**114**	**0.5**
SE(m)	**0.56**	**0.41**	**0.39**	**0.30**	**0.30**	**63.09**	**39.11**	**0.19**
S_1- Soil test based recommendations	29.7^{ab}	41.9^{c}	35.8^{b}	13	15	1501^{a}	2883^{a}	$12.58\ (2192)^{a}$
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	27.6^{bc}	47.3^{a}	37.5^{a}	12	12	1194^{b}	2530^{b}	$10.80\ (1862)^{b}$
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	28.1^{ab}	46.3^{a}	37.2^{a}	18	19	1213^{b}	2923^{a}	$12.14\ (2068)^{a}$
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	30.0^{a}	44.5^{b}	37.3^{a}	19	19	1374^{ab}	2858^{a}	$12.24\ (2116)^{a}$
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	25.7^{c}	39.0^{d}	32.3^{c}	14	15	1090^{b}	2205^{c}	$9.51\ (1647)^{c}$
C.D (0.05)	**2.1**	**1.5**	**1.4**	**NS**	**NS**	**237**	**147**	**0.7**
SE(m)	**0.72**	**0.53**	**0.50**	**0.39**	**0.39**	**81.44**	**50.48**	**0.24**
M_1S_1: ZT + Soil test based	38.8^{a}	39.3^{fg}	39.0^{bc}	19	21	2293^{a}	3306^{b}	$15.6\ (2800)^{a}$
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	26.0^{fgh}	47.2^{c}	36.6^{cd}	8	11	1159^{defg}	3206^{b}	$13.0\ (2183)^{b}$
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	31.8^{cde}	41.3^{ef}	36.5^{d}	24	26	1326^{cde}	3365^{b}	$13.8\ (2345)^{b}$
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	35.5^{ab}	54.9^{ab}	45.2^{a}	23	24	1740^{b}	3650^{a}	$15.6\ (2695)^{a}$
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	28.6^{ef}	41.3^{ef}	35.0^{de}	23	23	1241^{cdef}	2504^{de}	$10.8\ (1873)^{cd}$
M_2S_1: MT + Soil test based	27.2^{fg}	42.3^{de}	34.7^{de}	5	7	1230^{cdef}	2657^{d}	$11.3\ (1944)^{c}$
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	28.2^{ef}	42.1^{de}	35.1^{de}	14	15	1094^{efg}	2004^{gh}	$8.9\ (1549)^{ef}$
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	32.3^{bcd}	55.2^{a}	43.7^{a}	20	21	1535^{bcd}	2462^{def}	$11.3\ (1999)^{c}$
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	33.5^{bc}	37.4^{g}	35.4^{de}	20	19	1615^{bc}	2280^{ef}	$10.8\ (1948)^{cd}$
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	24.1^{ghi}	43.0^{de}	33.5^{efg}	13	15	1125^{efg}	2225^{fg}	$9.6\ (1675)^{de}$
M_3S_1: CT + Soil	23.0^{hij}	44.3^{d}	33.7^{ef}	16	15	980^{efg}	2685^{d}	$10.9\ (1832)^{cd}$
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	28.8^{def}	52.5^{b}	40.6^{b}	13	13	1330^{cde}	2380^{ef}	$10.6\ (1855)^{cd}$
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	20.2^{j}	42.3^{de}	31.2^{fg}	11	10	779^{g}	2943^{c}	$11.3\ (1861)^{c}$
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	21.0^{ig}	41.3^{ef}	31.1^{g}	14	12	768^{g}	2644^{d}	$10.3\ (1706)^{cd}$
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	24.3^{ghi}	32.7^{h}	28.5^{h}	7	8	904^{fg}	1884^{h}	$8.1\ (1394)^{f}$
C.D (0.05)	**3.6**	**2.7**	**2.5**	**NS**	**NS**	**411**	**255**	**1.2**
SE(m)	**1.24**	**0.91**	**0.86**	**0.68**	**0.68**	**141.07**	**87.44**	**0.42**

*R (weighted MSE) transformed values, original values in parentheses. In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

and S_4 all the other treatments resulted in lower spread during 2017, while in 2018, lowest spread was observed in S_5.

Effect of interaction between tillage and potassium and magnesium doses was found to be significant with respect to root spread of cowpea during the period of study. The highest root spread (2293 cm^2) was observed under ZT which received nutrients according to soil test results (M_1S_1) during 2017. It was followed by M_1S_4, M_2S_4, and M_2S_3. However, the lower rood spread of cowpea (768 cm^2) was noted in CT with K: $MgSO_4$ @ 40:60 kg/ha (M_3S_4) which was on par with M_3S_3, M_3S_5, M_3S_1, M_1S_2, M_2S_2, and M_2S_5 during 2017. In second year of experiment, the highest spread (3650 cm^2) was noticed with application of K: $MgSO_4$ @ 40:60 kg/ha under ZT (M_1S_4), followed by root spread observed under zero tillage with K: $MgSO_4$ @ 12.8:80 (M_1S_1), 20:60 (M_1S_2) and 20:80 (M_1S_3) kg/ha. Lower root spread was recorded under CT along with K: $MgSO_4$ @ 40:80 kg/ha (M_3S_5) which was on par to root spread recorded in K: $MgSO_4$ @ 20:60 kg/ha under minimum tillage (M_2S_2).

On pooling of the data, highest root spread (2379 cm^2) was recorded under zero tillage system. It was followed by MT and CT which were at par. Soil test based nutrition, K: $MgSO_4$ @ 20:80 kg/ha and K: $MgSO_4$ @ 40:60 kg/ha (S_4) resulted in higher root spread of cowpea. Application of K: $MgSO_4$ @ 40:80 kg/ha in conventional tillage registered lowest root spread (1647 cm^2). M_1S_1 and M_1S_4 produced higher root spread (2800 cm^2 and 2695 cm^2 respectively). The lowest spread was noticed under M_3S_5 (1394 cm^2).

K. Root weight

Influence of tillage and nutrient doses were found to be non-significant with respect to root weight of cowpea during 2017 (**Table 28**) and average root weight per plant was 3.8 g. However, significant variation in root weight due to tillage systems and nutrient doses was noticed during 2018.

In second year, there was significant variation in root weight due to tillage and K-$MgSO_4$ doses. Highest root weight was recorded under ZT (3.2 g) followed by MT (2.5 g) and CT (2.4 g). Among various K and $MgSO_4$ doses, application of K: $MgSO_4$ @ 20:80 kg/ha (S_3) and 20:60 kg/ha (S_2) resulted in higher root weight (3.0 g). In interaction, K: $MgSO_4$ applied @ 20:60 kg/ha under zero tillage condition (M_1S_2) resulted in highest root weight (4.4 g). Followed by minimum tillage with application of K: $MgSO_4$ @ 20:80 kg/ha (M_2S_3). The lowest weight (2 g) was seen in application of nutrients in accordance to soil test results, K: $MgSO_4$ @ 40:80 and 40:60 kg/ha under minimum tillage system (M_2S_1, M_2S_4, and M_2S_5) and also in conventional tillage (M_3S_2 and M_3S_5).

Pooled analysis shows that, zero tillage recorded highest root weight (3.5 g). It was followed by the root weight noticed under MT and CT (3.3g and 3g respectively) which were on par to each other. However, nutrient combinations and the interactions failed to influence root weight significantly.

J. Root-shoot ratio

Influence of tillage and K-$MgSO_4$ doses was found to be non-significant with respect to root-shoot ratio of cowpea **Table 28.** On an average the root-shoot ratio was 0.05 in 2017 and 0.03 in 2018.

4.2.2 Yield parameters

A. Pod length

Influence of various tillage systems, potassium-magnesium sulphate doses and their interaction was found to be non-significant with respect to pod length of cowpea **(Table 29)**. Under various tillage practices, K and $MgSO_4$ doses and in interaction, average pod length recorded was 28.1 cm during 2017, while corresponding values for the second year was 25.9 cm.

Table 28. Effect of tillage and nutrients on root weight (g/plant) and root-shoot ratio of cowpea on 90 DAS

Treatments	**Root weight (g)**			**Root-shoot ratio**	
Tillage	**2017**	**2018**	**Pooled**	**2017**	**2018**
M_1- Zero tillage (ZT)	3.8	3.2[a]	15.3 (3.5)[a]	0.04	0.04
M_2- Minimum tillage (MT)	4.0	2.5[b]	12.9 (3.3)[b]	0.05	0.03
M_3- Conventional tillage (CT)	3.7	2.4[b]	12.5 (3.0)[b]	0.06	0.03
C.D (0.05)	**NS**	**0.1**	**0.6**	**NS**	**NS**
SE(m)	**0.12**	**0.04**	**0.19**	**0.002**	**0.001**
S_1- Soil test based recommendations	3.7	2.5[b]	12.8 (3.1)	0.05	0.03
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	4.0	3.0[a]	14.9 (3.5)	0.05	0.04
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	3.8	3.0[a]	14.6 (3.4)	0.05	0.04
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	3.8	2.6[b]	13.2 (3.2)	0.05	0.03
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	3.7	2.3[c]	12.1 (3.0)	0.05	0.03
C.D (0.05)	**NS**	**0.1**	**NS**	**NS**	**NS**
SE(m)	**0.16**	**0.05**	**0.25**	**0.002**	**0.001**
M_1S_1: ZT + Soil test based	4.0	2.9[cde]	14.5 (3.4)	0.05	0.03
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	4.6	4.4[a]	20.3 (4.5)	0.05	0.05
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	3.6	3.0[cd]	14.3 (3.3)	0.04	0.03
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	3.2	2.7[def]	13.1 (3.0)	0.03	0.03
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	3.4	3.0[cd]	14.1 (3.2)	0.04	0.04
M_2S_1: MT + Soil test based	3.7	2.0[h]	10.8 (2.8)	0.05	0.03
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	4.2	2.6[f]	13.8 (3.4)	0.04	0.03
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	4.1	3.6[b]	17.0 (3.9)	0.05	0.05
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	4.0	2.0[h]	11.2 (3.0)	0.04	0.02
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	4.2	2.0[h]	11.5 (3.1)	0.06	0.03
M_3S_1: CT + Soil test based	3.5	2.7[ef]	13.2 (3.1)	0.06	0.03
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	3.3	2.0[h]	10.6 (2.6)	0.06	0.03
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	3.8	2.4[g]	12.5 (3.1)	0.06	0.03
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	4.2	3.1[c]	15.3 (3.6)	0.07	0.04
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	3.6	2.0[h]	10.8 (2.8)	0.06	0.03
C.D (0.05)	**NS**	**0.2**	**NS**	**NS**	**NS**
SE(m)	**0.28**	**0.08**	**0.43**	**0.004**	**0.002**

*R (weighted MSE) transformed values, original values in parentheses. In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

B. Pod weight

Average pod weight recorded in 2017 and 2018 under various tillage practices, K-Mg doses and their interaction was 4.4 g and 3.7 g respectively and the treatment differences were non-significant **(Table 29)**. A decrease in average pod weight in second year as compared to first year was observed.

C. Grains per pod

Effect of various tillage types and K-$MgSO_4$ doses on grains per pod was observed to be non-significant in both years **(Table 29)**. During both 2017 and 2018, average number of grains per pod recorded was 15.

D. Number of pods

Number of pods per M_2 varied significantly due to various tillage and K-$MgSO_4$ doses in both years under study **(Table 30)**.

In 2017 and 2018, minimum tillage produced higher number of pods per M_2 (44 and 45 respectively). In 2018, it maintained parity to number of pods recorded under CT (46). However, during 2017, lowest number of pods was recorded under conventional tillage (36). In 2018, lowest number of pods was recorded under zero tillage system (44).

In first year of experiment, higher number of pods per M_2 (42) was recorded in application of K and Mg @ 40:60 (S_4) and 40:80 (S_5) kg/ha. However, lower number of pods were registered in application of K: $MgSO_4$ @ 20:60 (S_2), 20:80 (S_3) and 10.6:80 (S_1) kg/ha and they were at par. In second year, highest number of pods per M_2 was observed in application of K: $MgSO_4$ @ 40:60 kg/ha (S_4) while all the other treatments were at par with each other.

Among interactions, application of nutrients with respect to soil test results under minimum tillage (M_2S_1) registered highest number of pods in 2017 (46). It was on par to pod numbers recorded under ZT along with application of K: $MgSO_4$ @ 40:60 and 40:80 kg/ha (M_1S_4 and M_1S_5 respectively), as well as to pod numbers registered under MT with application of K: $MgSO_4$ @ 20:60 and 40:60 kg/ha (M_2S_2 and M_2S_4 respectively). However, lower number of pods (32) were recorded under CT along with K: $MgSO_4$ @ 10.6:80 kg/ha (M_3S_1). It was on par to treatments such as M_1S_1, M_1S_2, and M_3S_3. Similar trend could be noticed in 2018 where, application of K: $MgSO_4$ @ 40:60 kg/ha under minimum tillage (M_2S_4) recorded higher number of pods per M_2 (50) which was on par to treatments such as M_1S_3, M_1S_4, M_2S_1, M_2S_2, and M_3S_5. Rest of the treatments produced lower number of pods and they were on par to each other.

Pooled data shows that, highest number of pods/M_2 was recorded under MT (45), followed by ZT and CT which were at par. Application of K: $MgSO_4$ @ 40:60 kg/ha (S_4) resulted in highest number of pods/M_2. The lowest was noted with application of K: $MgSO_4$ @ 20:80 kg/ha (S_3). Interaction of minimum tillage with application of K: $MgSO_4$ @ 40:60 kg/ha resulted in higher number of pods/M_2 (48) which was at par with M_1S_4, M_2S_1, M_2S_2, and M_3S_5.

E. Test weight

Test weight was not significantly affected by either various tillage systems nor by various nutrient doses or by their interaction **(Table 30)**. Average test weight of grains obtained due to various treatments imposed were 19.02 g in 2017 while it was 19.5 g in 2018.

F. Grain yield

Significant variation in grain yield was observed due to various tillage practices, K and $MgSO_4$ doses and their interaction (**Table 30)**. It could be noted that there was an increase in overall yield of cowpea in second year, compared to first year.

Highest grain yield was noted under minimum tillage (MT) which recorded a grain yield of 793 kg/ha in 2017. It was followed by grain yield under zero tillage (M_1)

and conventional tillage practices (M_3) during first year (541 and 496 kg/ha respectively). In second year, highest grain yield was recorded under CT (801 kg/ha) and it was followed by MT and ZT and they were at par with each other. It could be noted that, in second year, yield recorded under zero tillage and normal tillage, increased as compared to first year.

In both years, K: $MgSO_4$ @ 40:60 kg/ha resulted in highest grain yield (743 kg/ha and 868 kg/ha respectively), followed by soil test based nutrition (S_1) where K: $MgSO_4$ was applied @ 10.6:80 kg/ha and in K: $MgSO_4$ @ 40:80 kg/ha (S_5) in first year. In second year, superior treatment S_4 was followed by application of K: $MgSO_4$ @ 20:80 kg/ha (S_3) and S_5 and these treatments registered lower yield.

In interaction effect during first year higher grain yield (1016 kg/ha) was noticed under MT along with soil test based nutrition (K: $MgSO_4$ @ 10.6:80 kg/ha) (M_2S_1) which was on par to grain yield recorded (1000 kg/ha) under MT along with K: $MgSO_4$ @ 40:60 kg/ha (M_2S_4). In second year, highest grain yield (981 kg/ha) was noticed in CT with K: $MgSO_4$ @ 40:60 kg/ha (M_3S_4). It was followed by conventional tillage with K: $MgSO_4$ @ 40:80 kg/ha (M_3S_5), CT with K: $MgSO_4$ @ 20:80 kg/ha (M_3S_3), MT with K: $MgSO_4$ @ 40:60 kg/ha (M_2S_4), zero tillage with K: $MgSO_4$ @ 12.8:80 kg/ha (M_1S_1) and 40:60 kg/ha (M_1S_4). Zero tillage (ZT) with K and Mg @ 20:80 kg/ha (M_1S_3), M_1S_1, M_1S_2, M_2S_5, M_3S_1, M_3S_2, M_3S_3, in first year while, MT with K and Mg @ 20:80 kg/ha (M_2S_3), M_1S_2, and M_3S_1, in second year resulted in lower yield of cowpea.

On pooling, the data shows that, minimum tillage resulted in highest grain yield of cowpea (734.5 kg/ha). It was followed by CT and ZT which were on par to each other. Treatments which received K: $MgSO_4$ @ 40:60 kg/ha (S_4) produced highest grain yield (806 kg/ha). Among interactions highest grain was registered under MT with application of K: $MgSO_4$ @ 40:60 kg/ha (914.8 kg/ha). It was followed by grain yield (821.5 kg/ha) recorded under M_2S_1.

Table 29. Effect of tillage and nutrients on average pod weight, pod length and grains /pod of cowpea

Treatments	Average pod weight (g)		Pod length (cm)		Grains/ pod	
Tillage	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
M_1- Zero tillage (ZT)	4.3	4.0	28.4	26.3	15.4	15.3
M_2- Minimum tillage (MT)	4.5	3.9	28.4	26.5	16.1	16.1
M_3- Conventional tillage (CT)	4.3	3.2	27.5	24.8	14.8	14.2
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.05**	**0.07**	**0.22**	**0.17**	**0.14**	**0.19**
S_1- Soil test based recommendations	4.4	3.7	28.3	24.7	15.4	14.6
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	4.2	3.5	28.2	25.9	15.9	15.0
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	4.2	3.7	27.7	26.2	15.0	15.9
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	4.9	4.1	28.6	26.5	16.3	15.6
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	4.1	3.6	27.8	26.0	14.4	15.0
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.07**	**0.09**	**0.28**	**0.22**	**0.19**	**0.24**
M_1S_1: ZT + Soil test based	4.3	3.7	28.3	26.2	15.5	14.6
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	4.5	3.8	28.6	26.5	16.1	16.1
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	3.9	4.8	27.6	26.6	13.6	14.7
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	4.4	4.7	27.9	26.9	15.5	16.1
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	4.4	2.9	30.7	25.4	15.7	15.0
M_2S_1: MT + Soil test based	4.7	4.0	27.8	25.0	15.2	15.9
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	4.4	3.6	29.5	26.5	17.5	15.7
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	4.3	3.5	28.8	27.1	16.2	16.7
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	5.1	4.4	29.3	26.7	16.9	15.9
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	4.0	4.0	26.6	27.2	14.8	16.0
M_3S_1: CT + Soil test based	4.4	3.3	29.0	23.0	15.6	13.0
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	3.6	3.1	26.6	24.7	14.1	13.3
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	4.4	2.8	27.5	24.8	15.3	15.7
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	5.1	3.2	28.5	26.0	16.1	14.9
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	3.9	3.8	25.9	25.4	12.5	14.1
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.12**	**0.16**	**0.49**	**0.38**	**0.32**	**0.42**

Table 30. Effect of tillage and nutrients on number of pods/M_2, test weight (g) and grain yield (kg/ha) of cowpea

Treatments	Number of pods/M_2			Test weight (g)		Grain yield (kg/ha)		
Tillage	**2017**	**2018**	**Pooled**	**2017**	**2018**	**I**	**II**	**Pooled**
M_1- Zero tillage (ZT)	38^{b}	44^{b}	41^{b}	18.4	19.2	541^{b}	696^{b}	618.4^{b}
M_2- Minimum tillage (MT)	44^{a}	45^{a}	45^{a}	19.1	19.1	793^{a}	675^{b}	734.5^{a}
M_3- Conventional tillage (CT)	36^{c}	46^{a}	41^{b}	19.6	20.3	496^{b}	801^{a}	648.3^{b}
C.D (0.05)	**1.1**	**1.6**	**1.0**	**NS**	**NS**	**51.9**	**45.2**	**36.7**
SE(m)	**0.4**	**0.5**	**0.4**	**0.3**	**0.3**	**17.8**	**15.5**	**12.6**
S_1- Soil test based recommendations	37^{b}	45^{b}	41^{c}	19.1	20.0	635^{b}	649^{c}	641.8^{b}
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	38^{b}	45^{b}	41^{c}	19.0	19.2	550^{c}	651^{c}	600.8^{c}
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	37^{b}	43^{b}	40^{c}	19.1	19.3	544^{c}	698^{bc}	621.3^{b}
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	42^{a}	48^{a}	45^{a}	18.7	18.9	743^{a}	868^{a}	806.0^{a}
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	42^{a}	44^{b}	43^{b}	19.2	20.0	577^{bc}	754^{b}	665.3^{b}
C.D (0.05)	**1.4**	**2.0**	**1.3**	**NS**	**NS**	**67.0**	**58**	**47.3**
SE(m)	**0.5**	**0.7**	**0.6**	**0.4**	**0.4**	**23.0**	**20**	**16.3**
M_1S_1: ZT + Soil test based	33^{def}	41^{c}	37^{ef}	19.3	18.6	461^{cd}	794^{bcd}	627.5^{fgh}
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	33^{def}	41^{c}	37^{ef}	18.0	19.6	450^{cd}	521^{g}	485.5^{i}
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	35^{d}	47^{ab}	41^{bcd}	19.3	21.0	419^{d}	716^{def}	567.8^{h}
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	44^{ab}	48^{ab}	46^{a}	18.0	18.7	674^{b}	794^{bcd}	733.9^{cd}
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	45^{ab}	42^{c}	43^{b}	17.3	17.9	698^{b}	655^{ef}	676.6^{defg}
M_2S_1: MT + Soil test based	46^{a}	47^{ab}	47^{a}	18.0	19.5	1016^{a}	627^{f}	821.5^{b}
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	44^{ab}	47^{ab}	46^{a}	19.3	18.7	702^{b}	679^{ef}	690.5^{cdef}
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	43^{b}	41^{c}	42^{bc}	18.7	18.5	774^{b}	508^{g}	641.2^{efgh}
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	45^{ab}	50^{a}	48^{a}	19.7	18.4	1000^{a}	830^{bc}	914.8^{a}
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	39^{c}	42^{c}	41^{cd}	19.7	20.2	475^{cd}	733^{cde}	604.2^{gh}
M_3S_1: CT + Soil test based	32^{f}	46^{b}	39^{de}	20.0	22.0	428^{d}	526^{g}	476.7^{i}
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	35^{de}	46^{b}	41^{cd}	19.7	19.4	499^{cd}	754^{cde}	626.6^{fgh}
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	33^{ef}	41^{c}	37^{f}	19.3	18.5	439^{d}	870^{b}	654.7^{defg}
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	35^{d}	46^{b}	41^{cd}	18.3	19.6	557^{c}	981^{a}	768.8^{bc}
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	43^{b}	48^{ab}	46^{a}	20.0	22.0	558^{c}	873^{b}	714.9^{cde}
C.D (0.05)	**2.0**	**4.0**	**2.2**	**NS**	**NS**	**116.1**	**101.0**	**82.0**
SE(m)	**0.9**	**1.2**	**0.9**	**0.7**	**0.7**	**39.9**	**34.7**	**28.2**

4.2.4 Protein content

Crude protein content in grains was calculated in both the years and the data furnished in **Table 31.** There was no significant variation was observed in protein content of grains of cowpea due to various tillage practices adopted. However, significant variation was noticed in protein content with different doses of K and $MgSO_4$ and due to the interactions between tillage and nutrients.

In first year, among various levels of K and $MgSO_4$, higher protein content of 26.1 % was noticed in K: $MgSO_4$ @ 20:60 kg/ha (S_2), and it was at par with K: $MgSO_4$ @ 40:60 kg/ha (S_4) and 40:80 kg/ha (S_5), while in the second year, higher protein content of 25.0 % was noted in application of K: $MgSO_4$ @ 40:80 kg/ha (S_5) and it was on par to K: $MgSO_4$ @ 20:80 kg/ha (S_3) and to soil test-based nutrient application (S_1). The lower content (23.8 %) was noticed in application of nutrients according to soil test results (S_1) and to K: $MgSO_4$ @ 20:80 kg/ha (S_3) during first year. During second year, lower content was recorded in S_2 and S_4.

On pooling data reveals that, though interaction effect was statistically significant, many treatments were comparable. The values ranged between 22.6 % to 27.6 % in 2017 and 21 % to 26.7 % in 2018. In general treatments involving conventional tillage resulted in higher protein content.

Different tillage systems such as zero tillage, minimum tillage and conventional tillage, as well the interaction between tillage and nutrients had no significant effect on protein content in grains. Among various nutrient doses, K: $MgSO_4$ @ 40:80 kg/ha registered higher protein content (26.2 %) which was at par to protein content recorded (25.8 %) under K: $MgSO_4$ @ 20:80 kg/ha (S_3).

Table 31. Effect of tillage and nutrients on protein content (%) of cowpea.

Treatments	Protein content %		
Tillage	**2017**	**2018**	**Pooled**
M_1- Zero tillage (ZT)	24.8	23.0	24.6
M_2- Minimum tillage (MT)	25.3	23.5	25.1
M_3- Conventional tillage (CT)	25.3	25.3	26.9
C.D (0.05)	**NS**	**NS**	**NS**
SE(m)	**0.3**	**0.2**	**0.2**
Nutrients			
S_1- Soil test based recommendations	23.8^{b}	24.3^{ab}	25.0^{b}
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	26.1^{a}	23.5^{b}	25.5^{b}
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	24.8^{b}	24.8^{a}	25.8^{ab}
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	25.2^{ab}	23.7^{b}	25.2^{b}
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	25.7^{ab}	25.0^{a}	26.2^{a}
C.D (0.05)	**1.2**	**0.8**	**0.7**
SE(m)	**0.4**	**0.3**	**0.3**
Interaction			
M_1S_1: ZT + Soil test based	24.7^{bcd}	23.7^{bcd}	25.0
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	25.9^{abc}	21.0^{e}	23.8
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	23.7^{de}	23.5^{bcd}	24.5
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	25.3^{bcd}	22.5^{d}	24.5
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	24.1^{cde}	24.1^{bc}	25.0
M_2S_1: MT + Soil test based	24.1^{cde}	22.9^{cd}	24.3
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	26.0^{abc}	23.4^{bcd}	25.4
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	25.9^{abc}	24.6^{b}	26.1
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	24.9^{bcd}	22.5^{d}	24.4
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	25.3^{bcd}	24.0^{bc}	25.5
M_3S_1: CT + Soil test based	22.6^{e}	26.3^{a}	25.8
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	26.3^{ab}	26.2^{a}	27.3
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	24.8^{bcd}	26.3^{a}	26.7
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	25.2^{bcd}	26.0^{a}	26.7
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	27.6^{a}	26.7^{a}	28.1
C.D (0.05)	**2.1**	**1.3**	**NS**
SE(m)	**0.7**	**0.5**	**0.4**

4.2.5 Observation on weeds

Observation on weed dry matter production and species count were noted in two different stages of crop growth i.e., at 30 DAS and 60 DAS, and the data are furnished in **Table 32 and 33.**

A. Weed count (species-wise)

Diverse weed species were observed in the field during the period of study (**Table 32**). *Melochia corchorifolia* was the major weed species found. The weed spectrum constituted mainly of broad leaved weeds which included *Commelina diffusa, Aeshynomene indica, Ludwigia parviflora, Cyanotis axillaris, Elephantopus scaber, Synedrella nodiflora, Mollugo pentaphylla, Mollugo disticha, Emilia sonchifolia, Scoparia dulci, Cynodon dactylon, Cleome burmanii, Ageratum conyzoiides, Scoparia dulcis, Centrosema pubescens, Passiflora foetida, Digitaria sanguinalis, Alternanthera sessilis, Phyllanthus niruri, and Ipomea pes-tigridis.* The grass species *viz,* were *Echinochloa colona, Brachiaria mutica*, *Isachne miliacea,* competed with the crop in the vegetative phase. The main sedge observed was *Cyperus iria.* Among various tillage practices imposed, number of species recorded were more under CT with various levels of nutrients.

B. Weed DMP

Weed dry matter production found to have significant variation with respect to tillage and K-$MgSO_4$ doses, noted at 30 and 60 days after sowing of cowpea and the results obtained during the period of study are furnished in **Table 33.**

Significant variation in weed dry matter due to various tillage practices was observed. At both stages, weed dry matter produced was highest (16.7 g/ m^2 and 13.9 g/m^2) under CT (M_3) which was followed by dry matter produced under MT (M_2) and ZT (M_1) systems in both years. At 30 DAS and 60 DAS, lowest weed dry matter was obtained under zero tillage practice (6.1 g/m^2 and 5.6 g/m^2 respectively) during 2017. In second year also, same trend was noticed at both stages and CT resulted in highest dry matter production of weeds (11.7 g/m^2 at 30 DAS and 12.6 g/m^2 at 60 DAS). Lowest weed dry matter was noted under zero tillage practice (2.5 g/m^2 at 30 DAS and 1.4 g/m^2 at 60 DAS) in 2017.

Among various nutrient application practices imposed, highest dry matter (14.1 g/m^2) was obtained with treatment K: $MgSO_4$ @ 40:80 kg/ha (S_5) at 30 DAS while at 60 DAS, K: $MgSO_4$ @ 20:80 kg/ha (S_3) gave higher weed dry matter (11.4 g/m^2) which was on par with soil test based nutrition (S_1) during 2017. At 30 DAS, lowest weed dry matter (9.7 g/m^2) was observed in K: $MgSO_4$ @ 20:60 kg/ha (S_2) and at 60 DAS, lowest dry matter (7.8 g/m^2) was observed in K: $MgSO_4$ @ 40:80 kg/ha (S_5). During second year, the soil test based nutrient application (S_1), resulted in highest dry matter production of weeds was at both 30 DAS and 60 DAS (8.0 g/m^2 and 8.3 g/m^2 respectively). At both stages the treatment giving lower dry matter content (4.3 g/m and 4.7 g/m^2 respectively) was K: $MgSO_4$ @ 40:60 kg/ha (S_4). At 60 DAS, the treatments K: $MgSO_4$ @ 20:60 kg/ha (S_2), 20:80 kg/ha (S_3) and 40:80 kg/ha (S_5) gave same amount of weed dry matter, *i.e.* 5.7 g/m^2.

In 2017, at 30 DAS and 60 DAS, plots under conventional tillage with $MgSO_4$ @ 80 kg/ha with K @ 40 kg/ha (M_3S_5) gave higher dry matter (21.0 g/m^2 and 17.3 g/m^2 respectively) which was at par with weed dry matter produced in $MgSO_4$ @ 80 kg/ha and K_2O @ 20 kg/ha under CT (M_3S_3). The lower dry matter production was seen in zero tillage under K: $MgSO_4$ @ 20:80 kg/ha (M_1S_3), M_1S_2, and M_1S_5, at 30 DAS while, at 60 DAS the lower dry matter content was exhibited in zero tillage with K: $MgSO_4$ @ 40:80 kg/ha (M_1S_5), M_1S_2, M_1S_3, M_1S_4, and M_2S_2. In 2018, at 30 DAS and 60 DAS, plots under conventional tillage with $MgSO_4$ @ 60 kg/ha with K @ 20 kg/ha (M_3S_2) gave higher dry matter (14.3 g/m^2 and 15.0 g/m^2 respectively) which was at par with weed dry matter produced (14.3 g/m^2) is conventional tillage with soil test based nutrition at 30 DAS. At 60 DAS, M_3S_2 was on par to M_3S_3.

Pooled data revealed that, conventional tillage practices resulted in highest weed dry matter at 30 DAS (14.2 g/m^2) and 60 DAS (13.3 g/m^2). It was followed by MT. The lowest weed dry matter at 30 DAS and 60 DAS was recorded under ZT.

Application of soil test based nutrition (K: $MgSO_4$ @ 12:80 kg/ha) resulted in highest dry matter of weeds at 30 DAS and 60 DAS (9.9 and 9.6 g/m^2). At 30 DAS, K: $MgSO_4$ @ 40:80 kg/ha (S_5) also registered higher weed dry matter (10.7 g/m^2). Among interactions, soil test based nutrition and K: $MgSO_4$ @ 20:60 kg/ha under conventional tillage produced higher weed dry matter production at both stages of crop growth.

Table 32. Effect of tillage and nutrients on weed species count (per m^2)

	Melochia chorchorifolia	*Aeshynomene indica*	*Brachiaria mutica*	*Cyanotis axillaris*	*Commelina diffusa*	*Ludwigia parviflora*	*Elephantopus scaber*	*Synedrella nodiflora*	*Mullugo disticha*	*Mullugo pentaphylla*	*Scoparia dulcis*	*Isachne miliacea*	*Echinochloa colona*	*Cyperus iria*
30 DAS														
Zero tillage	8	2	2	1	-	-	-	1	-	-	1	-	1	-
Minimum tillage	14	1	2	1	-	-	1	1	1	1	-	3	-	-
Conventional tillage	32	2	1	1	1	1	-	2	-	-	-	-	-	-
60 DAS														
Zero tillage	2	1	1	-	-	-	-	1	-	-	1	-	1	-
Minimum tillage	2	1	2	1	-	-	1	1	1	1	-	3	-	1
Conventional tillage	10	1	-	1	1	1	-	-	-	-	-	-	-	-

Table 33. Effect of tillage and nutrients on weed dry matter production (g/m^2)

Treatments	**30 DAS**			**60 DAS**		
Tillage	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
M_1- Zero tillage (ZT)	6.1^{c}	2.5^{c}	$2.7\ (4.3)^{c}$	5.6^{c}	1.4^{c}	$3.2\ (3.5)^{c}$
M_2- Minimum tillage (MT)	12.7^{b}	4.0^{b}	$5.1\ (9.7)^{b}$	9.7^{b}	4.0^{b}	$7.0\ (6.8)^{b}$
M_3- Conventional tillage (CT)	16.7^{a}	11.7^{a}	$9.7\ (14.2)^{a}$	13.9^{a}	12.6^{a}	$17.1\ (13.3)^{a}$
C.D (0.05)	**1.5**	**0.8**	**0.6**	**1.2**	**0.4**	**0.5**
SE(m)	**0.5**	**0.3**	**0.2**	**0.4**	**0.1**	**0.2**
S_1- Soil test based recommendations	11.9^{b}	8.0^{a}	$6.7\ (9.9)^{a}$	10.9^{ab}	8.3^{a}	$11.8\ (9.6)^{a}$
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	9.7^{c}	6.2^{b}	$5.4\ (7.9)^{b}$	9.0^{b}	5.7^{b}	$8.5\ (7.3)^{c}$
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	12.0^{b}	4.6^{c}	$5.2\ (8.3)^{b}$	11.4^{a}	5.7^{b}	$9.3\ (8.6)^{b}$
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	11.4^{b}	4.3^{c}	$4.9\ (7.9)^{b}$	9.6^{b}	4.7^{c}	$7.7\ (7.1)^{c}$
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	14.1^{a}	7.3^{ab}	$7.0\ (10.7)^{a}$	7.8^{c}	5.7^{b}	$8.1\ (6.7)^{c}$
C.D (0.05)	**1.9**	**1.0**	**0.8**	**1.6**	**0.5**	**0.7**
SE(m)	**0.7**	**0.4**	**0.3**	**0.5**	**0.2**	**0.2**
M_1S_1: ZT + Soil test based	9.0^{de}	$2.^{7gh}$	$3.5\ (5.8)^{def}$	10.0^{b}	3.0^{h}	$6.1\ (6.5)^{fg}$
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	6.0^{efg}	3.3^{fg}	$3.1\ (4.7)^{ef}$	5.0^{cde}	1.0^{i}	$2.6\ (3.0)^{hi}$
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	3.3^{g}	1.0^{h}	$1.3\ (2.2)^{g}$	4.0^{de}	1.0^{i}	$2.3\ (2.5)^{hi}$
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	7.0^{ef}	1.0^{h}	$2.2\ (4.0)^{fg}$	6.0^{b}	1.0^{i}	$2.9\ (3.5)^{hi}$
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	5.3^{fg}	4.7^{ef}	$3.5\ (5.0)^{def}$	3.0^{e}	1.0^{i}	$1.9\ (2.0)^{i}$
M_2S_1: MT + Soil test based	15.3^{b}	7.0^{d}	$7.2\ (11.2)^{c}$	11.3^{b}	8.0^{e}	$11.6\ (9.7)^{d}$
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	7.0^{ef}	1.0^{h}	$2.2\ (4.0)^{fg}$	7.0^{c}	1.0^{i}	$3.2\ (4.0)^{h}$
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	13.0^{bc}	3.3^{fg}	$4.8\ (8.2)^{d}$	15.0^{a}	1.0^{i}	$5.7\ (8.0)^{g}$
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	12.0^{cd}	3.0^{fg}	$4.4\ (7.5)^{de}$	12.0^{b}	4.0^{g}	$7.8\ (8.0)^{e}$
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	16.0^{b}	5.7^{de}	$6.7\ (10.8)^{c}$	3.0^{e}	6.0^{f}	$7.0\ (4.5)^{ef}$
M_3S_1: CT + Soil test based	11.3^{cd}	14.3^{a}	$9.6\ (12.8)^{a}$	11.3^{b}	14.0^{b}	$17.7\ (12.7)^{b}$
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	16.0^{b}	14.3^{a}	$10.7(15.2)^{a}$	15.0^{a}	15.0^{a}	$19.9\ (15.0)^{a}$
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	19.7^{a}	9.3^{c}	$9.3\ (14.5)^{ab}$	15.3^{a}	15.0^{a}	$20.0\ (15.2)^{a}$
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	15.3^{b}	9.0^{c}	$8.1\ (12.2)^{bc}$	10.7^{b}	9.0^{d}	$12.4\ (9.8)^{d}$
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	21.0^{a}	11.7^{b}	$10.8\ (16.3)^{a}$	17.3^{a}	10.0^{c}	$15.5\ (13.7)^{c}$
C.D (0.05)	**3.3**	**1.8**	**1.4**	**2.7**	**0.8**	**1.2**
SE(m)	**1.1**	**0.6**	**0.5**	**0.9**	**0.3**	**0.4**

*R (weighted MSE) transformed values, original values in parentheses. In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

4.2.6 Plant nutrient content

Plants at 30 DAS and 90 DAS (at harvest), grains and haulm of the pods were analyzed during both years for the estimation of nutrient content, from which nutrient uptake was calculated.

a. Nitrogen content

No significant variation in nitrogen content in cowpea in different plant parts could be observed **(Table 34)**. Respective average nitrogen content in plants at 30 DAS and 90 DAS was 4.7 % and 2.3 %. In grains and haulm, it was 4.0 % and 1.4 % respectively during 2017. In 2018, plant nitrogen content at 30 DAS and 90 DAS was 3.1% and 2.1% respectively. In grains and haulm content noted was 3.9 % and 0.7 % respectively.

b. Phosphorus content

Tillage and nutrient doses failed to create significant variation in phosphorus content in plants (30 DAS and at harvest), during both years and the data are furnished in **Table 35**. It could be noted that there was not much variation in P content of plants at both stages. It could also be noted that, average grain phosphorus content was slightly higher than the plant content. The average values for phosphorus content in plants at 30 and 90 days after sowing, also in grains and haulm were 0.3 %, 0.25 %, 0.38 % and 0.10 % respectively during 2017. In second year, the values were 0.35 %, 0.23 %, 0.39 %, and 0.14 % respectively.

Table 34. Effect of tillage and nutrients on nitrogen content (%) of cowpea

Treatments	**30DAS**		**Harvest**		**Grain**		**Haulm**	
Tillage	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
M_1- Zero tillage (ZT)	4.8	3.2	1.9	2.1	4.0	3.7	1.3	0.7
M_2- Minimum tillage (MT)	4.8	3.2	2.1	2.2	4.0	3.7	1.4	0.6
M_3- Conventional tillage (CT)	4.6	2.9	2.8	1.9	4.1	4.2	1.5	0.7
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.07**	**0.03**	**0.05**	**0.06**	**0.05**	**0.04**	**0.03**	**0.03**
S_1- Soil test based recommendations	5.0	2.9	2.4	2.1	3.8	3.9	1.3	0.7
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	4.2	2.9	2.4	2.2	4.2	3.8	1.4	0.5
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	4.6	3.3	2.2	1.9	4.0	3.9	1.5	0.7
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	4.7	3.2	2.2	2.1	4.0	3.8	1.3	0.8
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	4.8	3.2	2.2	2.3	4.1	4.0	1.5	0.7
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.09**	**0.05**	**0.06**	**0.08**	**0.07**	**0.06**	**0.04**	**0.04**
M_1S_1: ZT + Soil test based	5.3	3.2	2.0	2.2	3.9	3.8	1.3	0.8
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	3.8	3.1	2.0	1.9	4.1	3.5	1.4	0.6
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	4.7	3.3	1.9	1.9	3.8	3.8	1.2	1.0
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	5.0	3.1	1.7	2.0	4.1	3.6	0.9	0.6
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	5.0	3.3	1.6	2.7	3.9	3.9	1.8	0.4
M_2S_1: MT + Soil test based	5.4	3.2	2.1	1.6	3.9	3.7	1.0	0.4
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	4.3	3.1	2.5	1.9	4.2	3.7	1.5	0.3
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	4.9	3.3	2.0	2.0	4.1	3.8	1.7	0.6
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	4.4	3.2	2.1	2.6	4.0	3.6	1.4	0.9
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	5.0	3.1	1.7	2.9	4.1	3.7	1.4	0.9
M_3S_1: CT + Soil test based	5.3	2.3	3.1	2.4	3.6	4.2	1.5	0.8
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	4.4	2.4	2.6	2.6	4.2	4.1	1.4	0.6
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	4.2	3.4	2.6	1.7	4.0	4.2	1.7	0.4
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	4.6	3.2	2.6	1.6	4.0	4.2	1.6	0.8
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	4.2	3.2	3.2	1.2	4.4	4.3	1.4	1.0
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.16**	**0.08**	**0.10**	**0.14**	**0.18**	**0.10**	**0.08**	**0.08**

Table 35. Effect of tillage and nutrients on phosphorus content (%) of cowpea

Treatments	**30DAS**		**Harvest**		**Grain**		**Haulm**	
Tillage	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
M_1- Zero tillage (ZT)	0.29	0.35	0.17	0.22	0.39	0.41	0.11	0.17
M_2- Minimum tillage (MT)	0.32	0.34	0.28	0.22	0.34	0.43	0.10	0.10
M_3- Conventional tillage (CT)	0.28	0.37	0.29	0.25	0.38	0.33	0.10	0.16
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.008**	**0.009**	**0.004**	**0.008**	**0.011**	**0.010**		
S_1- Soil test based recommendations	0.28	0.34	0.23	0.27	0.40	0.39	0.11	0.13
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	0.31	0.34	0.22	0.23	0.36	0.42	0.10	0.12
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.31	0.37	0.26	0.21	0.43	0.39	0.09	0.11
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.30	0.33	0.23	0.20	0.37	0.36	0.09	0.17
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.27	0.38	0.30	0.24	0.31	0.41	0.12	0.17
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.011**	**0.011**	**0.006**	**0.011**	**0.014**	**0.013**	**0.006**	**0.008**
M_1S_1: ZT + Soil test based	0.26	0.33	0.15	0.31	0.43	0.38	0.13	0.13
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	0.28	0.31	0.20	0.20	0.41	0.42	0.08	0.19
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.33	0.33	0.13	0.18	0.42	0.36	0.09	0.18
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.36	0.36	0.11	0.18	0.38	0.38	0.10	0.18
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.24	0.41	0.27	0.22	0.33	0.50	0.13	0.14
M_2S_1: MT + Soil test based	0.33	0.33	0.26	0.20	0.35	0.38	0.09	0.07
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	0.39	0.35	0.19	0.24	0.31	0.48	0.12	0.09
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.35	0.36	0.33	0.21	0.42	0.46	0.10	0.09
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.22	0.33	0.27	0.15	0.39	0.42	0.09	0.08
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.29	0.33	0.32	0.29	0.27	0.42	0.10	0.16
M_3S_1: CT + Soil test based	0.26	0.37	0.28	0.29	0.44	0.40	0.12	0.20
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	0.27	0.37	0.28	0.25	0.36	0.36	0.09	0.08
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.27	0.41	0.32	0.23	0.44	0.34	0.07	0.06
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.32	0.29	0.30	0.26	0.35	0.27	0.08	0.24
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.27	0.40	0.29	0.21	0.33	0.30	0.12	0.21
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.019**	**0.019**	**0.010**	**0.019**	**0.025**	**0.023**	**0.012**	**0.014**

c. Potassium content

Potassium content in plants during both years of study is furnished in **Table 36.** Various tillage systems, K-$MgSO_4$ doses and their interaction were found to influence potassium content of plants (at 30 DAS, at harvest).

Conventional tillage (CT) registered highest K content in plants (at 30 DAS and at harvest), grains as well as in haulm, It was followed by MT and ZT and they were on par with each other. In 2018, highest haulm K content was observed under MT (1.42 %).

In first year at 30 DAS, soil test based nutrition (S_1) where K and Mg was given @ 10.6 and 80 kg/ha registered highest K content (3.6 %). At 90 DAS in the plant and in haulm, K content was higher in K: $MgSO_4$ @ 40:80 kg/ha (S_5). However, grain K content was not significantly influenced due to various K- $MgSO_4$ levels. Treatment S_5, which resulted in lowest plant K content at 30 DAS registered highest plant K content at harvest. In second year, this trend was found to change and various K and $MgSO_4$ levels had significant effect on K content in plants, grains and haulm. K: $MgSO_4$ @ 20:80 kg/ha (S_3) recorded higher plant K content at 30 DAS (1.92 %), which was at par to S_4 and S_5. Whereas, K: $MgSO_4$ @ 40:80 kg/ha (S_5) registered highest plant K content at harvest (1.56 %), followed by S_4 (1.46 %). In grains also K: $MgSO_4$ @ 40:80 kg/ha (S_5) registered higher K content (1.42 %). It was at par to K: $MgSO_4$ @ 20:80 (S_3) and 40:60 kg/ha (S_4). In haulm K content was higher (1.40 %) in application of K: $MgSO_4$ @ 40: 60 kg/ha (S_4) and it was on par to K @ 40 kg/ha and Mg @ 80 kg/ha (S_5). However, lower K content was observed in soil test based nutrition (S_1) and K: $MgSO_4$ @ 20:60 kg/ha (S_2) in plants at 30 DAS and in grains of cowpea and they were at par to each other. In plants at harvest and in haulm S_1 resulted in lowest K content (0.97 % and 1.1 %).

During first year, plant and haulm K content was significantly influenced by interaction of K-Mg doses and tillage, but no significant effect on grain K content was observed. Interaction of all K-Mg doses with CT and MT recorded higher K content.

In plants at 30 DAS, CT with K: $MgSO_4$ @ 20:60 kg/ha (M_3S_2) registered higher K content (3.99 %) which was at par with M_1S_1 (3.93 %) and M_3S_1 (3.86 %). At harvest, highest K content was recorded under M_3S_3 *i.e.* K: $MgSO_4$ @ 20:80 kg/ha (3.40 %). It was followed by M_3S_2 (2.82 %) and M_3S_4 (2.60 %). In grains average K content was 1.90 %. In haulm, higher K content (2.33 %) was noticed in CT with K: $MgSO_4$ @ 40:80 kg/ha (M_3S_5) which showed parity to M_3S_3 and M_3S_4 during 2017. It could be noted that, at 30 DAS, lower K content was recorded in M_1S_2, M_1S_5, and at 90 DAS, lowest K content was observed in M_2S_3 (1.32 %). While treatments such as M_2S_4, M_2S_3, M_1S_4, and M_1S_5 registered lower K content in haulm.

In second year also, interaction of nutrients and tillage had significant influence on K content in plants (at both stages), grains and haulm. At 30 DAS, MT and CT along with K: $MgSO_4$ @ 20:80 kg/ha (M_2S_3, M_3S_3) and CT with K: $MgSO_4$ @ 40:80 kg/ha (M_3S_5) recorded higher K content (2.22 %, 2.19 % and 2.12 % respectively). At 90 DAS also, CT with K: $MgSO_4$ @ 40:80 kg/ha (M_3S_5) registered highest K content in plants (1.74 %). It was followed by M_2S_5 and M_3S_4. Whereas in grains, ZT and CT with application of K: $MgSO_4$ @ 40:80 kg/ha (M_1S_5 and M_3S_5) and CT with K: $MgSO_4$ @ 20:80 kg/ha with (M_3S_3) recorded higher K content (1.50 %, 1.46 % and 1.45 % respectively). In haulm, MT along with K: $MgSO_4$ @ 40:80 kg/ha (M_2S_5) registered higher K (1.59 %) which was on par to K content (1.56 %) noted under minimum tillage with K: $MgSO_4$ @ 40:60 kg/ha (M_2S_4).

In plants at 30 DAS, lowest K content was observed in M_2S_2 (1.30 %). While treatments such as M_1S_1, M_1S_2, M_1S_3, M_2S_1 and M_3S_1 resulted in lower K content in plants at harvest. Whereas in grains, M_1S_1, M_1S_2, M_1S_3, M_1S_4, M_2S_1, M_2S_2, M_2S_5 and M_3S_2 recorded lower K content. However, in haulm lowest values for potassium content was noticed under M_1S_1 (1.06 %).

Table 36. Effect of tillage and nutrients on potassium content (%) of cowpea

Treatments	30 DAS		Harvest		Grain		Haulm	
Tillage	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
M_1- Zero tillage (ZT)	3.07^{b}	1.56^{b}	1.97^{b}	1.17^{c}	1.87^{ab}	1.40^{b}	1.92^{b}	1.20^{b}
M_2- Minimum tillage (MT)	3.18^{b}	1.66^{b}	1.83^{b}	1.24^{b}	1.81^{b}	1.38^{b}	1.87^{b}	1.42^{a}
M_3- Conventional tillage (CT)	3.45^{a}	1.92^{a}	2.59^{a}	1.44^{a}	2.01^{a}	1.44^{a}	2.14^{a}	1.21^{b}
C.D (0.05)	**0.16**	**0.10**	**0.13**	**0.05**	**0.14**	**0.03**	**0.09**	**0.05**
SE(m)	**0.06**	**0.03**	**0.05**	**0.02**	**0.01**	**0.01**	**0.03**	**0.02**
S_1- Soil test based recommendations	3.63^{a}	1.58^{b}	1.91^{b}	0.97^{d}	1.80	1.39^{b}	1.99^{ab}	1.10^{c}
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	3.26^{b}	1.49^{b}	2.06^{b}	1.22^{c}	1.91	1.36^{b}	1.97^{ab}	1.25^{b}
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	3.22^{b}	1.92^{a}	2.29^{a}	1.22^{c}	1.87	1.42^{a}	1.93^{b}	1.24^{b}
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	3.17^{b}	1.79^{a}	2.00^{b}	1.46^{b}	1.91	1.42^{a}	1.89^{b}	1.40^{a}
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	2.89^{c}	1.74^{a}	2.40^{a}	1.56^{a}	1.99	1.45^{a}	2.10^{a}	1.38^{a}
C.D (0.05)	**0.21**	**0.13**	**0.17**	**0.06**	**NS**	**0.03**	**0.12**	**0.06**
SE(m)	**0.07**	**0.04**	**0.06**	**0.02**	**0.02**	**0.01**	**0.04**	**0.02**
M_1S_1: ZT + Soil test based	3.93^{ab}	1.53^{efg}	1.99^{fg}	0.92^{h}	1.68	1.40^{de}	2.00^{cde}	1.06^{f}
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	2.52^{e}	1.57^{efg}	1.65^{h}	1.06^{gh}	1.70	1.35^{de}	1.98^{cdef}	1.31^{d}
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	2.93^{cd}	1.38^{efg}	2.18^{ef}	1.04^{gh}	1.67	1.40^{de}	1.92^{def}	1.13^{e}
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	3.22^{c}	1.55^{efg}	1.80^{gh}	1.40^{de}	1.72	1.36^{de}	1.79^{fgh}	1.29^{d}
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	2.69^{de}	1.66^{de}	2.32^{de}	1.43^{cde}	1.74	1.50^{a}	1.86^{fgh}	1.18^{de}
M_2S_1: MT + Soil test based	3.09^{c}	1.36^{g}	2.20^{ef}	0.96^{gh}	1.63	1.34^{de}	1.89^{efg}	1.14^{e}
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	3.23^{c}	1.30^{h}	1.70^{gh}	1.22^{f}	1.63	1.33^{e}	2.04^{defg}	1.32^{d}
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	3.66^{b}	2.22^{a}	1.32^{i}	1.12^{fg}	1.75	1.42^{cd}	1.70^{gh}	1.46^{bc}
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	3.05^{cd}	1.97^{bc}	1.61^{h}	1.37^{e}	1.69	1.44^{bc}	1.62^{h}	1.56^{ab}
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	2.91^{cd}	1.44^{efg}	2.42^{cde}	1.53^{bc}	1.67	1.37^{de}	2.12^{bcd}	1.59^{a}
M_3S_1: CT + Soil test based	3.86^{ab}	1.86^{cd}	1.60^{h}	1.02^{gh}	1.63	1.43^{bc}	2.05^{bcde}	1.09^{e}
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	3.99^{a}	1.58^{ef}	2.82^{b}	1.36^{e}	1.69	1.40^{de}	1.84^{efg}	1.13^{e}
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	3.10^{c}	2.19^{a}	3.40^{a}	1.48^{cd}	1.65	1.45^{ab}	2.17^{abc}	1.12^{e}
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	3.20^{c}	1.84^{cd}	2.60^{bc}	1.62^{b}	1.67	1.44^{bc}	2.27^{ab}	1.34^{d}
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	3.08^{c}	2.12^{ab}	2.50^{cd}	1.74^{a}	1.78	1.46^{ab}	2.33^{a}	1.37^{cd}
C.D (0.05)	**0.37**	**0.22**	**0.30**	**0.11**	**NS**	**0.06**	**0.20**	**0.11**
SE(m)	**0.13**	**0.08**	**0.10**	**0.04**	**0.03**	**0.02**	**0.07**	**0.04**

C. Calcium content

Calcium content was estimated in both years and the data recorded are furnished in **Table 37**.

Various tillage practices, K-Mg doses and their interaction resulted in non-significant effect on plant calcium content during both years. Average calcium content in plants at 30 DAS, 90 DAS, grains, and haulm were 1.7%, 1%, 0.2% and 0.3% respectively.

C. Magnesium content

Data on magnesium content in plants, grains and haulm are furnished in **Table 38.** It could be noted that different types of tillage systems such as zero tillage, minimum tillage and conventional tillage failed to create significant variation in magnesium content in both years. Average magnesium content in plants at 30 and 90 DAS as well as in grains and haulm during first year were 0.85 %, 0.94 %, 0.21 % and 0.32 % respectively. Corresponding values for next year were 0.86 %, 0.64 %, 0.22 %, and 0.33 % respectively.

Influence of various K and Mg levels was found to be non-significant with respect to Mg content in plants, grains and haulm during 2017. Similarly, in 2018, though significant variation in Mg content in plants was observed, it was found to non-significant with regard to Mg content in grains as well as in haulm. At 30 DAS, highest plant magnesium content (0.96 %) was noted in K: $MgSO_4$ @ 40:80 kg/ha (S_5), whereas at 90 DAS, soil test based application (K: $MgSO_4$ @ 10.6:80 kg/ha), K: $MgSO_4$ @ 20:80 (S_3) and 40:60 kg/ha (S_4) resulted in higher Mg content which were on par to each other. However, lowest content at both stages of crop growth was registered in K: $MgSO_4$ @ 20:60 kg/ha (S_2). Average Mg content recorded in grains and haulm were 0.22 % and 0.33 % respectively.

Interaction effect also was significant in magnesium content of plants, grains and haulm recorded during both years of experiment. In 2017, at 30 DAS, CT with soil test based nutrient application (M_3S_1) recorded highest magnesium content (1.09 %), followed by ZT with K: $MgSO_4$ @ 20:60 kg/ha (M_1S_2) with a content of 1.06 %. Lowest content (0.68 %) was recorded with MT along with soil test based nutrition (M_2S_1). At 90 DAS, trend was changed and CT along with K: $MgSO_4$ @ 20:80 kg/ha (M_3S_3) registered highest plant Mg content (1.10 %), followed by CT with soil test based nutrition (M_3S_1) with Mg content of 1.07 %. The lowest content (0.68 %) was recorded in combination of MT with K: $MgSO_4$ @ 20:80 kg/ha (M_2S_3). In grains highest Mg content (0.26 %) was observed under ZT along with soil test based nutrition (M_1S_1). It maintained parity to ZT with K: $MgSO_4$ @ 20:60 kg/ha (M_1S_2) and MT with K: $MgSO_4$ @ 40:60 kg/ha (M_2S_4) and to ZT with K: $MgSO_4$ @ 40:60 kg/ha (M_1S_4) and CT with K: $MgSO_4$ @ 40:60 kg/ha (M_3S_4). The lowest magnesium content in grains and haulm was recorded in CT with K: $MgSO_4$ @ 40: 80 kg/ha (M_3S_5).

In 2018 also interaction effect was found to be significant. In plants at 30 DAS, MT with K: $MgSO_4$ @ 40:80 kg/ha (M_2S_5) recorded higher Mg content (1.12 %), which was on part to MT with soil test based nutrient application (M_2S_1). The lower content (0.69%) was noted in MT with K: $MgSO_4$ @ 20:80 kg/ha (M_2S_3) and it was at par to M_2S_2, M_2S_4, and M_3S_1. Mg content in plants at 90 DAS was higher under ZT with K: $MgSO_4$ @ 40:60 kg/ha (M_1S_4) registered highest plant Mg content (0.74 %). This was on par to Mg content recorded in M_1S_1, M_2S_2, M_2S_3, M_2S_5, M_3S_1, and M_3S_2. The lowest content recorded at 90 DAS (0.43 %) was with application of K: $MgSO_4$ @ 20:60 kg/ha under ZT (M_1S_2). In grains, ZT along with K: $MgSO_4$ @ 20:60 kg/ha (M_1S_2), 20:80 kg/ha (M_1S_3), as well as with soil test based nutrition (M_1S_1) and MT along with K: $MgSO_4$ @ 40:60 kg/ha (M_2S_4), registered higher grain Mg content (0.24 %). The lower content in grains was recorded under conventional tillage + soil test based nutrition (M_3S_1) and in M_3S_2.

However, in haulm higher magnesium content was recorded under ZT with K: $MgSO_4$ @ 40:60 kg/ha (M_1S_4) and CT with K: $MgSO_4$ @ 20:80 kg/ha (M_3S_3) and 20:60 kg/ha (M_3S_2), (0.40 %, 0.39 %, and 0.37 % respectively). The lowest Mg content in haulm.

Table 37. Effect of tillage and nutrients on calcium content (%) of cowpea

Treatments	**30 DAS**		**Harvest**		**Grain**		**Haulm**	
Tillage	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
M_1- Zero tillage (ZT)	1.7	1.7	1.2	1.0	0.2	0.2	0.4	0.4
M_2- Minimum tillage (MT)	1.6	1.8	1.2	0.8	0.2	0.2	0.3	0.3
M_3- Conventional tillage (CT)	1.5	1.7	1.0	0.8	0.2	0.1	0.3	0.3
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.009**	**0.029**	**0.001**	**0.014**	**0.002**	**0.003**	**0.005**	**0.005**
S_1- Soil test based recommendations	1.6	1.7	1.2	0.9	0.2	0.2	0.3	0.3
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	1.7	1.7	1.2	0.9	0.2	0.2	0.4	0.4
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	1.7	1.8	1.3	0.8	0.2	0.2	0.3	0.3
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	1.5	1.8	0.9	0.7	0.2	0.2	0.3	0.3
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	1.5	1.9	1.2	0.9	0.1	0.1	0.2	0.2
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.011**	**0.037**	**0.001**	**0.018**	**0.003**	**0.003**	**0.006**	**0.007**
M_1S_1: ZT + Soil test based	2.0	1.3	1.3	1.2	0.2	0.2	0.3	0.3
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	1.8	1.6	1.2	1.0	0.2	0.2	0.5	0.4
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	1.5	1.9	1.6	1.0	0.2	0.2	0.3	0.3
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	1.5	1.6	1.0	0.9	0.2	0.2	0.4	0.4
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	1.9	2.3	1.1	1.1	0.1	0.1	0.3	0.3
M_2S_1: MT + Soil test based	1.7	1.9	1.4	0.6	0.1	0.1	0.3	0.3
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	1.6	1.8	1.4	1.0	0.2	0.2	0.3	0.3
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	2.2	1.9	1.1	0.7	0.1	0.1	0.3	0.3
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	1.4	1.6	1.0	0.7	0.2	0.2	0.3	0.3
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	1.2	1.7	1.4	0.8	0.2	0.2	0.3	0.3
M_3S_1: CT + Soil test based	1.3	1.8	1.0	1.0	0.2	0.2	0.3	0.3
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	1.6	1.6	1.1	0.9	0.2	0.2	0.4	0.4
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	1.6	1.5	1.3	0.8	0.1	0.2	0.4	0.4
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	1.5	2.1	0.7	0.7	0.2	0.2	0.3	0.3
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	1.4	1.6	1.0	0.6	0.1	0.0	0.1	0.1
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.020**	**0.065**	**0.002**	**0.031**	**0.006**	**0.003**	**0.011**	**0.012**

Table 38. Effect of tillage and nutrients on magnesium content (%) of cowpea

Treatments	**30 DAS**		**Harvest**		**Grain**		**Haulm**	
Tillage	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
M_1- Zero tillage (ZT)	0.88	0.88	0.93	0.62	0.23	0.23	0.35	0.35
M_2- Minimum tillage (MT)	0.83	0.88	0.89	0.66	0.21	0.22	0.31	0.32
M_3- Conventional tillage (CT)	0.83	0.83	1.01	0.63	0.21	0.21	0.33	0.33
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.003**	**0.014**	**0.001**	**0.010**	**0.003**	**0.003**	**0.006**	**0.005**
S_1- Soil test based recommendations	0.88	0.90^{b}	1.05	0.68^{a}	0.22	0.22	0.34	0.32
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	0.84	0.78^{d}	0.95	0.60^{c}	0.22	0.22	0.35	0.35
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.85	0.82^{c}	1.04	0.64^{ab}	0.21	0.22	0.31	0.33
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.80	0.84^{c}	0.75	0.65^{ab}	0.24	0.23	0.37	0.35
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.86	0.96^{a}	0.92	0.62^{b}	0.20	0.21	0.28	0.30
C.D (0.05)	**NS**	**0.05**	**NS**	**0.04**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.004**	**0.018**	**0.001**	**0.013**	**0.004**	**0.004**	**0.007**	**0.007**
M_1S_1: ZT + Soil test based	0.81^{g}	0.86^{c}	1.04^{d}	0.69^{ab}	0.26^{a}	0.24^{a}	0.33^{defg}	0.31^{d}
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	1.06^{b}	0.80^{de}	0.99^{f}	0.43^{g}	0.25^{a}	0.24^{a}	0.37^{bc}	0.35^{bc}
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.84^{ef}	0.98^{b}	1.04^{d}	0.59^{de}	0.22^{bc}	0.24^{a}	0.30^{gh}	0.33^{cd}
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.83^{fg}	0.92^{b}	0.70^{l}	0.74^{a}	0.24^{a}	0.23^{bc}	0.43^{a}	0.40^{a}
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.86^{e}	0.85^{cd}	0.86^{h}	0.64^{bc}	0.20^{cd}	0.22^{bcd}	0.32^{efg}	0.34^{bc}
M_2S_1: MT + Soil test based	0.68^{j}	1.09^{a}	1.05^{c}	0.65^{bc}	0.21^{c}	0.21^{cd}	0.32^{efg}	0.33^{cd}
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	0.73^{h}	0.77^{ef}	1.02^{e}	0.70^{ab}	0.20^{cd}	0.21^{cd}	0.31^{fg}	0.34^{cd}
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	1.00^{c}	0.69^{f}	0.68^{m}	0.69^{ab}	0.20^{cd}	0.20^{de}	0.27^{h}	0.27^{e}
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.84^{ef}	0.70^{ef}	0.82^{j}	0.57^{ef}	0.25^{a}	0.24^{a}	0.34^{cde}	0.33^{cd}
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.89^{d}	1.12^{a}	0.87^{g}	0.69^{ab}	0.20^{cd}	0.20^{cde}	0.32^{efg}	0.32^{cd}
M_3S_1: CT + Soil test based	1.09^{a}	0.75^{ef}	1.07^{b}	0.70^{ab}	0.20^{cd}	0.19^{g}	0.36^{bcd}	0.34^{cd}
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	0.72^{hi}	0.79^{de}	0.84^{i}	0.68^{ab}	0.20^{cd}	0.20^{fg}	0.39^{b}	0.37^{ab}
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.72^{hi}	0.78^{de}	1.10^{a}	0.60^{de}	0.21^{c}	0.23^{bc}	0.36^{bcd}	0.39^{a}
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.71^{i}	0.90^{b}	0.72^{k}	0.62^{cd}	0.24^{ab}	0.22^{bcd}	0.34^{cde}	0.32^{cd}
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.84^{ef}	0.91^{b}	1.04^{d}	0.54^{f}	0.18^{d}	0.20^{ef}	0.21^{i}	0.23^{f}
C.D (0.05)	**0.02**	**0.09**	**0.01**	**0.07**	**0.02**	**0.02**	**0.04**	**0.04**
SE(m)	**0.007**	**0.031**	**0.002**	**0.023**	**0.008**	**0.008**	**0.013**	**0.012**

(0.23 %) was observed in CT and K: $MgSO_4$ @ 40:80 kg/ha (M_3S_5).

f. Sulphur content

None of the tillage systems practiced influenced sulphur content in cowpea at 30 DAS, at harvest and in grains as well as in haulm significantly during both years (**Table 39**), and the average sulphur content was 0.62 %, 0.71 %, 0.49 % and 0.45 % respectively in the first year, while the corresponding values for second year were 0.49 %, 0.55 %, 0.28 %, and 0.23 % respectively. During both years K and $MgSO_4$ doses had no significant effect on plant sulphur content at initial stage (30 DAS) but differed significantly at harvest, in grains and in haulm. Interaction effect was also found to be significant with respect to sulphur content in grains and haulm **(Table 39)**. It could be noted that, sulphur content in second year was lower than that of first year values.

During 2017 sulphur content in plants at harvest was highest in soil test based nutrient application (S_1). K: $MgSO_4$ @ 20:60 (S_2) and 40:60 kg/ha (S_4) recorded lower content in plants at 90 DAS (0.48% and 0.49 %), while, it was K: $MgSO_4$ @ 20:60 kg/ha (S_2) in grains (0.38 %) and K: $MgSO_4$ @ 20:80 kg/ha in haulm (0.30 %) resulted in lowest S content. During second year, S_2 and S_3 recorded higher S content in plants at 90 DAS (0.61 % and 0.63 %), while in grains, sulphur content was highest (0.46 %) in application of K: $MgSO_4$ @ 40:80 kg/ha (S_5) followed by application of K: $MgSO_4$ @ 20:80 kg/ha (S_3). In haulms higher content was recorded with S_1 and S_3 (0.29 % and 0.32 %).

In 2017, S_2 and S_4 recorded lower plant S content at 90 DAS, while in grains, lowest S content (0.38 %) was recorded in K: $MgSO_4$ @ 20:60 kg/ha (S_2) and lowest haulm content was noticed under S_3 (0.30 %). In 2018, soil test based nutrition resulted in lowest S content (0.45 %) in plants at harvesting stage. In grains S_2 and S_4 registered lower grain S content, while lowest haulm S content (0.10 %) was noted in application of K @ 20 kg/ha and Mg @ 60 kg/ha (S_2).

Table 39. Effect of tillage and nutrients on sulphur content (%) of cowpea

Treatments	**30 DAS**		**Harvest**		**Grain**		**Haulm**	
Tillage	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
M_1- Zero tillage (ZT)	0.52	0.49	0.74	0.53	0.56	0.34	0.48	0.16
M_2- Minimum tillage (MT)	0.65	0.45	0.72	0.61	0.42	0.25	0.40	0.25
M_3- Conventional tillage (CT)	0.70	0.53	0.66	0.52	0.50	0.26	0.47	0.27
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.065**	**0.005**	**0.031**	**0.029**	**0.007**	**0.009**	**0.005**	**0.011**
S_1- Soil test based recommendations	0.63	0.48	1.06^{a}	0.45^{c}	0.62^{a}	0.25^{c}	0.52^{a}	0.29^{ab}
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	0.78	0.40	0.49^{d}	0.61^{a}	0.38^{d}	0.18^{d}	0.41^{b}	0.10^{d}
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.55	0.52	0.80^{b}	0.63^{a}	0.51^{b}	0.36^{b}	0.30^{c}	0.32^{a}
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.60	0.42	0.48^{d}	0.51^{b}	0.53^{b}	0.17^{d}	0.51^{a}	0.15^{c}
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.55	0.63	0.70^{c}	0.58^{b}	0.44^{c}	0.46^{a}	0.52^{a}	0.27^{b}
C.D (0.05)	**NS**	**NS**	**0.07**	**0.11**	**0.03**	**0.03**	**0.02**	**0.04**
SE(m)	**0.084**	**0.006**	**0.042**	**0.038**	**0.009**	**0.012**	**0.006**	**0.014**
M_1S_1: ZT + Soil test based	0.64	0.50	1.03	0.42	0.56^{ef}	0.34^{de}	0.70^{a}	0.15^{def}
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	0.58	0.43	0.84	0.56	0.68^{bc}	0.17^{g}	0.21^{j}	0.07^{g}
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.36	0.46	1.01	0.68	0.79^{a}	0.42^{b}	0.30^{h}	0.22^{c}
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.58	0.43	0.63	0.46	0.63^{cd}	0.18^{fg}	0.65^{b}	0.12^{fg}
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.45	0.64	0.83	0.54	0.16^{k}	0.61^{a}	0.55^{d}	0.23^{c}
M_2S_1: MT + Soil test based	0.73	0.53	0.82	0.50	0.59^{de}	0.23^{f}	0.60^{c}	0.21^{cd}
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	0.41	0.37	0.50	0.62	0.19^{k}	0.19^{fg}	0.44^{e}	0.10^{fg}
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.81	0.43	0.90	0.63	0.53^{fg}	0.29^{e}	0.33^{g}	0.37^{b}
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.78	0.38	0.46	0.62	0.45^{h}	0.17^{g}	0.27^{hi}	0.12^{fg}
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.62	0.53	0.74	0.69	0.36^{i}	0.36^{cd}	0.37^{f}	0.46^{a}
M_3S_1: CT + Soil test based	0.57	0.41	0.74	0.43	0.72^{b}	0.18^{fg}	0.25^{i}	0.52^{a}
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	1.04	0.41	0.33	0.66	0.28^{j}	0.19^{fg}	0.58^{cd}	0.14^{efg}
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.51	0.68	0.56	0.57	0.21^{k}	0.36^{bcd}	0.28^{h}	0.36^{b}
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.47	0.45	0.47	0.43	0.50^{g}	0.15^{g}	0.60^{c}	0.20^{cde}
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.62	0.71	0.80	0.50	0.79^{a}	0.41^{bc}	0.64^{b}	0.12^{fg}
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**0.05**	**0.06**	**0.03**	**0.07**
SE(m)	**0.145**	**0.011**	**0.083**	**0.066**	**0.016**	**0.020**	**0.010**	**0.025**

Interaction between tillage and nutrients resulted in significant variation in sulphur content of grains and haulm during both years. In first year, in grains, both zero tillage with K: $MgSO_4$ @ 20:80 kg/ha (M_1S_3; 0.79 %) and CT + K: $MgSO_4$ @ 40:80 kg/ha (M_3S_5, 0.79 %) registered higher S content. In grains the lower sulphur content was observed in K: $MgSO_4$ @ 40: 80 kg/ha under ZT (0.16 % S), K: $MgSO_4$ @ 20:60 kg/ha under MT (0.19 %) and K: $MgSO_4$ @ 20:60 kg/ha under ZT (0.21 %) respectively and they were at par.

In 2018, highest grain sulphur content (0.61 %) was recorded in same nutrient treatment *i.e.* K: $MgSO_4$ @ 40:80 kg/ha but under zero tillage system (M_1S_5). Among various interaction treatments, nutrient treatments consisting of $MgSO_4$ @ 60 kg/ha along with any form of tillage produced lower values. Higher S content (0.52%) with respect to haulm was observed under CT with soil test based nutrient application (M_3S_1) which was on par to MT with K: $MgSO_4$ @ 40:80 kg/ha (0.46 %). S content in haulm recorded with application of K: $MgSO_4$ @ 20:80 kg/ha under MT and CT were on par. Haulm S content was lowest (0.07 %) in ZT + K: $MgSO_4$ @ 20:60 kg/ha (M_1S_2).

g. Micronutrient content

Micronutrient content in plants, grains and haulm did not differ significantly, **(Table 40-43).** In 2017, average iron content recorded in plants at 30 DAS 2017 was 0.16 % while in 2018 it was 0.11 %. At harvest Fe content in plants was 0.07 % in both years. In both years, iron content in grains was 0.03% and in haulm it was 0.02 %.

Mn content in plants at 30 DAS during 2017 was 0.032 % and in and 2018 it was 0.031 %. At harvest, Mn content in plants recoded was 0.017 % during 2017 and in 2018 it was 0.016 %. During both years. 0.003 % was the Mn content in grains and in haulm it was 0.006 %. Average zinc content recorded in plants at 30 DAS, 90 DAS, were 0.01 %, and 0.008 % during 2017 and in 2018, plants at both stages consisted of 0.011 % Mn, In 2017, grains and haulm recorded Mn content of 0.008 %, and, 0.005 % and it was 0.008 %, and 0.005 % in 2018.

Table 40. Effect of tillage and nutrients on iron content (%) of cowpea

Treatments	**30 DAS**		**Harvest**		**Grain**	
Tillage	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
M_1- Zero tillage (ZT)	0.17	0.12	0.07	0.05	0.03	0.03
M_2- Minimum tillage (MT)	0.18	0.12	0.06	0.08	0.03	0.03
M_3- Conventional tillage (CT)	0.13	0.10	0.08	0.07	0.03	0.03
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.001**	**0.002**	**0.001**	**0.001**	**0.001**	**0.001**
S_1- Soil test based recommendations	0.18	0.10	0.07	0.07	0.03	0.03
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	0.14	0.11	0.08	0.08	0.03	0.03
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.15	0.10	0.08	0.05	0.03	0.03
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.17	0.12	0.06	0.08	0.03	0.03
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.15	0.12	0.06	0.08	0.02	0.03
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.001**	**0.002**	**0.001**	**0.001**	**0.001**	**0.001**
M_1S_1: ZT + Soil test based	0.17	0.14	0.08	0.04	0.02	0.02
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	0.16	0.14	0.08	0.04	0.03	0.03
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.13	0.11	0.08	0.04	0.03	0.03
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.23	0.12	0.06	0.08	0.03	0.03
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.17	0.11	0.06	0.07	0.03	0.03
M_2S_1: MT + Soil test based	0.23	0.10	0.07	0.07	0.03	0.03
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	0.13	0.13	0.05	0.08	0.03	0.04
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.22	0.09	0.05	0.07	0.03	0.03
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.14	0.11	0.05	0.08	0.03	0.03
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.16	0.14	0.05	0.08	0.03	0.03
M_3S_1: CT + Soil test based	0.14	0.06	0.06	0.08	0.03	0.03
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	0.14	0.07	0.08	0.08	0.03	0.03
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.11	0.10	0.08	0.06	0.03	0.03
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.14	0.13	0.05	0.04	0.03	0.02
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.12	0.09	0.07	0.06	0.02	0.02
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.001**	**0.004**	**0.001**	**0.001**	**0.001**	**0.001**

Table 41. Effect of tillage and nutrients on manganese content (%) of cowpea

Treatments	**30 DAS**		**Harvest**		**Grain**		**Haulm**	
Tillage	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
M_1- Zero tillage (ZT)	0.04	0.03	0.02	0.02	0.003	0.003	0.007	0.006
M_2- Minimum tillage (MT)	0.03	0.03	0.017	0.02	0.003	0.003	0.006	0.006
M_3- Conventional tillage (CT)	0.03	0.03	0.014	0.02	0.003	0.003	0.006	0.006
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**
S_1- Soil test based recommendations	0.04	0.03	0.02	0.02	0.003	0.003	0.006	0.007
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	0.03	0.03	0.01	0.02	0.003	0.003	0.007	0.007
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.03	0.03	0.02	0.02	0.003	0.003	0.007	0.007
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.03	0.03	0.02	0.02	0.003	0.003	0.006	0.006
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.03	0.03	0.01	0.02	0.003	0.003	0.005	0.005
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**
M_1S_1: ZT + Soil test based	0.04	0.02	0.02	0.01	0.003	0.003	0.006	0.006
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	0.04	0.03	0.02	0.01	0.003	0.003	0.006	0.007
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.02	0.03	0.02	0.02	0.003	0.003	0.007	0.006
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.04	0.03	0.02	0.02	0.003	0.003	0.007	0.007
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.04	0.04	0.02	0.02	0.003	0.003	0.007	0.006
M_2S_1: MT + Soil test based	0.03	0.04	0.03	0.01	0.003	0.003	0.007	0.007
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	0.02	0.03	0.01	0.02	0.003	0.003	0.007	0.007
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.04	0.03	0.02	0.02	0.003	0.003	0.005	0.006
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.02	0.03	0.02	0.01	0.003	0.003	0.006	0.007
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.03	0.03	0.01	0.02	0.003	0.003	0.006	0.006
M_3S_1: CT + Soil test based	0.04	0.03	0.02	0.02	0.003	0.003	0.006	0.008
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	0.03	0.04	0.01	0.02	0.003	0.003	0.008	0.008
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.02	0.02	0.02	0.01	0.003	0.003	0.009	0.008
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.02	0.03	0.01	0.01	0.003	0.003	0.006	0.006
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.02	0.03	0.01	0.02	0.002	0.003	0.003	0.003
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**

Table 42. Effect of tillage and nutrients on zinc content (%) of cowpea

Treatments	**Plant (30 DAS)**		**Plant (Harvest)**		**Grain**	
Tillage	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
M_1- Zero tillage (ZT)	0.010	0.013	0.008	0.010	0.008	0.008
M_2- Minimum tillage (MT)	0.012	0.011	0.007	0.011	0.008	0.008
M_3- Conventional tillage (CT)	0.008	0.011	0.008	0.010	0.008	0.008
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**
S_1- Soil test based recommendations	0.015	0.011	0.009	0.012	0.008	0.008
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	0.009	0.011	0.008	0.010	0.009	0.009
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.008	0.014	0.008	0.010	0.008	0.009
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.009	0.01	0.006	0.010	0.009	0.009
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.008	0.011	0.007	0.012	0.007	0.008
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**
M_1S_1: ZT + Soil test based	0.012	0.009	0.007	0.011	0.010	0.009
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	0.012	0.010	0.010	0.010	0.008	0.008
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.007	0.020	0.008	0.010	0.008	0.008
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.008	0.011	0.007	0.011	0.009	0.008
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.010	0.012	0.009	0.010	0.008	0.008
M_2S_1: MT + Soil test based	0.022	0.011	0.008	0.011	0.008	0.008
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	0.008	0.011	0.006	0.010	0.008	0.009
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.011	0.011	0.008	0.011	0.009	0.009
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.010	0.010	0.006	0.011	0.009	0.009
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.007	0.011	0.005	0.015	0.008	0.008
M_3S_1: CT + Soil test based	0.010	0.012	0.012	0.014	0.008	0.007
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	0.008	0.012	0.007	0.010	0.009	0.009
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.007	0.010	0.009	0.010	0.009	0.010
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.008	0.010	0.005	0.008	0.009	0.009
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.008	0.011	0.008	0.010	0.007	0.007
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**

Table 43. Effect of tillage and nutrients on copper content (%) of cowpea

Treatments	**30 DAS**		**Harvest**		**Grain**		**Haulm**	
Tillage	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
M_1- Zero tillage (ZT)	0.003	0.002	0.003	0.001	0.001	0.001	0.001	0.001
M_2- Minimum tillage (MT)	0.003	0.002	0.002	0.001	0.001	0.002	0.002	0.002
M_3- Conventional tillage (CT)	0.003	0.001	0.003	0.001	0.001	0.001	0.002	0.002
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**
S_1- Soil test based recommendations	0.003	0.002	0.002	0.001	0.001	0.001	0.001	0.001
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	0.003	0.002	0.003	0.001	0.001	0.001	0.002	0.002
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.003	0.002	0.002	0.001	0.001	0.001	0.001	0.002
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.003	0.001	0.001	0.002	0.002	0.002	0.002	0.002
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.004	0.002	0.003	0.001	0.002	0.002	0.001	0.001
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**
M_1S_1: ZT + Soil test based	0.004	0.003	0.002	0.001	0.001	0.001	0.001	0.001
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	0.003	0.003	0.005	0.001	0.001	0.000	0.001	0.001
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.003	0.002	0.002	0.001	0.001	0.001	0.001	0.001
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.003	0.001	0.001	0.002	0.002	0.002	0.001	0.001
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.004	0.001	0.003	0.002	0.001	0.001	0.001	0.001
M_2S_1: MT + Soil test based	0.003	0.003	0.002	0.001	0.001	0.001	0.001	0.001
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	0.003	0.002	0.001	0.002	0.001	0.002	0.004	0.005
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.003	0.001	0.001	0.001	0.001	0.001	0.001	0.001
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.004	0.002	0.001	0.002	0.001	0.001	0.001	0.001
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.003	0.003	0.002	0.001	0.003	0.003	0.001	0.001
M_3S_1: CT + Soil test based	0.003	0.001	0.003	0.001	0.001	0.001	0.001	0.001
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	0.003	0.002	0.003	0.001	0.001	0.001	0.001	0.001
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.003	0.002	0.003	0.001	0.002	0.002	0.002	0.003
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.003	0.001	0.002	0.001	0.002	0.002	0.003	0.003
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.004	0.001	0.003	0.001	0.001	0.001	0.001	0.001
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**

Average copper content observed in plants at 30 DAS, 90 DAS, were 0.003 % and 0.002 % during 2017. In 2018, it was 0.002 % and 0.001 %. In both years, Mn content recorded in both grains and haulm was 0.001 %.

4.2.7. Nutrient uptake

Nutrient uptake was estimated at 30 DAS and at harvest. Data pertaining to nutrient uptake at 30 DAS during first year showed that conventional tillage treatments (M_3S_1, M_3S_2 or M_3S_5) recorded superior values for uptake. During second year a similar pattern was observed.

a. Nitrogen uptake

The data on nitrogen uptake at 30 DAS and at harvest during both years are furnished in **Table 44.** It could be noted that, at 30 DAS, nitrogen uptake followed same trend in both years. The highest uptake of nitrogen (17.5 kg/ha and 22.6 kg/ha respectively) was observed under conventional tillage (M_3), followed by minimum tillage (M_2) and the lowest (9.1 kg/ha and 14.6 kg/ha respectively) was noticed under zero tillage system (M_1) and they differed significantly.

Various K-Mg doses also showed significant variation on nitrogen uptake at 30 DAS during both years. In 2017, nitrogen uptake was higher (15.1 kg/ha) in application of nutrients with respect to soil test results (S_1), which was on par (13.7 kg N/ha) with K: $MgSO_4$ @ 20:60 kg/ha (S_2). Lowest uptake (11.6 kg/ha) was recorded in K: $MgSO_4$ @ 40:80 kg/ha (S_5). However, in 2018, application of K: $MgSO_4$ @ 20:80 kg/ha (S_3) registered higher nitrogen uptake (21.6 kg/ha) and it was on par with uptake recorded in S_5 (21.3 kg/ha N) and S_4 (18.9 kg N/ha). Lower nitrogen uptake was noticed in application of K: $MgSO_4$ @ 20:60 kg/ha (S_2) and soil test based nutrition (S_1).

Interaction between tillage and nutrients found to bring about significant influence on N uptake by cowpea at 30 DAS in both 2017 and 2018. In first year of study, it was observed that, higher uptake (21.7 kg N/ha) was recorded under CT along

Table 44. Effect of tillage and nutrients on nitrogen uptake (kg/ha) by cowpea

Treatments	**Plant (30 DAS)**		**Plant (Harvest)**		
Tillage	**2017**	**2018**	**2017**	**2018**	**Pooled**
M_1- Zero tillage (ZT)	9.1^{c}	14.6^{c}	57.9^{c}	72.4^{b}	65.1^{b}
M_2- Minimum tillage (MT)	13.2^{b}	19.0^{b}	81.0^{a}	72.6^{b}	76.8^{a}
M_3- Conventional tillage (CT)	17.5^{a}	22.6^{a}	70.9^{b}	87.2^{a}	79.1^{a}
C.D (0.05)	**1.2**	**2.5**	**3.9**	**4.6**	**3.4**
SE(m)	**0.4**	**0.9**	**1.3**	**1.6**	**1.2**
S_1- Soil test based recommendations	15.1^{a}	16.0^{b}	75.7^{a}	82.3^{a}	79.0^{a}
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	13.7^{ab}	15.6^{b}	66.6^{b}	77.6^{ab}	72.1^{b}
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	13.0^{bc}	21.6^{a}	61.3^{c}	70.5^{c}	65.9^{c}
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	13.0^{bc}	18.9^{a}	77.3^{a}	83.2^{a}	80.3^{a}
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	11.6^{c}	21.3^{a}	68.9^{b}	73.4^{bc}	71.2^{b}
C.D (0.05)	**1.6**	**3.2**	**5.0**	**6.0**	**4.3**
SE(m)	**0.5**	**1.1**	**1.7**	**1.9**	**1.5**
M_1S_1: ZT + Soil test based	10.7^{fgh}	15.2^{efgh}	60.4^{efg}	95.8^{a}	78.1^{cde}
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	8.3^{h}	15.9^{defg}	54.6^{gh}	59.7^{de}	57.2^{h}
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	12.6^{def}	20.0^{cde}	47.6^{h}	70.0^{cd}	58.8^{h}
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	8.7^{gh}	11.0^{fgh}	61.8^{efg}	66.9^{cd}	64.4^{gh}
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	5.1^{i}	10.8^{gh}	65.0^{ef}	69.4^{cd}	67.2^{g}
M_2S_1: MT + Soil test based	14.7^{cd}	9.6^{h}	86.4^{b}	52.4^{e}	69.4^{fg}
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	10.9^{efgh}	14.5^{efgh}	83.9^{b}	67.7^{cd}	75.8^{def}
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	13.3^{def}	26.7^{ab}	74.8^{cd}	67.4^{cd}	71.1^{efg}
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	11.2^{efg}	22.8^{bc}	102.0^{a}	99.8^{a}	100.9^{a}
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	16.1^{c}	21.1^{cd}	58.0f^{g}	75.8^{bc}	66.9^{g}
M_3S_1: CT + Soil test based	19.6^{ab}	23.1^{bc}	80.3^{bc}	98.6^{a}	89.5^{b}
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	21.7^{a}	16.4^{def}	61.3^{efg}	105.5^{a}	83.4^{bc}
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	13.4^{de}	18.3^{cde}	61.5^{efg}	74.1^{bc}	67.8^{g}
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	19.0^{b}	23.1^{bc}	67.9^{de}	82.9^{b}	75.4^{def}
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	13.9^{cd}	32.0^{a}	83.8^{b}	75.0^{bc}	79.4^{cd}
C.D (0.05)	**2.8**	**5.6**	**8.7**	**10.3**	**7.5**
SE(m)	**0.9**	**1.9**	**3.0**	**3.4**	**2.6**

with application of K: $MgSO_4$ @ 20:60 kg/ha (M_3S_2) which was at par with nitrogen uptake noted in CT with soil test based nutrition (M_3S_1). Lowest uptake of nitrogen (5.1 kg N/ha) could be observed in ZT with K: $MgSO_4$ @ 40:80 kg/ha (M_1S_5). In 2018, CT along with K: $MgSO_4$ @ 40:80 kg/ha (M_3S_5) recorded higher N uptake of 32.0 kg/ha, which was on par to uptake recorded under MT + K: $MgSO_4$ @ 20:80 kg/ha (M_2S_3). Minimum tillage with soil test based nutrition (M_2S_1) registered lower uptake of nitrogen (9.6 kg N/ha) which was on par to M_1S_1, M_1S_4, M_1S_5, and M_2S_2.

At harvest, minimum tillage (M_2) recorded the highest uptake of nitrogen (81.04 kg/ha) in 2017. It was followed by conventional tillage. The lowest N uptake (57.9) at harvest was noticed under ZT. In 2018, highest uptake of 87.2 kg/ha was observed under conventional tillage (M_3). The lower uptake was noticed under MT and ZT and they were on par to each other.

Various K-Mg doses also showed significant variation on nitrogen uptake at harvest during both years. In 2017, application of soil test based nutrition (S_1) and K: $MgSO_4$ @ 40:60 kg/ha (S_4) registered higher uptake at harvest (75.7 kg/ha and 77.3 kg/ha respectively) and they were on par. In 2018, application of soil test based nutrition (S_1), K: $MgSO_4$ @ 40:60 kg/ha (S_4) and K: $MgSO_4$ @ 20:60 kg/ha (S_2) registered higher uptake at harvest. During both the years, the lowest N uptake (61.3 kg/ha and 70.5 kg/ha respectively) was noted with K: $MgSO_4$ @ 20:80 kg/ha (S_3).

Interaction between tillage and nutrients found to bring about significant influence on N uptake by cowpea at harvest in both 2017 and 2018. In first year of study, it was observed that, highest uptake (102 kg N/ha) was recorded under MT with K: $MgSO_4$ @ 40:60 kg/ha (M_2S_4). In 2018, M_3S_2 (105.5 kg N/ha), M_2S_4 (99.8 kg N/ha), M_3S_1 (98.6 kg N/ha), and M_1S_1 (95.8 kg N/ha).

From the pooling it is very clear that, MT and CT recorded higher nitrogen uptake at harvest. Among nutrient doses S_1 and S_4 registered higher uptake at harvest. Interactions between MT and K_2O @ 40 kg/ha with $MgSO_4$ @ 60 kg/ha registered highest uptake of N (100.9 kg/ha).

b. Phosphorus uptake

Data shows that types of tillage, K-$MgSO_4$ doses and their interaction had no significant influence on P uptake of cowpea at 30 DAS and at harvest during both years **(Table 45)**. On an average uptake recorded at 30 DAS during 2017 and 2018 was 0.86 kg P/ha and 2.2 kg P/ha respectively, whereas corresponding values for uptake recorded at harvest was 7.1 kg/ha and 8.6 kg/ha respectively.

c. Potassium uptake

Influence of various tillage systems, levels of K & $MgSO_4$, and their interaction found to be significant with respect to K uptake at 30 DAS and at harvest. It could be noted that there was an increase in K uptake by plants with increase in intensity of tillage at initial stage of crop growth in both years and they differed statistically **(Table 46).** K uptake maintained the same trend as observed in case of nitrogen uptake by cowpea at 30 DAS.

In both 2017 and 2018 highest K uptake was noticed under conventional tillage (M_3) with an uptake of 13.4 kg K/ha and 15.1 kg K/ha respectively. It was followed by minimum tillage (M_2). The lowest content (5.9 kg/ha and 7.0 kg/ha respectively) was noted under zero tillage system (M_1) during the period of study.

Among various K and Mg doses, in 2017, K: $MgSO_4$ @ 20:60 kg/ha (S_2) recorded higher K uptake (11.2 kg/ha). It was on par to soil test based nutrition where K: $MgSO_4$ was applied @ 10.5:80 kg/ha (S_1). However application of higher levels of K and $MgSO_4$ *i.e.* @ 40:80 kg/ha (S_5) resulted in lowest uptake. In 2018, higher uptake (12.7 kg/ha) was noted in K: $MgSO_4$ @ 20:80 kg/ha (S_3) which was on par to K: $MgSO_4$ @ 40:80 kg/ha (S_5) and lowest potassium uptake (8.5 kg/ha) was noticed in application of K: $MgSO_4$ @ 20:60 kg/ha (S_2). Interaction effect was also found to be significant with respect to K uptake of cowpea at 30 DAS and at harvest. During both years various K-$MgSO_4$ levels along with conventional tillage (CT) recorded higher uptake values.

Table 45. Effect of tillage and nutrients on phosphorus uptake (kg/ha) by cowpea

Treatments	**Plant (30 DAS)**		**Plant (Harvest)**	
Tillage	**2017**	**2018**	**2017**	**2018**
M_1- Zero tillage (ZT)	0.57	1.6	5.5	8.3
M_2- Minimum tillage (MT)	0.86	2.0	8.9	7.7
M_3- Conventional tillage (CT)	1.07	2.9	6.9	9.7
C.D (0.05)	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.03**	**0.1**	**0.1**	**0.3**
S_1- Soil test based recommendations	0.79	2.1	7.3	10.0
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	0.97	1.9	5.8	8.7
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.89	2.4	6.7	7.5
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.83	1.9	7.7	8.1
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.69	2.5	7.7	8.4
C.D (0.05)	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.04**	**0.2**	**0.2**	**0.3**
M_1S_1: ZT + Soil test based	0.53	1.6	5.2	12.5
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	0.60	1.6	5.2	7.4
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.87	2.0	3.9	6.9
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.62	1.3	5.0	7.2
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.25	1.4	8.0	7.4
M_2S_1: MT + Soil test based	0.88	1.0	9.2	6.0
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	0.98	1.6	6.4	8.8
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.94	2.9	9.5	7.5
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	0.57	2.4	11.2	7.6
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.93	2.2	8.1	8.6
M_3S_1: CT + Soil test based	0.97	3.8	7.7	11.6
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	1.33	2.6	6.0	9.9
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	0.85	2.2	6.8	8.1
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	1.30	2.0	6.9	9.7
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.90	4.1	7.1	9.3
C.D (0.05)	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.06**	**0.3**	**0.3**	**0.5**

In 2017, highest K uptake (19.9 kg/ha) at 30 DAS was observed under CT with K: $MgSO_4$ @ 20:60 kg/ha (M_3S_2). It was followed by CT with soil test based nutrition and K: $MgSO_4$ @ 40:60 kg/ha (M_3S_1 & M_3S_4 respectively). It could be also noted that, interaction between various levels of potash and magnesium to zero tillage (ZT) resulted in inferior values of uptake during 2017. The lowest K-uptake (2.8 kg/ha) was noticed in M_1S_5, *i.e.* ZT along with K: $MgSO_4$ @ 40:80 kg/ha (M_1S_5).

In second year higher uptake (21.0 kg/ha) at 30 DAS was recorded under CT with K: $MgSO_4$ @ 40:80 kg/ha (M_3S_5). It was on par to K-uptake recorded (18.7 kg/ha) under CT with soil test based nutrition where K: $MgSO_4$ was supplied @ 12.8:80 kg/ha (M_3S_1) and K uptake (18.0 kg/ha) registered under minimum tillage (MT) with K: $MgSO_4$ @ 20:80 kg/ha (M_2S_3). Lower K uptake values (4.1 kg/ha) were observed under MT with soil test based nutrition (M_2S_1). It was on par with M_1S_3, M_1S_4, and M_2S_2.

At harvest, highest K uptake was noticed under minimum tillage (M_2) with an uptake of 59.6 kg K/ha, followed by the uptake recorded under CT (55.4 kg K/ha) in 2017. The lowest uptake registered during 2017 was under zero tillage (50.3 kg K/ha). In 2018, highest uptake of potassium (54 kg K/ha) was recorded under conventional tillage system (M_3), while MT and ZT recorded lower uptake of potassium and they were at par.

In 2017, soil test based nutrition under MT (M_2S_1) recorded higher uptake of K (70.3 kg/ha) and was on par to M_2S_4 (69.1 kg K/ha), M_3S_3 (65.1 kg K/ha), M_1S_5 (63.8 kg K/ha), and M_2S_5 (63.7 kg K/ha). In 2018, highest K uptake (65.9 kg K/ha) was noticed under conventional tillage with K: $MgSO_4$ @ 40:80 kg/ha (M_3S_5), followed by M_2S_4 and M_3S_4.

In pooled analysis highest uptake (54.7 kg/ha) was noticed under conventional tillage. Higher uptake of potassium was registered with application of K: $MgSO_4$ @ 40:60 and 40:80 kg/ha. Treatments such as M_2S_4, M_3S_4 and M_3S_5 registered higher uptake of potassium.

Table 46. Effect of tillage and nutrients on potassium uptake (kg/ha) by cowpea

Treatments	**Plant (30 DAS)**		**Plant (Harvest)**		
Tillage	**2017**	**2018**	**2017**	**2018**	**Pooled**
M_1- Zero tillage (ZT)	5.9^{c}	7.0^{c}	50.3^{c}	38.4^{b}	44.4^{c}
M_2- Minimum tillage (MT)	8.7^{b}	10.4^{b}	59.6^{a}	40.4^{b}	50.0^{b}
M_3- Conventional tillage (CT)	13.4^{a}	15.1^{a}	55.4^{b}	54.0^{a}	54.7^{a}
C.D (0.05)	**0.8**	**1.4**	**3.5**	**2.5**	**2.4**
SE(m)	**2.8**	**0.5**	**1.2**	**1.7**	**0.8**
S_1- Soil test based recommendations	10.2^{ab}	10.1^{c}	55.0^{bc}	38.2^{d}	46.6^{b}
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	11.2^{a}	8.5^{d}	47.9^{d}	42.7^{c}	45.3^{b}
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	9.1^{bc}	12.7^{a}	51.3^{c}	41.0^{c}	46.1^{b}
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	8.9^{c}	10.8^{bc}	58.9^{ab}	51.9^{a}	55.4^{a}
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	7.4^{d}	12.1^{ab}	62.5^{a}	47.6^{b}	55.1^{a}
C.D (0.05)	**1.1**	**1.8**	**4.5**	**3.2**	**3.0**
SE(m)	**3.6**	**0.6**	**1.6**	**2.3**	**1.0**
M_1S_1: ZT + Soil test based	7.8^{e}	7.3^{ef}	51.9^{ef}	43.3^{e}	47.6^{efg}
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	5.4^{f}	8.1^{def}	39.0^{g}	34.4^{hi}	36.7^{i}
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	7.8^{e}	8.4^{def}	45.4^{fg}	36.2^{gh}	40.8^{hi}
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	5.6^{f}	5.5^{fg}	51.3^{ef}	41.0^{efg}	46.1^{fg}
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	2.8^{g}	5.5^{fg}	63.8^{abc}	37.3^{fgh}	50.6^{def}
M_2S_1: MT + Soil test based	8.4^{cde}	4.1^{g}	70.3^{a}	28.9^{i}	49.6^{def}
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	8.2^{de}	6.2^{fg}	51.7^{ef}	40.6^{efg}	46.2^{fg}
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	9.9^{cd}	18.0^{a}	43.4^{g}	37.6^{fgh}	40.5^{hi}
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	7.9^{e}	13.8^{b}	69.1^{a}	55.4^{bc}	62.2^{ab}
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	9.4^{cde}	9.8^{cde}	63.7^{abc}	39.7^{efgh}	51.7^{de}
M_3S_1: CT + Soil test based	14.3^{b}	18.7^{a}	42.8^{g}	42.5^{ef}	42.6^{gh}
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	19.9^{a}	11.1^{bcd}	52.8^{def}	53.0^{cd}	52.9^{cd}
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	9.7^{cd}	11.8^{bc}	65.1^{ab}	49.2^{d}	57.2^{bc}
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	13.2^{b}	13.1^{b}	56.4^{cde}	59.4^{b}	57.9^{abc}
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	10.1^{c}	21.0^{a}	60.1^{bcd}	65.9^{a}	63.0^{a}
C.D (0.05)	**1.9**	**3.1**	**7.9**	**5.6**	**5.3**
SE(m)	**6.4**	**1.1**	**2.7**	**3.9**	**1.8**

d. Calcium uptake

Influence of different tillage practices such as conventional tillage, minimum tillage, and zero tillage, as well as K-$MgSO_4$ doses and their interaction were found to be non-significant with respect to calcium uptake at 30 DAS during both years of study. However, at harvest tillage and treatments differed significantly **(Table 47)**.

In 2017, highest uptake was recorded in MT (27.9 kg/ha), followed by uptake recorded in ZT, and CT system resulted in lowest calcium uptake (18.2 kg/ha) in 2017. In 2018, ZT and CT resulted in higher Ca uptake, (24.2 kg/ha and 22.9 kg/ha respectively). Lowest uptake was observed in minimum tillage system (17.9 kg/ha).

It could be noted that at harvest, application of nutrients according to soil test results (S_1) resulted in highest uptake (26.2 kg/ha) during 2017 while in 2018 S_1 and S_2 resulted in higher Ca uptake at harvest (27.4 kg/ha and 24.7 kg/ha respectively). Rest of the treatments registered lower values for uptake. Lowest uptake during 2017 was observed in K: $MgSO_4$ @ 40:60 kg/ha (S_4) (20.9 kg/ha).

ZT and MT resulted in higher uptake of calcium on pooling of data. The lowest was noticed under CT. Application of soil test based nutrition resulted in highest Ca uptake. Treatments M_1S_1 (15.7 kg/ha) and M_2S_2 (14.6 kg/ha) registered higher uptake.

e. Magnesium uptake

Data on magnesium uptake by cowpea at 30 DAS and at harvest during 2017 and 2018 are furnished in **Table 48.** Data showed that various tillage systems such as zero tillage, minimum tillage and conventional tillage, potassium and magnesium sulphate doses had significant effect on magnesium uptake during both years at both stages of crop growth. Conventional tillage (M_3) resulted in highest uptake at 30 DAS and harvest (3.2 kg/ha and 6.5 kg/ha respectively), followed by MT (M_2) and lowest uptake (1.7 kg/ha and 4.1 kg/ha respectively) was observed under zero tillage system

Table 47. Effect of tillage and nutrients on calcium uptake (kg/ha) by cowpea

Treatments	Plant (30 DAS)		Plant (Harvest)		
Tillage	**2017**	**2018**	**2017**	**2018**	**Pooled**
M_1- Zero tillage (ZT)	3.3	9.8	23.3^{b}	24.2^{a}	12.5^{a} (23.8)
M_2- Minimum tillage (MT)	4.3	10.5	27.9^{a}	17.9^{b}	12.9^{a}(22.9)
M_3- Conventional tillage (CT)	5.7	13.7	18.2^{c}	22.9^{a}	10.4^{b}(20.5)
C.D (0.05)	**NS**	**NS**	**1.1**	**2.1**	**0.7**
SE(m)	**0.1**	**0.5**	**0.4**	**0.7**	**0.2**
S_1- Soil test based recommendations	4.4	10.0	26.2^{a}	27.4^{a}	14.0^{a}(26.8)
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	5.3	9.4	22.4^{b}	24.7^{a}	12.3^{b}(23.6)
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	4.9	11.7	22.6^{b}	19.5^{b}	11.4^{bc}(21.1)
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	4.1	10.7	20.9^{c}	19.2^{b}	10.7^{c}(20.0)
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	3.5	11.7	23.6^{b}	17.4^{b}	11.3^{c}(20.5)
C.D (0.05)	**NS**	**NS**	**1.4**	**2.7**	**0.9**
SE(m)	**0.2**	**0.6**	**0.5**	**0.9**	**0.3**
M_1S_1: ZT + Soil test based	3.9	6.0	25.7^{cd}	37.4^{a}	15.7^{a}(31.5)
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	4.0	8.5	20.8^{fgh}	22.6^{bcd}	11.3^{efg}(21.7)
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	4.0	11.4	25.4^{de}	22.4^{bcd}	12.8^{cdef}(23.9)
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	2.6	5.8	21.7^{fg}	18.2^{def}	10.8^{bcde}(19.9)
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	1.9	7.6	23.1^{ef}	20.5^{cde}	11.7^{defg}(21.8)
M_2S_1: MT + Soil test based	4.5	5.9	31.2^{a}	11.5^{g}	12.9^{cdef}(21.3)
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	3.9	8.4	29.3^{ab}	24.6^{bc}	14.6^{ab}(26.9)
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	5.8	15.6	22.1^{fg}	16.9^{ef}	10.7^{gh}(19.5)
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	3.5	11.3	27.9^{bc}	20.7^{cde}	13.4^{bcd}(24.3)
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	3.9	11.5	29.3^{ab}	15.6^{fg}	13.0^{bcde}(22.4)
M_3S_1: CT + Soil test based	4.7	18.2	21.6^{fg}	33.4^{a}	13.5^{bc}(27.5)
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	7.9	11.3	17.2^{i}	26.9^{b}	10.8^{gh}(22.0)
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	4.9	8.1	20.4^{gh}	19.3^{def}	10.6^{gh}(19.8)
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	6.3	15.0	13.0^{j}	18.6^{def}	7.9^{i}(15.8)
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	4.6	16.0	18.5^{hi}	16.1^{efg}	9.3^{hi}(17.3)
C.D (0.05)	**NS**	**NS**	**2.4**	**4.6**	**1.6**
SE(m)	**0.3**	**1.0**	**0.8**	**1.6**	**0.5**

*R (weighted MSE) transformed values, original values in parentheses. In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

(M_1) during 2017 and 2018.

K and Mg doses were also found to bring about significant influence on magnesium uptake during both years at initial stages of crop growth. Higher uptake was noted in S_1, S_2, and S_3. S_4 and S_5 were found to record lower Mg uptake (2.2 kg/ha). In next year, application K: Mg @ 40:80 kg/ha registered highest magnesium uptake. All the treatments, except S_2, maintained parity to each other at this stage in 2018. Lowest uptake (4.4 kg/ha) was observed in K: $MgSO_4$ @ 20:60 kg/ha (S_2).

Significant influence on Mg uptake due to interaction of tillage and nutrients was noticed in both years at 30 DAS. In 2017 highest magnesium uptake (4.3 kg/ha) was noticed under CT with soil test based nutrient application (M_3S_1) and was followed by application of K: $MgSO_4$ @ 20:60 kg/ha (M_3S_2). The lowest uptake was recorded under zero tillage system with application of K @ 40 kg/ha and $MgSO_4$ @ 80 kg/ha (M_1S_5). In second year higher uptake of 9.0 kg/ha was recorded in K: $MgSO_4$ applied @ 40:80 kg/ha under CT (M_3S_5) which was on par to MT + K: $MgSO_4$ @ 40:80 kg/ha (M_2S_5) as well as to CT along with application of nutrients in accordance to soil test results (M_3S_1) and uptake recorded were 7.7 kg/ha and 7.6 kg/ha respectively.

At later stages (harvest), MT resulted in highest uptake (21.6 kg/ha) in 2017. It was followed by ZT and CT and they were at par to each other. In 2018, highest uptake was noticed in CT (19.5 kg/ha) while the other tillage systems (ZT and MT) resulted in uptake which was comparable to each other. Among various nutrient doses, soil test based nutrition where K: $MgSO_4$ @ 11-13: 80 kg/ha recorded highest uptake during the period of study. Rest of the treatments registered lower uptake.

During 2017, highest uptake at harvest (25.9 kg/ha and 24.9 kg/ha) was observed under MT with soil test based nutrition (M_2S_1) and MT with K: $MgSO_4$ @ 40:60 kg/ha (M_2S_4), whereas in the following year soil test based nutrition under ZT and CT (M_1S_1 and M_3S_1) as well as in CT with K: $MgSO_4$ @ 20:60 kg/ha resulted in higher Mg uptake values and was on par to each other.

In pooled data, MT resulted in highest uptake (16.8 kg/ha) and the lowest uptake of Mg was recorded in ZT. Nutrient application based on soil test registered highest Mg uptake. Magnesium uptake was observed higher under soil test based nutrition under ZT, MT, and CT, as well as in MT with K: $MgSO_4$ @ 40:60 kg/ha.

f. Sulphur uptake

Data on uptake of sulphur estimated at initial and harvesting growth stage of cowpea during both years of experiment are furnished in **Table 49.**

Various types of tillage systems, K and $MgSO_4$ doses, as well as their interaction did not have significant influence on sulphur uptake at 30 DAS in both years of study. The average value for uptake recorded for the two years were 1.7 kg/ha and 2.6 kg/ha respectively. It could be noted that overall, sulphur uptake increased in second year of experiment compared to first year.

At harvesting stage, sulphur uptake varied significantly due to different types of tillage and potassium and magnesium doses during the period of study. Among various tillage systems highest S uptake was recorded under ZT (20.8 kg/ha) during first year, while in 2018, CT resulted in higher uptake (16.6 kg/ha) which was at par with MT (15.2 kg/ha), which in turn was at par with ZT.

Application of nutrients in accordance with soil test results (K: $MgSO_4$ @ 10.8: 80 kg/ha) resulted in highest uptake (20.3 kg/ha), while the lowest uptake (11.2 kg/ha) could be observed in K: $MgSO_4$ @ 20:60 kg/ha (S_2) during 2017. In 2018, higher uptake (17.2 kg/ha) was recorded in K: $MgSO_4$ @ 20:80 kg/ha (S_3) and it was on par to S_2 and S_5.

In interactions, during 2017, ZT along with soil test based nutrition resulted in highest sulphur uptake (28.9 kg/ha). Lower uptake was noticed in M_3S_2 and M_3S_3. During 2018, higher uptake was recorded under M_1S_3, M_2S_2, M_2S_3, M_3S_1, M_3S_2, M_3S_3 and M_1S_4.

Table 48. Effect of tillage and nutrients on magnesium uptake (kg/ha) by cowpea

Treatments	Plant (30 DAS)		Plant (Harvest)		
Tillage	**2017**	**2018**	**2017**	**2018**	**Pooled**
M_1- Zero tillage (ZT)	1.7[c]	4.1[c]	18.1[b]	15.9[b]	14.6[c](17.0)
M_2- Minimum tillage (MT)	2.3[b]	5.0[b]	21.6[a]	16.2[b]	16.8[a](18.9)
M_3- Conventional tillage (CT)	3.2[a]	6.5[a]	18.2[b]	19.5[a]	15.5[b](18.7)
C.D (0.05)	**0.2**	**0.7**	**0.6**	**1.6**	**0.6**
SE(m)	**0.1**	**0.2**	**0.2**	**0.6**	**0.2**
S_1- Soil test based recommendations	2.6[a]	5.0[b]	23.0[a]	20.1[a]	18.5[a](21.6)
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	2.6[a]	4.4[c]	17.9[c]	17.2[b]	14.8[b](17.6)
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	2.4[ab]	5.3[b]	18.5[c]	16.4[bc]	15.0[b](17.5)
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	2.2[b]	4.9[b]	17.8[c]	17.8[b]	14.9[b](17.8)
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	2.2[b]	6.5[a]	19.5[b]	14.5[c]	15.1[b](17.0)
C.D (0.05)	**0.3**	**0.8**	**0.8**	**2.0**	**0.8**
SE(m)	**0.1**	**0.3**	**0.3**	**0.8**	**0.3**
M_1S_1: ZT + Soil test based	1.6[f]	4.1[fgh]	21.0[cd]	23.3[a]	18.1[ab](22.2)
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	2.3[de]	4.1[fgh]	17.1[f]	11.6[f]	13.0[fg](14.4)
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	2.2[e]	6.0[cd]	17.7[f]	14.9[def]	14.2[def](16.3)
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	1.4[f]	3.4[h]	15.5[g]	16.7[cde]	13.3[efg](16.1)
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.9[g]	2.8[h]	19.2[e]	13.0[f]	14.6[cde](16.1)
M_2S_1: MT + Soil test based	1.8[ef]	3.3[h]	25.9[a]	13.5[ef]	18.7[ab](19.7)
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	1.9[ef]	3.6[gh]	22.9[b]	18.0[cd]	18.0[fg](20.5)
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	2.7[cd]	5.6[cde]	14.8[gh]	17.6[cd]	13.0[ffg](16.2)
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	2.2[e]	5.0[defg]	24.9[a]	18.3[cd]	19.3[a](21.6)
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	2.8[c]	7.7[ab]	19.4[e]	13.5[ef]	14.8[cd](16.5)
M_3S_1: CT + Soil test based	4.3[a]	7.6[ab]	22.0[bc]	23.4[a]	18.7[ab](22.7)
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	3.6[b]	5.4[cdef]	13.5[hi]	21.9[ab]	13.3[fg](17.7)
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	2.3[de]	4.2[efgh]	23.0[b]	16.6[cde]	17.7[b](19.8)
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	2.9[c]	6.4[bc]	13.0[i]	18.5[bc]	12.2[g](15.8)
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	2.8[c]	9.0[a]	19.7[de]	17.0[cde]	15.9[c](18.4)
C.D (0.05)	**0.5**	**1.5**	**1.4**	**3.5**	**1.3**
SE(m)	**0.2**	**0.5**	**0.5**	**1.3**	**0.5**

*R (weighted MSE) transformed values, original values in parentheses. In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

Table 49. Effect of tillage and nutrients on sulphur uptake (kg/ha) by cowpea

Treatments	30 DAS		Harvest		
Tillage	**2017**	**2018**	**2017**	**2018**	**Pooled**
M_1- Zero tillage (ZT)	1.0	2.2	20.8[a]	13.8[b]	8.7[a](17.3)
M_2- Minimum tillage (MT)	1.8	2.6	17.2[b]	15.2[ab]	7.6[b](16.2)
M_3- Conventional tillage (CT)	2.8	4.2	12.8[c]	16.6[a]	6.6[c](14.7)
C.D (0.05)	**NS**	**NS**	**1.3**	**2.0**	**0.5**
SE(m)	**0.3**	**0.1**	**0.5**	**0.5**	**0.2**
S_1- Soil test based recommendations	1.8	2.7	20.3[a]	14.1[b]	10.0[a](17.2)
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	3.0	2.2	11.2[d]	16.2[ab]	6.1[c](13.7)
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	1.5	3.3	16.5[bc]	17.2[a]	7.8[b](16.9)
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	1.6	2.5	15.0[c]	13.5[c]	6.7[c](14.3)
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	1.5	4.3	17.4[b]	15.2[ab]	7.7[b](16.3)
C.D (0.05)	**NS**	**NS**	**1.7**	**2.6**	**0.7**
SE(m)	**0.4**	**0.2**	**0.6**	**0.7**	**0.2**
M_1S_1: ZT + Soil test based	1.2	2.4	28.9[a]	15.6[bcd]	10.9[a](22.3)
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	1.2	2.2	15.3[e]	13.0[cdef]	6.7[de](14.2)
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	1.0	2.8	19.4[c]	17.2[abc]	8.6[bc](18.3)
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	1.0	1.6	17.6[cde]	10.1[f]	6.8[de](13.9)
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	0.5	2.1	17.8[cde]	13.4[cdef]	7.5[cd](15.6)
M_2S_1: MT + Soil test based	1.9	1.6	23.7[b]	10.8[ef]	8.6[bc](17.3)
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	1.0	1.7	10.7[f]	15.1[bcde]	5.8[e](12.9)
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	2.1	3.5	20.3[c]	17.3[abc]	8.9[b](18.8)
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	2.0	2.7	15.7[de]	17.7[ab]	7.7[cd](16.7)
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	1.9	3.6	15.7[de]	15.0[bcde]	7.2[d](15.4)
M_3S_1: CT + Soil test based	2.1	4.1	16.2[de]	16.0[abcd]	7.5[cd](16.1)
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	6.6	2.8	7.6[g]	20.3[a]	5.9[e](14.0)
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	1.6	3.6	9.8[fg]	17.1[abcd]	5.9[e](13.5)
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	1.9	3.2	11.9[f]	12.6[def]	5.6[e](12.3)
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	2.0	7.0	18.5[cd]	17.2[abc]	8.3[bc](17.9)
C.D (0.05)	**NS**	**NS**	**3.0**	**4.6**	**1.5**
SE(m)	**0.7**	**0.3**	**1.0**	**1.2**	**0.4**

*R (weighted MSE) transformed values, original values in parentheses. In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

Zero tillage registered highest sulphur uptake on pooling of the data, and the lowest uptake was noticed under conventional tillage. Application of nutrients in accordance to soil test results recorded highest sulphur uptake and ZT with soil test based nutrition recorded highest uptake of sulphur.

4.2.8 Soil analysis

A. Soil pH, EC and organic carbon content

Soil pH, EC and organic carbon was estimated before sowing and after harvest of the crop in period of study, 2017 and 2018 and the data are furnished in **Table 50.** . Initial soil pH was 4.7 and 4.5 in 2017 and 2018 respectively.

During the period of study various tillage practices, K-$MgSO_4$ doses failed to produce significant variation in soil pH, EC and organic carbon content. Average soil pH was 5.2, while electrical conductivity was 1.40 dS/m, and the average organic carbon content after the harvest of crop was 0.78 %.

B. Available nitrogen

Data pertaining the available nitrogen content of soils during experiments of 2017 and 2018 are furnished in **Table 51.** Various tillage practices, nutrient doses and their interactions resulted in significant difference in available nitrogen content of soil in both years under experiment. The soil available nitrogen noticed in post-harvest analysis of soil in 2018 was higher, compared to that recorded in 2017.

In 2017 and 2018, among various tillage practices MT (M_2) resulted in highest available nitrogen content (179.5 kg/ha and 245.5 kg/ha respectively). Conventional tillage and zero tillage were statistically on par in 2017. Meanwhile, in second year minimum tillage and conventional tillage differed statistically and the lowest content (222.4 kg/ha) was recorded in zero tillage.

Table 50. Effect of tillage and nutrients on soil pH, soil EC, and soil organic carbon content

Treatments	**pH**		**EC** dS/m		**Organic C %**	
Tillage	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
M_1- Zero tillage (ZT)	5.2	5.1	1.37	1.39	0.86	0.68
M_2- Minimum tillage (MT)	5.4	5.2	1.42	1.32	0.83	0.74
M_3- Conventional tillage (CT)	5.3	5.4	1.43	1.34	0.86	0.73
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.08**	**0.05**	**0.003**	**0.002**	**0.01**	**0.01**
S_1- Soil test based recommendations	5.6	5.2	1.54	1.48	0.80	0.72
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	5.2	5.0	1.39	1.40	0.88	0.68
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	5.6	5.4	1.22	1.05	0.81	0.77
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	5.0	5.4	1.42	1.43	0.84	0.77
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	5.1	5.2	0.13	0.08	0.93	0.62
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.10**	**0.06**	**0.004**	**0.003**	**0.01**	**0.01**
M_1S_1: ZT + Soil test based	5.6	5.3	1.65	1.57	0.91	0.65
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	5.4	5.2	1.51	1.50	0.85	0.65
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	5.6	5.2	1.22	1.26	0.78	0.77
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	4.9	5.2	1.17	1.25	0.92	0.71
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	4.6	4.7	1.33	1.38	0.85	0.59
M_2S_1: MT + Soil test based	5.9	5.0	1.35	1.21	0.75	0.66
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	5.6	5.4	1.75	1.58	0.86	0.73
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	5.8	5.9	1.43	1.43	0.85	0.82
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	4.7	4.9	1.12	0.90	0.70	0.83
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	4.7	4.9	1.46	1.46	0.99	0.66
M_3S_1: CT + Soil test based	5.3	5.3	1.41	1.41	0.73	0.86
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	4.5	4.4	1.37	1.36	0.92	0.65
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	5.3	5.3	1.51	0.151	0.79	0.74
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	5.6	6.0	1.38	0.100	0.90	0.77
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	5.9	6.0	1.46	0.144	0.93	0.62
C.D (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.17**	**0.11**	**0.007**	**0.004**	**0.01**	**0.01**

Application of K: $MgSO_4$ @ 20:80 kg/ha (S_3) resulted in highest available nitrogen content (191.7 kg/ha) in first year, and all the other treatments were at par. Whereas in second year K: $MgSO_4$ @ 40:80 kg/ha (S_5) resulted in higher available N and it was at par to S_3 (243.6 kg/ha). Lower available soil nitrogen (216.9 kg/ha and 221.2 kg/ha), was recorded under soil test based nutrient application (S_1) and K: $MgSO_4$ @ 20:60 kg/ha (S_2).

Effect of interaction between tillage and nutrient doses varied significantly with respect to available soil N in both years. Significantly higher soil available nitrogen (225.3 kg/ha) was recorded in K: $MgSO_4$ supplied @ 40:80 kg/ha under minimum tillage (M_2S_5) in first experiment, which was on par to available N content 205.1 kg/ha noted under conventional tillage with K: $MgSO_4$ supplied @ 20:80 kg/ha (M_3S_3). While in the following year, minimum tillage with K: $MgSO_4$ supplied @ 20:80 kg/ha (M_2S_3) resulted in highest available N (274.4 kg/ha), which was on par to available N (271.4 kg/ha) noted in conventional tillage with K: $MgSO_4$ supplied @ 40:80 kg/ha (M_1S_5). The lowest available N (97.3 kg/ha) was resulted from CT with K: $MgSO_4$ @ 40:80 kg/ha (M_3S_5) in first year, while in the following year, lower N was recorded under ZT along with soil test based nutrient application (M_1S_1), K: $MgSO_4$ @ 20:80 kg/ha (M_1S_2). CT with soil test based nutrition (M_3S_1) and application of K: $MgSO_4$ @ 20:60 kg/ha (M_3S_3).

Pooling of the data showed that, minimum tillage practice recorded significantly highest available nitrogen content in soil (212.5 kg/ha). Which was followed by ZT and CT (193.2 kg/ha and 193.1 kg/ha respectively) and they were at par. Application of K_2O @ 20 kg/ha along with $MgSO_4$ @ 80 kg/ha registered highest available N (217.7 kg/ha), followed by the treatment which received K_2O @ 40 kg/ha along with $MgSO_4$ @ 80 kg/ha (S_5). Interaction effect was also significant and adoption of MT along with application of K_2O @ 20 kg/ha along with $MgSO_4$ @ 80 kg/ha (M_2S_3) registered highest available soil nitrogen (249.9 kg/ha).

E. Available phosphorus

Data on available phosphorus content of soil after experiments in 2017 and 2018 are furnished in **Table 51**. During both years, tillage practices and K and $MgSO_4$ doses failed to create significant variation with respect to available phosphorus in soil. Average phosphorus content in soil was 20.9 kg/ha and 31.5 kg/ha.

F. Available potassium

Available potassium in soil during 2017 and 2018 is furnished in **Table 52.** There observed significant variation in available K under various tillage practices and K-Mg doses in both the years.

Among tillage treatments, during 2017, conventional tillage (M_3) recorded highest values *i.e.* 199.3 kg/ha, followed by zero tillage (M_1) and minimum tillage (M_2) which was on par to each other. The lower values (147.1 kg/ha and 148.9 kg/ha) were recorded under MT and ZT. In second year higher values for available potassium (287.9 kg/ha) was noted in CT which was at par to MT system (250.6 kg/ha). However, the lowest value (178.3 kg/ha) was noticed in ZT.

Various levels of K and $MgSO_4$ influenced available K content of soil significantly during the period of study. In first year, soil test based nutrient application (S_1) resulted in higher available K (188.4 kg/ha) which was on par to application of K: $MgSO_4$ @ 20:60 kg/ha (S_2). The lower K content was registered from plots which received K: $MgSO_4$ @ 20:80 (S_3), 40:60 (S_4), 40:80 (S_5) kg/ha. While in the second year, soil test best nutrition (S_1) resulted in lower values.

Table 51. Effect of tillage and nutrients on available nitrogen, and phosphorus content in 2017-18 and 2018-19

Treatments	**N (kg/ha)**			**P (kg/ha)**		
Tillage	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
M_1- Zero tillage (ZT)	164.0^{b}	222.4^{c}	17.1^{b} (193.2)	20.0	28.7	24.4
M_2- Minimum tillage (MT)	179.5^{a}	245.5^{a}	18.7^{a} (212.5)	18.2	34.6	26.4
M_3- Conventional tillage (CT)	154.3^{b}	231.9^{b}	17.4^{b} (193.1)	24.4	31.0	27.7
C.D (0.05)	**12.0**	**6.9**	**0.6**	**NS**	**NS**	**NS**
SE(m)	**4.1**	**2.4**	**0.2**	**0.8**	**0.2**	**0.5**
S_1- Soil test based recommendations	163.7^{b}	216.9^{c}	16.9^{c} (190.3)	19.4	33.4^{a}	26.4
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	158.0^{b}	221.2^{c}	16.9^{c} (189.6)	22.4	30.7^{b}	26.5
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	191.7^{a}	243.6^{a}	19.2^{a} (217.7)	21.3	33.2^{a}	27.2
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	164.6^{b}	233.9^{b}	17.6^{c} (199.3)	21.0	30.5^{b}	25.7
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	151.6^{b}	250.9^{a}	18.0^{b} (201.2)	20.3	29.7^{b}	24.9
C.D (0.05)	**15.5**	**8.9**	**0.7**	**NS**	**NS**	**NS**
SE(m)	**5.3**	**3.1**	**0.3**	**1.0**	**0.4**	**0.6**
M_1S_1: ZT + Soil test based	168.2^{cde}	204.4^{g}	16.4^{efg} (186.3)	22.9	25.5	24.2
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	145.6^{de}	221.2^{def}	16.6^{defg}(183.4)	16.1	25.9	21.0
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	144.8^{e}	212.8^{efg}	16.1^{fg} (178.8)	22.3	27.4	24.9
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	177.2^{c}	227.8^{cde}	17.9^{cd} (202.5)	16.4	32.0	24.2
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	184.4^{bc}	246.0^{b}	18.4^{bc} (215.2)	22.8	32.8	27.8
M_2S_1: MT + Soil test based	144.0^{e}	238.9^{bc}	17.5^{cdef}(191.5)	17.4	45.4	31.4
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	182.9^{bc}	240.8^{bc}	18.8^{bc} (211.9)	16.9	37.9	27.4
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	225.3^{a}	274.4^{a}	22.0^{a} (249.9)	20.9	29.9	25.4
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	171.8^{c}	238.2^{bc}	17.6^{cde} (205.0)	17.4	33.0	25.2
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	173.2^{c}	235.2^{bcd}	17.9^{cd} (204.2)	19.4	26.9	23.2
M_3S_1: CT + Soil test based	178.9^{bc}	207.3^{fg}	16.9^{def} (193.1)	18.9	29.1	24.0
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	145.4^{de}	201.6^{g}	15.5^{g} (173.5)	31.2	28.2	28.2
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	205.1^{ab}	243.6^{b}	19.6^{g} (224.3)	20.8	42.2	31.5
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	144.8^{e}	235.8^{bcd}	17.3^{b} (190.3)	30.4	26.6	26.6
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	97.3^{f}	271.4^{a}	17.8^{cde} (184.4)	19.4	29.1	24.2
C.D (0.05)	**26.8**	**15.5**	**1.3**	**NS**	**NS**	**NS**
SE(m)	**9.2**	**5.3**	**0.4**	**1.7**	**0.6**	**1.1**

*R (weighted MSE) transformed values, original values in parentheses. In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

The interaction effect was found to be significant during both years. During first year, CT with K: $MgSO_4$ applied @ 40:80 kg/ha (M_3S_5) recorded higher available K (245.5 kg/ha). It was on par (available K, 221.7 kg/ha) with K: $MgSO_4$ applied @ 40:60 kg/ha under CT (M_3S_4). Soil test based nutrient application with various types of tillage (M_1S_1, M_2S_1, and M_3S_1) resulted in on par values. K: $MgSO_4$ @ 40:80 kg/ha under zero tillage resulted in lowest available K (83 kg/ha). It could be noted that, available K in soil recorded under ZT with various K and Mg doses decreased gradually from M_1S_1, M_1S_2 M_1S_3 M_1S_4 and M_1S_5.

In second year, application of K: $MgSO_4$ @ 40:60 kg/ha under CT (M_3S_4) recorded higher available K which was on par to available K recorded (306.4 kg/ha) in application of K: $MgSO_4$ @ 20:80 kg/ha under CT (M_3S_3). Nonetheless, the lower values were recorded under zero tillage system along with various doses of K and $MgSO_4$ and they were at par to each other and was at par to M_2S_1.

Perusal of pooled data revealed that conventional tillage practices registered highest available K content (243.6 kg/ha) whereas available K noted under zero tillage system was the lowest (163.6 kg/ha). Nutrient combinations however failed to effect available K content significantly. Interaction of conventional tillage to K: $MgSO_4$ @ 40:60 and 40:80 kg/ha under conventional tillage (M_3S_4 and M_3S_5) recorded higher values for available K. The same nutrient combination under zero tillage resulted in lower values for available K.

G. Calcium

Calcium content in soil during both years varied significantly due to various tillage practices during the period of study, while influence of potassium and magnesium doses on available calcium was significant only during second year. However during both years, there found significant difference in calcium in soil due to interaction of tillage and nutrients **(Table 52)**.

During first year, CT was superior to other treatments with highest available Ca content in soil (279.4 mg/kg) as observed in case of available P and K content in soil. It was followed by Ca content under MT (247.8 mg/kg) and ZT (247.8 mg/kg) and they were at par to each other. During second year, same trend was noticed with CT resulted in highest calcium content (279.7 mg/kg). Followed by Ca content under minimum tillage (249.2 mg/kg) and zero tillage (248.2 mg/kg), which shown parity to each other.

Significant variation in soil Ca due to different K- $MgSO_4$ doses was not observed during first year. In second year, soil test based nutrition (S_1) registered highest value for available Ca (266.1 mg/kg). It was followed by soil Ca recorded in (263.8 mg/kg) application of K: $MgSO_4$ @ 20:80 kg/ha (S_3). Calcium content in soil recorded lowest (249.3 mg/kg) in application of K: $MgSO_4$ @ 20:60 kg/ha (S_2).

In interactions, CT along with K: $MgSO_4$ @ 40:80 kg/ha (M_3S_5) with 325.3 mg/kg soil, resulted in significantly higher among all the other interaction treatments. This was on par with K: $MgSO_4$ @ 20:80 kg/ha under conventional tillage (M_3S_3). However, K: $MgSO_4$ @ 20:60 kg/ha in conventional tillage (M_3S_2) showed least soil calcium content (198.4 mg/kg). In second year of experiment application of higher dose of K: $MgSO_4$ *i.e.* @ 40:80 kg/ha under CT (M_3S_5) recorded highest amount of calcium (325.5 mg/kg), followed by which was the application of K: $MgSO_4$ @ 20:80 kg/ha under CT (M_3S_3). However, conventional tillage along with application of K: $MgSO_4$ @ 20:60 kg/ha (M_3S_2) recorded the lowest content (M_3S_2).

Table 52. Effect of tillage and nutrients on available potassium and calcium content in 2017-18 and 2018-19

Treatments	K (kg/ha)			Ca (mg/kg)		
Tillage	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
M_1- Zero tillage (ZT)	148.9^{b}	178.3^{b}	6.7 (163.6)^{c}	247.8^{b}	248.2^{b}	403.7(248.0)^{b}
M_2- Minimum tillage (MT)	147.1^{b}	250.6^{a}	7.5 (198.8)^{b}	248.9^{b}	249.2^{b}	405.4(249.0)^{b}
M_3- Conventional tillage (CT)	199.3^{a}	287.9^{a}	9.5(243.6)^{a}	279.4^{a}	279.7^{a}	455.0(279.5)^{a}
C.D (0.05)	**12.2**	**32.0**	**0.5**	**12.5**	**0.2**	**0.4**
SE(m)	**4.2**	**11.0**	**0.2**	**4.3**	**0.1**	**0.1**
S_1- Soil test based recommendations	188.4^{a}	194.7^{b}	8.1 (191.5)	265.8	266.1^{a}	432.9(266.0)^{a}
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	172.9^{a}	219.6^{b}	7.9 (196.2)	249.0	249.3^{e}	405.7(249.2)^{e}
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	157.0^{b}	253.9^{ab}	7.8 (205.5)	263.4	263.8^{b}	429.0(263.6)^{b}
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	154.9^{b}	274.6^{a}	8.0 (214.7)	260.3	260.7^{c}	424.1(260.5)^{c}
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	152.2^{b}	252.0^{ab}	7.7 (202.1)	254.9	255.2^{d}	415.2(255.0)^{d}
C.D (0.05)	**15.7**	**41.3**	**NS**	**NS**	**0.3**	**0.5**
SE(m)	**5.4**	**14.1**	**0.3**	**5.5**	**0.1**	**0.2**
M_1S_1: ZT + Soil test based	197.8^{bc}	172.8^{fg}	8.1(185.3)^{bc}	265.8^{bc}	266.0^{h}	432.9(265.9)^{h}
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	184.2^{cd}	164.6^{fg}	7.6(174.4)^{bcd}	270.6^{bc}	270.9^{g}	440.8(270.8)^{g}
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	160.8^{de}	186.9^{efg}	7.2(173.9)^{cd}	247.5^{cd}	247.8^{j}	403.2(247.6)^{j}
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	118.4^{g}	155.0^{g}	5.5(136.7)^{e}	228.5^{de}	228.8^{l}	372.2(228.6)^{l}
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	83.0^{h}	212.1^{def}	5.1(147.5)^{e}	226.6^{de}	226.9^{m}	369.2(226.8)^{m}
M_2S_1: MT + Soil test based	173.0^{cde}	184.7^{efg}	7.5(178.9)^{bcd}	249.5^{cd}	249.8^{i}	406.4(249.6)^{i}
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	149.5^{ef}	258.6^{bcd}	7.7(204.0)^{bcd}	278.1^{b}	278.4^{e}	453.0(278.3)^{e}
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	160.2^{de}	268.4^{bcd}	8.1(214.3)^{bc}	232.4^{de}	232.6^{k}	378.6(232.5)^{k}
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	124.5^{fg}	291.2^{bc}	7.3(207.9)^{cd}	271.6^{bc}	271.9^{f}	442.4(271.8)^{f}
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	128.2^{fg}	250.0^{bcd}	6.9(189.1)^{d}	212.8^{ef}	213.0^{n}	346.6(212.9)^{n}
M_3S_1: CT + Soil test based	194.3^{c}	226.6^{cde}	8.7(210.4)^{b}	282.1^{b}	282.4^{c}	459.5(282.3)^{c}
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	184.8^{cd}	235.4^{bcde}	8.5(210.1)^{b}	198.4^{f}	198.6^{o}	323.2(198.5)^{o}
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	150.1^{ef}	306.4^{ab}	8.2(228.2)^{bc}	310.3^{a}	310.5^{b}	505.3(310.4)^{b}
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	221.7^{ab}	377.4^{a}	11.3(299.6)^{a}	280.9^{b}	281.1^{d}	457.5(281.0)^{d}
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	245.5^{a}	293.9^{bc}	11.0(269.7)^{a}	325.3^{a}	325.5^{a}	529.7(325.4)^{a}
C.D (0.05)	**26.8**	**15.5**	**1.2**	**27.9**	**0.5**	**0.9**
SE(m)	**9.3**	**24.6**	**0.4**	**9.6**	**0.2**	**0.315**

*R (weighted MSE) transformed values, original values in parentheses.

In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

From the pooled analysis it is clear that, conventional tillage practices registered higher soil calcium (279.5 mg/kg). It was followed by minimum tillage and zero tillage which were on par to each other. Effect of application of various nutrient combinations was also significant. Highest content was recorded with application of nutrients in accordance with soil test results. The lowest values were obtained when K_2O was applied @ 20 kg/ha with $MgSO_4$ @ 60 kg/ha (S_2). Among interactions, M_3S_5 resulted in highest soil calcium content and M_3S_2 recorded the lowest content.

H. Magnesium

Significant variation in magnesium content of soil due to various tillage systems, nutrient doses and their interactions was noticed during the period of study **(Table 53)**. Magnesium was found highest in soils (82.3 mg/kg and 82.9 mg/kg) under conventional tillage (M_3) and it was followed by Mg content (76.8 mg/kg and 77.2 mg/kg) in zero tillage (M_1) during both years. Zero tillage was on par to Mg recorded in minimum tillage (M_2) in 2017. While in 2018, minimum tillage registered the lowest (74.4 kg/ha) value for soil magnesium.

During first year, nutrient application in accordance to K: $MgSO_4$ @ 20:80 kg/ha (S_3) gave highest soil available Mg (85.2 mg/kg) which shown parity to soil Mg content (82.9 mg/kg) in plots which received soil test based nutrition (S_1) and to K: $MgSO_4$ @ 20:60 kg/ha (S_2). Lowest content (64.9 mg/kg) was recorded in soils under supply of K: $MgSO_4$ @ 40:60 kg/ha (S_4). Trend changed in second year, K: $MgSO_4$ @ 20:80 kg/ha (S_3) registered highest Mg content (85.6 mg/kg). This was followed by soil test based nutrient application (S_1), whereas the lowest content of magnesium (65.4 mg/kg) was recorded in treatment K: $MgSO_4$ @ 40:60 kg/ha (S_4) as observed in 2017.

Highest Mg content (105.8 mg/kg) was observed in soils under CT along with application of K: $MgSO_4$ @ 20:80 kg/ha (M_3S_3), followed by Mg content of soils (87.5 mg/kg) of MT with K: $MgSO_4$ @ 20:60 kg/ha (M_2S_2) during 2017. The lower content was recorded in MT with K: $MgSO_4$ @ 40:60 kg/ha (M_2S_4). In second year, CT with

K: $MgSO_4$ @ 20:80 kg/ha (M_3S_3) with a content of 106.4 mg/kg recorded highest soil Mg. Followed by MT along with $MgSO_4$ @ 20:60 kg/ha (M_2S_2). The lowest content (56.7 mg/kg) was observed in application of K: $MgSO_4$ @ 40:60 kg/ha under ZT (M_1S_4).

Perusal of the pooled analyzed data revealed that, highest magnesium content in soil was obtained under conventional tillage. Minimum tillage recorded the lowest soil magnesium content. Application of various nutrient doses also affected the soil magnesium content significantly. Highest values were registered under K: $MgSO_4$ @ 20:80 kg/ha, followed by soil test based nutrition. The lowest values were registered with application of K: $MgSO_4$ @ 40:60 kg/ha (S_4). Conventional tillage with K: $MgSO_4$ @ 20:80 kg/ha resulted in highest soil magnesium content, followed by M_2S_2. The lowest content was recorded under M_1S_4.

I. Sulphur

Available sulphur in soil varied significantly due to various tillage and nutrient doses as well as due to the interaction during the period of study **(Table 53)**. In first year, highest value for soil sulphur was observed under zero tillage soils (M_1). It is different from the trend observed in other macronutrients where, conventional tillage (M_3) resulted in highest available macro nutrients. However, in second year higher sulphur content in soil (9.6 mg/kg and 8 mg/kg) was recorded in MT and ZT which were at par.

In both the years, various nutrient doses found to influence soil sulphur content significantly. In first year, soil test based nutrient application (S_1) recorded highest soil sulphur (20.9 mg/kg) followed by treatment K: $MgSO_4$ @ 20:80 kg/ha (S_3) and the lowest content (12.3 mg/kg) was noted in K: $MgSO_4$ @ 20:60 kg/ha (S_2). In second year, K and Mg @ 40:80 kg/ha (S_5) registered higher sulphur content in soils, (10.8 mg/kg). This was on par with sulphur content (10.5 mg/kg and 8.8 mg/kg) recorded in application of K: $MgSO_4$ @ 20:80 kg/ha (S_3) and 20:60 kg/ha (S_2). The lowest sulphur content in soils (3.6 mg/kg) was recorded in K: $MgSO_4$ @ 40:60 kg/ha.

With regard to interaction effect, ZT with supply of nutrients based on soil test (M_1S_1) recorded highest soil available sulphur (43.1 mg/kg) in 2017. It was followed by sulphur content (27.1 mg/kg) registered under ZT with K: $MgSO_4$ @ 20:80 kg/ha (M_1S_3). However, the lowest soil S (4.1 mg/kg) was observed under MT with soil test based nutrient application (M_2S_1). While in the following year, sulphur content recorded under ZT with application of K: $MgSO_4$ @ 40:80 kg/ha (M_1S_5) registered higher available S content (16.7 mg/kg), which was on par to sulphur content recorded (14.2 mg/kg) under CT with K: $MgSO_4$ @ 20:80 kg/ha (M_1S_3). However, lower soil sulphur content was observed under ZT with K: $MgSO_4$ @ 40:60 kg/ha (M_1S_4). It shown parity to sulphur contents recorded in treatments such as minimum tillage (MT) along with K: $MgSO_4$ @ 40:60 kg/ha (M_2S_4), conventional tillage (CT) with K: $MgSO_4$ @ 20:60 kg/ha (M_3S_2), ZT with soil test based nutrient application (M_1S_1), and ZT with K: $MgSO_4$ @ 20:80 kg/ha (M_3S_3) with a sulphur content of 3.1 mg/kg, 3.7 mg/kg, 4.0 mg/kg, and 4.2 mg/kg respectively.

Pertaining to the pooled data, zero tillage resulted in highest soil sulphur content. Followed by CT and the lowest was noticed under MT. Among nutrient doses, soil test based nutrition which received K: $MgSO_4$ @ 12: 80 kg/ha registered highest sulphur content and the lower values were obtained when applied $MgSO_4$ @ 60 kg/ha with either K @ 20 kg/ha or 40 kg/ha. Interaction effect was also significant and M_1S_1 resulted in highest soil sulphur content. The lowest soil sulphur was noticed under M_2S_1.

J. Micronutrients (Fe, Mn, Zn, and Cu) status of soil

Types of tillage and various nutrient doses had significant effect on soil iron content, while no significant variation could be observed in manganese, zinc and copper content during 2017 and 2018, **(Table 54)**.

Significant variation in soil iron content due to different tillage practices like normal tillage (CT), minimum tillage (MT) and zero tillage (ZT) was observed. The highest iron content was observed in conventional tillage (CT) with a content of 53.1

Table 53. Effect of tillage and nutrients on soil magnesium and sulphur content in 2017-18 and 2018-19

Treatments	**Mg (mg/kg)**			**S (mg/kg)**		
Tillage	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
M_1- Zero tillage (ZT)	76.8^{b}	77.2^{b}	505.9(77.0)^{b}	21.3^{a}	8.0^{ab}	27.1(14.7)^{a}
M_2- Minimum tillage (MT)	73.9^{b}	74.4^{c}	487.6(74.2)^{c}	11.0^{c}	9.6^{a}	15.3(10.3)^{c}
M_3- Conventional tillage (CT)	82.3^{a}	82.9^{a}	543.1(82.6)^{a}	15.9^{b}	7.2^{b}	20.5(11.6)^{b}
C.D (0.05)	**3.8**	**0.1**	**0.7**	**0.3**	**1.6**	**0.6**
SE(m)	**1.29**	**0.02**	**0.23**	**0.11**	**0.53**	**0.19**
S_1- Soil test based recommendations	82.9^{a}	83.3^{b}	546.2(83.1)^{b}	20.9^{a}	7.6^{b}	26.5(14.3)^{a}
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	81.6^{a}	82.0^{c}	537.7(81.8)^{c}	12.3^{d}	8.8^{a}	16.7(10.6)^{d}
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	85.2^{a}	85.6^{a}	561.3(85.4)^{a}	18.9^{b}	10.5^{a}	24.8(14.7)^{b}
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	64.9^{c}	65.4^{e}	428.8(65.2)^{e}	14.0^{c}	3.6^{c}	17.3(8.8)^{d}
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	73.8^{b}	74.3^{d}	487.1(74.1)^{d}	14.3^{c}	10.8^{a}	19.4(12.5)^{c}
C.D (0.05)	**4.9**	**0.1**	**0.9**	**0.4**	**2.0**	**0.7**
SE(m)	**1.67**	**0.03**	**0.32**	**0.14**	**0.69**	**0.25**
M_1S_1: ZT + Soil test based	78.6^{cde}	78.9^{g}	517.3(78.8)^{g}	43.1^{a}	4.0^{f}	41.7(23.5)^{a}
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	86.0^{bc}	86.3^{d}	565.9(86.2)^{d}	17.1^{f}	12.3^{bc}	23.2(14.7)^{e}
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	76.6^{de}	77.0^{h}	504.4(76.8)^{h}	27.1^{b}	4.2^{f}	33.0(15.7)^{b}
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	56.3^{h}	56.7^{m}	371.4(56.5)^{m}	12.8^{h}	2.8^{f}	15.7(7.8)^{h}
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	86.6^{bc}	87.0^{c}	570.5(86.8)^{c}	6.5^{k}	16.7^{a}	11.7(11.6)^{i}
M_2S_1: MT + Soil test based	85.3^{bc}	85.7^{e}	561.5(85.5)^{e}	4.1^{l}	10.7^{cd}	7.4(7.4)^{j}
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	87.5^{b}	88.0^{b}	576.5(87.7)^{b}	7.1^{k}	10.5^{cd}	10.9(8.8)^{i}
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	73.1^{ef}	73.5^{i}	482.0(73.3)^{i}	11.8^{i}	13.1^{bc}	17.0(12.4)^{g}
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	65.5^{fg}	66.0^{k}	432.6(65.8)^{k}	8.4^{j}	3.1^{f}	10.7(5.8)^{i}
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	58.3^{gh}	58.8^{l}	385.3(58.5)^{l}	23.6^{c}	10.5^{cd}	30.4(17.0)^{c}
M_3S_1: CT + Soil test based	84.9^{bcd}	85.4^{f}	559.9(85.1)^{f}	15.6^{g}	8.^{de}	20.3(11.9)^{f}
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	71.4^{ef}	71.8^{j}	470.6(71.6)^{j}	12.8^{h}	3.7^{f}	16.0(8.3)^{gh}
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	105.8^{a}	106.4^{a}	697.5(106.1)^{a}	17.9^{e}	14.2^{ab}	24.5(16.0)^{d}
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	73.0^{ef}	73.6^{i}	482.3(73.3)^{i}	20.6^{d}	4.8^{ef}	25.5(12.7)^{c}
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	76.6^{de}	77.1^{h}	505.5(76.9)^{h}	12.8^{h}	5.1^{ef}	16.3(8.9)^{gh}
C.D (0.05)	**8.4**	**0.1**	**1.6**	**0.7**	**3.5**	**1.2**
SE(m)	**2.89**	**0.05**	**0.56**	**0.25**	**1.20**	**0.43**

*R (weighted MSE) transformed values, original values in parentheses. In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

mg/kg and 53.2 mg/kg in first and second year respectively, which was on par to iron content recorded in minimum tillage with a content of 51.0 mg/kg and 51.6 mg/kg in first and second year respectively. In zero till plot (ZT) iron content was lower (49.70 mg/kg and 49.73 mg/kg respectively). Various tillage practices failed to influence soil manganese, zinc and copper content in both the years under study.

Influence of various doses of K and $MgSO_4$ was found to be significant with regard to iron content of soil in 2017 and2018. In both years of study, K: $MgSO_4$ @ 40:80 kg/ha (S_5) recorded highest iron content (57.3 mg/kg) in first year and higher iron content (60.7 mg/kg) in the second year. In first year, application of K: $MgSO_4$ @ 40:60 kg/ha (S_4) was on par to S_5. The lowest content (45.8 mg/kg) was observed where lower doses of both K (20 kg/ha) and Mg (60 kg/ha) was supplied (S_2) and it was on par to K: $MgSO_4$ @ 20:80 kg/ha (S_3). Meanwhile in second year, superior treatment S_5 was followed by application of K: $MgSO_4$ @ 40:60 kg/ha (S_4) with a content of 51.8 mg/kg. Interaction effect of K-Mg doses and various tillage practices was non-significant with respect to soil manganese, zinc and copper content.

In the first year, same trend with regard to iron content was noticed in interaction effect, where K: $MgSO_4$ @ 40:80 kg/ha under CT (M_3S_5) had higher iron content (63.3 mg/kg). It was on par to supply of K: $MgSO_4$ @ 40:60 kg/ha under CT (M_3S_4) which recorded iron content of 62.0 mg/kg. Lower iron content was observed (44.0 mg/kg and 44.1 mg/kg) in ZT with K: $MgSO_4$ @ 20:80 kg/ha (M_1S_3) and in minimum tillage soils with K: $MgSO_4$ @ 20:60 kg/ha (M_2S_2) respectively.

In 2018, statistical analysis of micronutrients showed that with respect to iron content interactions resulted in significant difference and similar trend as in first year was noticed. CT with K: $MgSO_4$ @ 40:80 kg/ha (M_3S_5) resulted in content of 68.8 mg/kg. It was followed by K: $MgSO_4$ supplied @ 40:80 kg/ha under zero tillage (M_1S_5) and K: $MgSO_4$ supplied @ 40:60 kg/ha under conventional tillage (M_3S_4), and MT with soil test based nutrition (M_2S_1) where iron content recorded was 59.2 mg/kg 58.0 mg/kg and 54.7 mg/kg respectively. It could be noted that, higher levels of K and

Mg (20 kg/ha and 80 kg/ha respectively) under different types of tillage recorded higher values of soil iron. However, interaction of K: $MgSO_4$ @ 20:60 kg/ha (M_1S_2) and soil test based nutrition under CT (M_3S_2 and M_3S_1 respectively) as well as K: $MgSO_4$ @ 20:60 kg/ha under ZT system (M_1S_2) recorded lower values for soil iron.

H. Soil microbial status

Soil microbial status under various tillage systems varied significantly, and effect of nutrient doses and interactions was also observed to be significant (**Table 55 and 56**).

Data pertaining to microbial analysis showed that highest population of bacteria, fungi and beneficial nitrogen fixers were noticed under zero tillage. It was followed by minimum tillage. The lowest population of microbes were recorded under conventional tillage. Application of K_2O @ 40 kg/ha together with $MgSO_4$ @ 80 kg/ha (S_5) resulted in higher number of bacterial colonies in both years. In 2018, this treatment was at par to treatments S_4 and S_1. During the period of study, application of K_2O @ 20 kg/ha with $MgSO_4$ @ 60 kg/ha (S_2) registered higher number of fungal colonies and it maintained parity to K_2O @ 20 kg/ha with $MgSO_4$ @ 80 kg/ha (S_3). The treatment also showed parity to the number of colonies recorded with application of K: $MgSO_4$ @ 40:60 kg/ha during 2017. Interaction effect was also significant, with respect to bacterial colonies were observed with application of K_2O @ 40 kg/ha with $MgSO_4$ @ 80 kg/ha under ZT systems during both years. Higher number of fungal colonies were registered under ZT along with the application of K: MgSO4 @ 20: 80 kg/ha (M_1S_3). However, lowest number of both bacterial and fungal colonies were observed under conventional tillage with application of higher levels of both K and $MgSO_4$ during both years.

Table 54. Effect of tillage and nutrients on soil micronutrients in 2017-18 and 2018-19

Treatments	Fe (mg/kg)		Mn (mg/kg)		Zn (mg/kg)		Cu (mg/kg)	
Tillage	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
M_1- Zero tillage (ZT)	49.7[b]	49.7[b]	8.07	7.82	3.24	3.36	1.05	1.02
M_2- Minimum tillage (MT)	51.0[ab]	51.6[ab]	7.44	7.51	4.74	4.67	0.94	0.96
M_3- Conventional tillage (CT)	53.1[a]	53.2[a]	8.79	8.54	4.60	4.74	1.18	1.15
C.D (0.05)	**2.4**	**2.5**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**0.8**	**0.9**	**0.1**	**0.1**	**0.1**	**0.1**	**0.02**	**0.02**
S_1- Soil test based recommendations	51.6[b]	49.9[b]	8.50	8.62	3.53	3.61	0.99	1.01
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	45.8[c]	45.6[c]	6.60	6.49	3.48	3.54	0.83	0.81
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	46.9[c]	49.5[b]	8.25	8.07	3.28	3.18	1.02	1.01
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	54.7[ab]	51.8[b]	7.25	7.26	6.30	6.58	1.03	1.04
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	57.3[a]	60.7[a]	9.89	9.33	4.38	4.38	1.41	1.33
C.D (0.05)	**3.1**	**3.2**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**1.1**	**1.1**	**0.2**	**0.2**	**0.09**	**0.09**	**0.02**	**0.02**
M_1S_1: ZT + Soil test based	53.8[b]	50.8[cd]	7.50	7.50	2.49	2.65	0.90	0.90
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	46.6[cd]	44.4[e]	5.10	5.15	3.94	4.10	0.74	0.75
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	44.0[d]	47.8[de]	9.12	8.60	2.86	2.80	1.17	1.10
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	49.8[bc]	46.5[de]	7.88	7.80	3.86	4.20	1.16	1.15
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	54.4[b]	59.2[b]	10.75	10.05	3.03	3.00	1.28	1.20
M_2S_1: MT + Soil test based	54.1[b]	54.7[bc]	8.54	8.90	4.25	4.05	0.96	1.00
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	44.1[d]	47.9[de]	7.63	7.20	3.37	3.30	0.95	0.90
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	50.4[bc]	50.4[cd]	7.52	8.00	3.50	3.30	0.89	0.95
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	52.5[b]	51.0[cd]	6.31	6.50	9.10	9.10	0.87	0.90
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	54.2[b]	54.2[bc]	7.21	7.00	3.49	3.60	1.03	1.00
M_3S_1: CT + Soil test based	46.9[cd]	44.3[e]	9.45	9.45	3.85	4.10	1.10	1.10
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	46.8[cd]	44.6[e]	7.08	7.15	3.12	3.25	0.79	0.80
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	46.4[cd]	50.5[cd]	8.11	7.65	3.47	3.40	1.01	0.95
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	62.0[a]	58.0[b]	7.58	7.50	5.93	6.45	1.06	1.05
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	63.3[a]	68.8[a]	11.72	10.95	6.62	6.55	1.93	1.80
C.D (0.05)	**5.4**	**5.5**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
SE(m)	**1.9**	**1.9**	**0.3**	**0.3**	**0.2**	**0.2**	**0.04**	**0.04**

With respect to beneficial nitrogen fixers, compared to conventional system of tilling, higher number of colonies were noticed under conservation tillage systems (**Table 56)**. The lowest colonies were observed under conventional tillage system during 2017 and 2018 (1.2×10^{-4} cfu and 1.0×10^{-4} cfu respectively). Among various nutrient doses higher number was observed with application of K: $MgSO_4$ @ 20:60 kg/ha during both years (1.8×10^{-4} cfu and 1.6×10^{-4} cfu respectively). Interaction was also found to be significant and the higher number of colonies were registered under M_1S_1 and M_2S_2. The lower number of beneficial nitrogen fixers were registered under CT along with the application of K: $MgSO_4$ @ 20:80 kg/ha (M_3S_3).

Microbial analysis of the soil also indicated that, population of actinomycetes is almost nil in the soil under study (**Table. 57**). During both years, application of K: MgSO4 @ 20: 60 kg/ha (M_1S_2), 20:80 kg/ha (M_1S_3), and 40:60 kg/ha (M_1S_4) under zero tillage shown the presence of actinomycetes. However, no colonies were observed under conventional and minimum tillage systems. Similarly, even though leguminous crop was cultivated, no sign of rhizobium population was observed in the soil which may be due to the acidic soil pH.

I. Soil bulk density

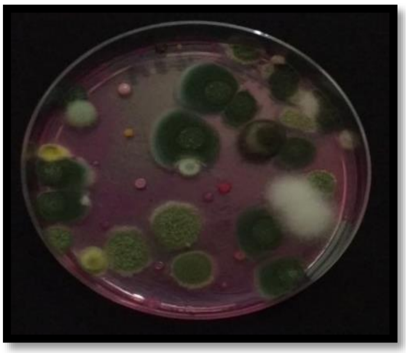
Perusal of the data shows that, effect of various tillage systems on soil bulk density was significant while effect of potassium and magnesium sulphate doses was not significant (**Table 58**). Zero tillage registered significantly highest bulk density indicating increased soil compaction during both years. It was followed by MT. The lowest bulk density (1.1 g/cc and 1.2 g/cc) was observed under conventional tillage system. Interaction between tillage and nutrients also had non-significant effect on bulk density.

Table 55. Effect of nutrients and tillage on soil microbial status (cfu/g) in 2017 & 2018

Treatments	Bacteria		Fungi	
Tillage	**2017**	**2018**	**2017**	**2018**
M_1- Zero tillage (ZT)	5.52(3.4)[a]	5.51(3.6)[a]	4.43(2.7)[a]	4.43(2.8)[a]
M_2- Minimum tillage (MT)	5.24(1.8)[b]	5.27(2.0)[b]	4.32(2.1)[b]	4.31(2.1)[b]
M_3- Conventional tillage (CT)	5.25(1.4)[c]	5.15(1.5)[c]	4.06(1.2)[c]	4.02(1.1)[c]
C.D (0.05)	**0.02**	**0.02**	**0.01**	**0.02**
SE(m)	**0.006**	**0.006**	**0.004**	**0.008**
S_1- Soil test based recommendations	5.21(2.1)[b]	5.32(2.2)[a]	4.25(1.9)[b]	4.27(2.0)[b]
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	5.19(2.1)[b]	5.29 (2.1)[b]	4.29(2.0)[a]	4.31(2.2)[a]
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	5.07(2.0)[c]	5.29(2.0)[b]	4.31(2.2)[a]	4.30(2.2)[ab]
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	5.32(2.2)[a]	5.30(2.3)[a]	4.29(2.1)[a]	4.26(2.0)[b]
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	5.34(2.6)[a]	5.32(2.5)[a]	4.20(1.7)[c]	4.18(1.6)[c]
C.D (0.05)	**0.02**	**0.02**	**0.02**	**0.03**
SE(m)	**0.008**	**0.007**	**0.006**	**0.008**
M_1S_1: ZT + Soil test based	5.42(2.6)[d]	5.48(3.1)[c]	4.47(2.9)[b]	4.51(3.2)[a]
$M_1M_1S_2$: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	5.48(3.0)[c]	5.42(2.6)[d]	4.35(2.2)[d]	4.40(2.5)[c]
$M_1M_1S_3$: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	5.48(3.0)[c]	5.45(2.9)[c]	4.54(3.4)[a]	4.52(3.3)[a]
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	5.54(3.4)[b]	5.56(3.7)[b]	4.46(2.9)[b]	4.48(3.0)[ab]
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	5.68(4.8)[a]	5.64(4.4)[a]	4.31(2.0)[e]	4.29(1.9)[de]
M_2S_1: MT + Soil test based	5.40(2.6)[d]	5.38(2.4)[e]	4.25(1.8)[f]	4.25(1.8)[e]
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	5.19(1.6)[f]	5.30(2.0)[f]	4.40(2.5)[c]	4.44(2.7)[bc]
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	5.13(1.4)[g]	5.21(1.6)[hi]	4.29(2.0)[e]	4.31(2.1)[d]
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	5.21(1.6)[f]	5.22(1.6)[h]	4.37(2.4)[d]	4.31(2.1)[d]
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	5.28(1.9)[e]	5.25(1.8)[g]	4.29(2.0)[e]	4.28(1.9)[de]
M_3S_1: CT + Soil test based	5.10(1.3)[g]	5.10(1.3)[j]	4.03(1.1)[h]	4.04(1.1)[gh]
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	5.19(1.6)[f]	5.19(1.6)[hi]	4.12(1.3)[g]	4.10(1.3)[f]
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	5.19(1.6)[f]	5.19(1.6)[hi]	4.11(1.3)[g]	4.06(1.1)[fg]
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	5.20(1.6)[f]	5.18(1.6)[i]	4.03(1.1)[h]	3.99(1.0)[hi]
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	5.05(1.1)[h]	5.08(1.5)[j]	4.00(1.0)[h]	3.97(0.9)[i]
C.D (0.05)	**0.04**	**0.04**	**0.03**	**0.05**
SE(m)	**0.013**	**0.013**	**0.010**	**0.018**

*R (weighted MSE) transformed values, original values in the range of x 10^4 for bacteria and 10^5 for fungi in parentheses.
In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

Zero tillage



Minimum tillage

Conventional tillage

Plate 15. Fungal colonies under various tillage systems

Table 56. Effect of nutrients and tillage on beneficial nitrogen fixers in soil (cfu/g) in 2017-18 and 2018-19

Treatments	**Beneficial N fixers**	
Tillage	**2017**	**2018**
M_1- Zero tillage (ZT)	4.27(1.9)[a]	4.21(1.7)[a]
M_2- Minimum tillage (MT)	4.25(1.7)[a]	4.24(1.8)[a]
M_3- Conventional tillage (CT)	4.06(1.2)[c]	3.98(1.0)[b]
C.D (0.05)	**0.02**	**0.04**
SE(m)	**0.007**	**0.012**
S_1- Soil test based recommendations	4.19(1.6)[b]	4.19(1.6) [a]
S_2- K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	4.23(1.8)[a]	4.16(1.6)[a]
S_3- K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	4.19(1.6)[b]	4.18(1.6)[a]
S_4- K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	4.13(1.4)[c]	4.08(1.2)[b]
S_5- K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	4.17(1.5)[b]	4.12(1.4)[b]
C.D (0.05)	**0.03**	**0.05**
SE(m)	**0.009**	**0.016**
M_1S_1: ZT + Soil test based	4.39(2.4)[a]	4.36(2.3)[a]
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	4.29(1.9)[bc]	4.24(1.7)[c]
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	4.33(2.1)[b]	4.22(1.6)[c]
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	4.16(1.4)[e]	4.08(1.2)[e]
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	4.21(1.6)[d]	4.18(1.5)[cd]
M_2S_1: MT + Soil test based	4.12(1.3)[ef]	4.10(1.3)[de]
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	4.38(2.4) [a]	4.32(2.1)[ab]
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	4.25(1.8)[c]	4.34(2.2)[a]
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	4.15(1.4)[e]	4.19(1.5)[c]
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	4.16(1.4)[e]	4.24(1.7)[bc]
M_3S_1: CT + Soil test based	4.07(1.2)[gh]	4.11(1.3)[de]
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	4.03(1.1)[hi]	3.93(0.9)[f]
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	4.00(1.0)[i]	3.93(1.0)[f]
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	4.09(1.2)[fg]	3.97(0.9)[f]
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	4.13(1.4)[e]	3.98(0.9)[f]
C.D (0.05)	**0.04**	**0.08**
SE(m)	**0.015**	**0.027**

*R (weighted MSE) transformed values, original values in the range of x 10^4 for bacteria and 10^5 for fungi in parentheses.
In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

Table 57. Effect of nutrients and tillage on soil microbial status in 2017 & 2018

Treatments	Actinomycetes		Rhizobium	
	2017	2018	2017	2018
M_1S_1: ZT + Soil test based	A	A	A	A
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	2	3	A	A
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	2	4	A	A
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	1	2	A	A
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	A	A	A	A
M_2S_1: MT + Soil test based	A	A	A	A
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	A	A	A	A
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	A	A	A	A
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	A	A	A	A
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	A	A	A	A
M_3S_1: CT + Soil test based	A	A	A	A
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	A	A	A	A
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	A	A	A	A
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	A	A	A	A
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	A	A	A	A

*****A**-** absent

Table 58. Effect of nutrients and tillage on soil bulk density in 2017 & 2018

Treatments	**Bulk density (g/cc)**	
Tillage	**2017**	**2018**
M_1- Zero tillage (ZT)	1.5^a	1.6^a
M_2- Minimum tillage (MT)	1.3^b	1.3^b
M_3- Conventional tillage (CT)	1.2^c	1.1^c
C.D (0.05)	**1.0**	**1.0**

Zero tillage

Minimum tillage

Conventional tillage

Plate 16. Biological nitrogen fixers under various tillage systems

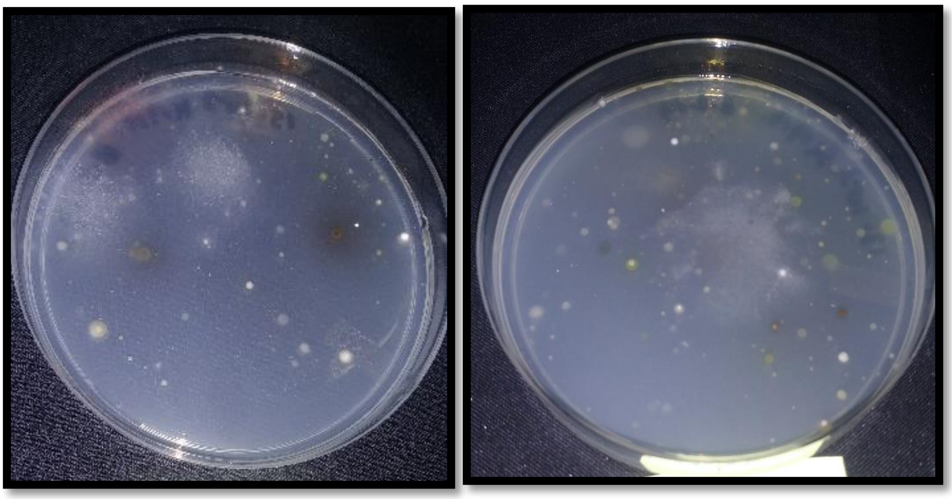


Plate 17. Actinomycetes colonies under zero tillage

4.2.9 Economics

The grain yield in different treatments varied from 419 kg/ha to 1016 kg/ha during 2017 and 508 kg/ha to 981 kg/ha during 2018, and in 476.7 kg/ha to 914.8 kg/ha on pooling. The economics analysis was done based on pooled analysis of yield data. Cost of production incurred for various treatments gross and net returns obtained as well as B: C ratio is furnished in **Table 59.**

The cost of cultivation ranged from Rs. 21144/- to Rs. 23864/-. Among the various tillage practices, the cost of cultivation was higher under zero tillage system as the labour requirement for sowing was higher. Under no tilled systems seeds has to be dibbled to ensure good germination, which requires more labour. The cost excluding various K and $MgSO_4$ doses were Rs. 5400/ha for zero tillage, Rs. 4800/ha for minimum tillage and Rs.6000 /ha for conventional. The additional cost for remaining K and $MgSO_4$ doses varied for S_1 – Rs. 2630/ha to S_5- Rs. 3476/ha.

The highest gross returns as well as net return were realized under minimum tillage with K: $MgSO_4$ @ 40:60 kg/ha (M_2S_4) with Rs. 45,735/- and Rs. 23,982 /ha. A higher B: C ratio of 2.3 was also recorded. The net return was almost double than the corresponding K-$MgSO_4$ dose under conventional tillage.

The two best treatments with respect to net returns were under the minimum tillage under all the three tillage practices. Application of K: $MgSO_4$ @ 40:60 kg/ha resulted in more returns.

Table 59. Effect of nutrients and tillage on economics (Rs. /ha) of cowpea production

Treatment	Cost of cultivation	Gross returns			Net returns			B: C ratio		
		2017	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
M_1S_1: ZT + Soil test based	23630	23056	39698	31377	-574	16068	7747	1.0	1.7	1.3
M_1S_2: ZT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	23544	22520	26032	24276	-1024	2488	732	1.0	1.1	1.0
M_1S_3: ZT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	23864	20972	35810	28391	-2892	11946	4527	0.9	1.5	1.2
M_1S_4: ZT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	24156	33690	39698	36694	9534	15542	12538	1.4	1.6	1.5
M_1S_5: ZT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	24476	34914	32746	33830	10438	8270	9354	1.4	1.3	1.4
M_2S_1: MT + Soil test based	**21230**	50813	31333	41073	29583	10103	19843	2.4	1.5	**1.9**
M_2S_2: MT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	21144	35099	33952	34526	13955	12808	13382	1.7	1.6	1.6
M_2S_3: MT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	21464	38710	25413	32062	17246	3949	10598	1.8	1.2	1.5
M_2S_4: MT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	**21756**	50000	41476	**45738**	28244	19720	**23982**	2.3	1.9	**2.1**
M_2S_5: MT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	22076	23750	36667	30208	1674	14591	8132	1.1	1.7	1.4
M_3S_1: CT + Soil test based	22430	21382	26286	23834	-1048	3856	1404	1.0	1.2	1.1
M_3S_2: CT + K_2O 20 kg/ha + $MgSO_4$ 60 kg/ha	22344	24960	37698	31329	2616	15354	8985	1.1	1.7	1.4
M_3S_3: CT + K_2O 20 kg/ha + $MgSO_4$ 80 kg/ha	22664	21944	43524	32734	-720	20860	10070	1.0	1.9	1.4
M_3S_4: CT + K_2O 40 kg/ha + $MgSO_4$ 60 kg/ha	22956	27831	49048	38439	4875	26092	15483	1.2	2.1	1.7
M_3S_5: CT + K_2O 40 kg/ha + $MgSO_4$ 80 kg/ha	23276	27887	43651	35744	4611	20375	12468	1.2	1.9	1.5

Plate 18. Crop stand in application of K: $MgSO_4$ @ 40:60 kg/ha under minimum tillage

Plate 19. Cowpea at flowering & pod setting stage in application of K: $MgSO_4$ @ 40:60 kg/ha under minimum tillage

Plate 20. Cowpea at pod maturity stage in application of K: $MgSO_4$ @ 40:60 kg/ha under minimum tillage

Plate 21. Harvesting of pods in application of K: $MgSO_4$ @ 40:60 kg/ha under minimum tillage

Plate 22. Harvested of pods from application of K: $MgSO_4$ @ 40:60 kg/ha under minimum tillage

Discussion

V. DISCUSSION

The results of experiments conducted to study the effect of tillage, potassium and magnesium application on rice fallow cowpea production are discussed in this chapter.

Effect of tillage and nutrients on germination of cowpea

Tillage is an important operation in crop production and good land husbandry practices are gaining importance due to increasing concern on conservation and sustainable use of natural resources in agriculture. This study included a comparison of various tillage practices such as herbicide based zero tillage, minimum tillage (strip-tillage) and conventional tillage in rice fallow cowpea production.

The results indicated that, germination percentage was influenced by different types of tillage systems **(Fig. 6.)**. During both the years, conventional tillage resulted in highest germination percentage and it was on an average 79 per cent as compared to 58 per cent under minimum tillage and 44 per cent under no tillage and this directly influenced the crop density. Though gap filling was done to ensure uniform plant population, the establishment in zero till system remained inferior to conventional tillage. Compared to zero till, minimum tillage was superior with respect to germination of cowpea and crop establishment as strip tillage loosened the soil and favourable tilth was created. Similar results were reported by Sangakkara (2004), who found that in green gram, germination and crop growth reduced under no tillage system because of soil compaction and low soil moisture.

Plant population greatly affects crop growth which finally influences yield parameters and yield. Optimum plant population can be achieved with optimum seed rate, spacing and also by ensuring good germination. Apart from quality of seeds, germination requires good tilth with enough soil moisture and aeration.

Lower germination rate under zero tillage was due to soil compaction, which resulted in higher soil resistance to germinating seeds. This is a characteristic feature

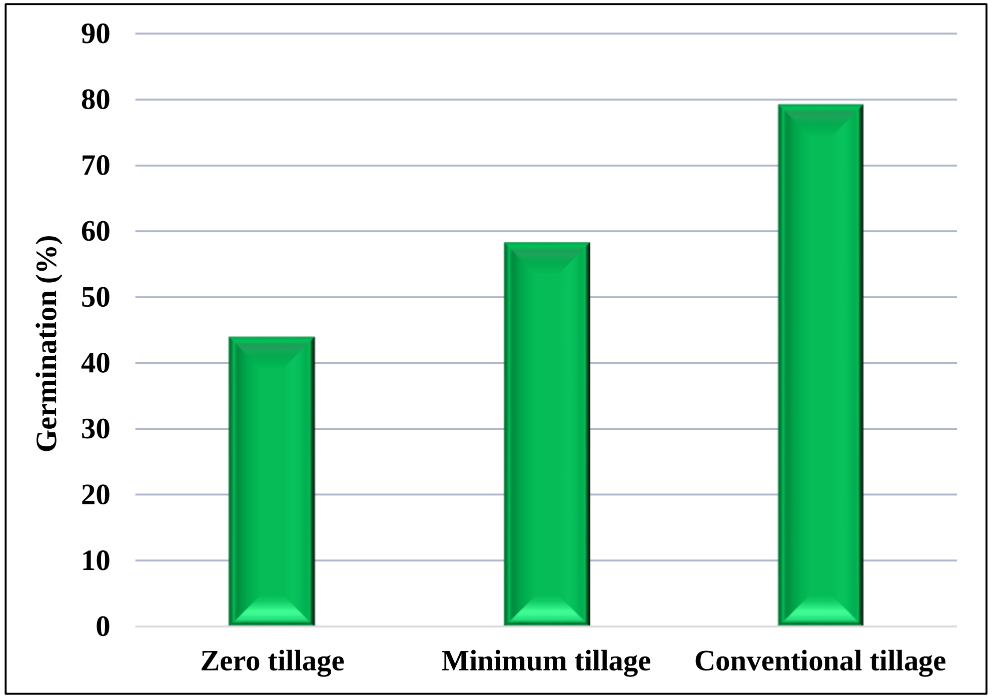


Fig 6. Germination percentage of cowpea as affected by tillage practices

of zero tillage. In this treatment seeds were dibbled at the required spacing and there was no loosening of soil which resulted in hard tilth and poor germination in zero till.

Conventionally tilled plots provided loose soil with good aeration, soil moisture status, and low bulk density, which ultimately favoured seed germination and thereby highest germination percentage. The low bulk density value (1.2 g/cc) in conventional tillage compared to high bulk density of 1.5 g/cc in zero tillage plots indicated soil compaction and poor aeration which is not ideal for germination. This might have also led to unfavourable moisture condition for germination of seeds. Amanullah *et al*. (2015) also found that in green gram, thorough land preparation resulted in higher percentage of germination. According to Baker and Saxton (2007), under no-tillage system poor placement of seeds lead to poor seedling emergence as under this tillage system seeds will be exposed or would be placed under crop residue. Seedling emergence in dry bean was delayed under zero tillage as compared to conventional tillage; however this did not affected maturity date (Blackshaw *et al*., 2007).

Germination percentage was not affected either with application of K-$MgSO_4$ doses or with the interaction of tillage *vs.* K-$MgSO_4$. Germination percentage in green gram varied insignificantly under various levels of potassium (Abbas *et al*., 2011). Nutrient status of soil had no direct effect on germination and early establishment.

Effect on growth parameters

The low germination percentage under zero tillage resulted in low plant population, even though gap filling was done to ensure good crop stand. Significant variation in most of the growth parameters in the present study can be explained in terms of difference in plant population under various tillage systems. In general, competition for soil moisture, nutrients, and light increased among plants growing with higher plant population compared to plants under low population densities. The initial growth of the plant, competition from adjacent plants were less which might be one reason for higher values for the different growth parameters like number of branches, LAI, and root parameters recorded under conservation tillage systems. These findings are in line with findings of Ahmad *et al.* (2004) where decreasing plant density resulted in availability of more space for growth and nutrients in the root zone. Shakarami and Rafiee (2009) suggested that lower plant population can avail more sunlight and photosynthesis.

Plant height

Plant height varied insignificantly among various tillage practices. Tillage had no significant effect on plant height of cowpea **(Table 20)**. The plant height at 60 DAS was 47.5 cm, 52.9 cm and 48.4 cm under zero tillage, minimum tillage and conventional tillage respectively Akinyemi *et al*. (2003) also reported that there is no significant influence on plant height in cowpea under zero, ridge and flat tillage systems. According to Yau *et al.* (2010), plant height of chickpea varied non-significantly under zero tillage and conventional tillage practices. George (2011) also reported that there was no significant difference in plant height of fodder cereals grown in rice fallows under normal, minimum and zero tillage systems.

Soil application of K-$MgSO_4$ doses also failed to bring significant difference in plant height of cowpea. This was probably due to the fact that both K and Mg has no direct role in enhancing vegetative growth as in the case of nitrogen. There was no effect on different levels of potassium on plant height of wheat (Khan *et al*., 2017).

Number of branches

Branching of cowpea was significantly influenced by various tillage practices as evident from data on number of branches at 45 and 60 DAS **(Fig. 7)**. At 45 DAS, zero tillage resulted in more number of branches (8.5 nos/plant) which was at par with minimum tillage (8.2 nos/plant). At 60 DAS, number of branches noted under minimum tillage was highest (14 nos/plant) followed by zero tillage (12 nos/plant). At both stages of crop growth lowest number of branches was recorded under conventional tillage. The lower branching in conventional tillage might have resulted

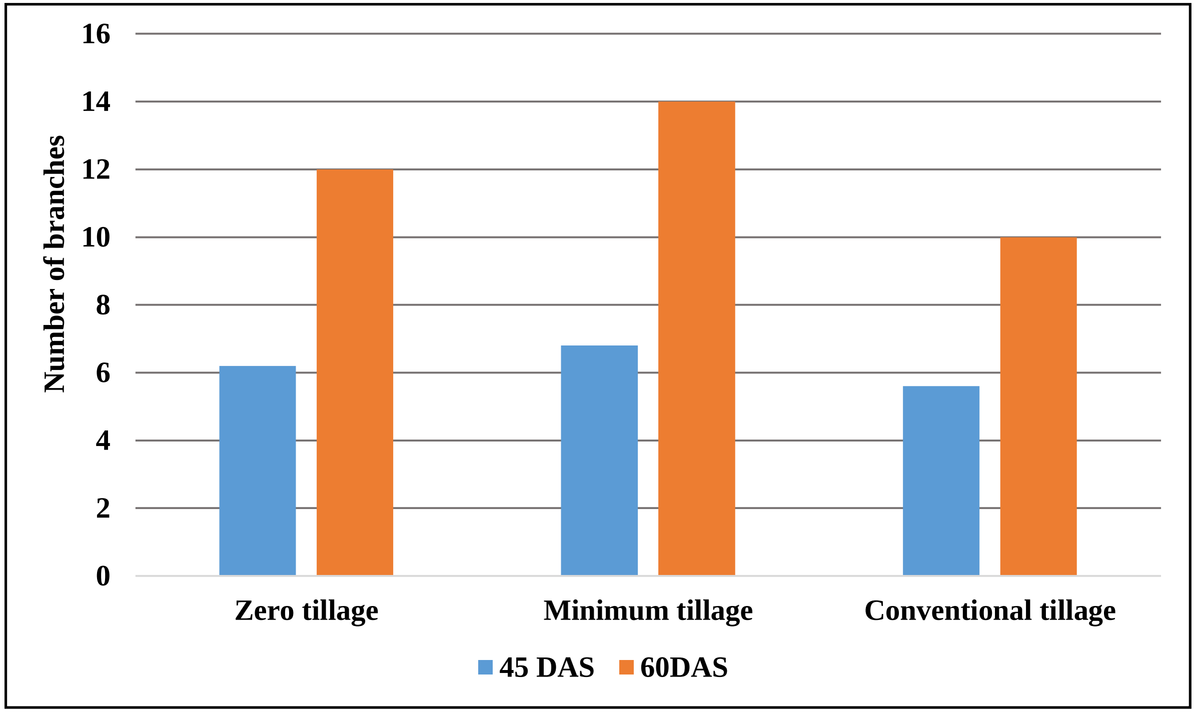


Fig. 7. Number of branches of cowpea as affected by tillage practices

from more number of plants per unit area due to good seed germination which lead to more plant density.

On the contrary, the lower plant population observed under conservation tillage might have resulted in availability of more space and lesser plant to plant competition, which ultimately led to production of more branches as a result of plasticity of plants to adjust their growth according to space and other growth factors. Alege and Mustapha (2007) found that increasing plant densities resulted in reduction of the number of branches per plant in cowpea. Similarly, Chaghazardi *et al.* (2016) reported that reduced tillage recorded higher number of main and lateral branches in chickpea. In reduced tillage system ideal soil moisture condition also might have contributed to good growth and branching.

LAI

Tillage systems, nutrient doses and their interactions significantly influenced leaf area index **(Fig. 8)**. Zero tillage recorded highest LAI due to better growth and branching of individual plants in these treatments. On the contrary, conventional tillage resulted in low LAI due to poor branching. El-Naim and Jabereldar (2010) also found that higher the plant density, lower was the number of leaves per plant in cowpea. But Guzzetti *et al.* (2020) observed significantly higher number of leaves in cowpea under normal tillage, however at later stages no significant difference was noted between no tillage and conventional tillage.

LAI in minimum tillage was 10.2, while plants under conventional tillage system recorded lowest LAI of 5.5. Chaghazardi *et al.* (2016) reported that in chickpea, reduced tillage recorded highest biomass and LAI, over no-tillage and conventional tillage. Boydston *et al.* (2018) found that in dry bean under moisture stress, leaf area index, and canopy cover were higher in strip tillage than that in conventional tillage which can be attributed to favourable soil moisture and nutrient status under strip tillage.

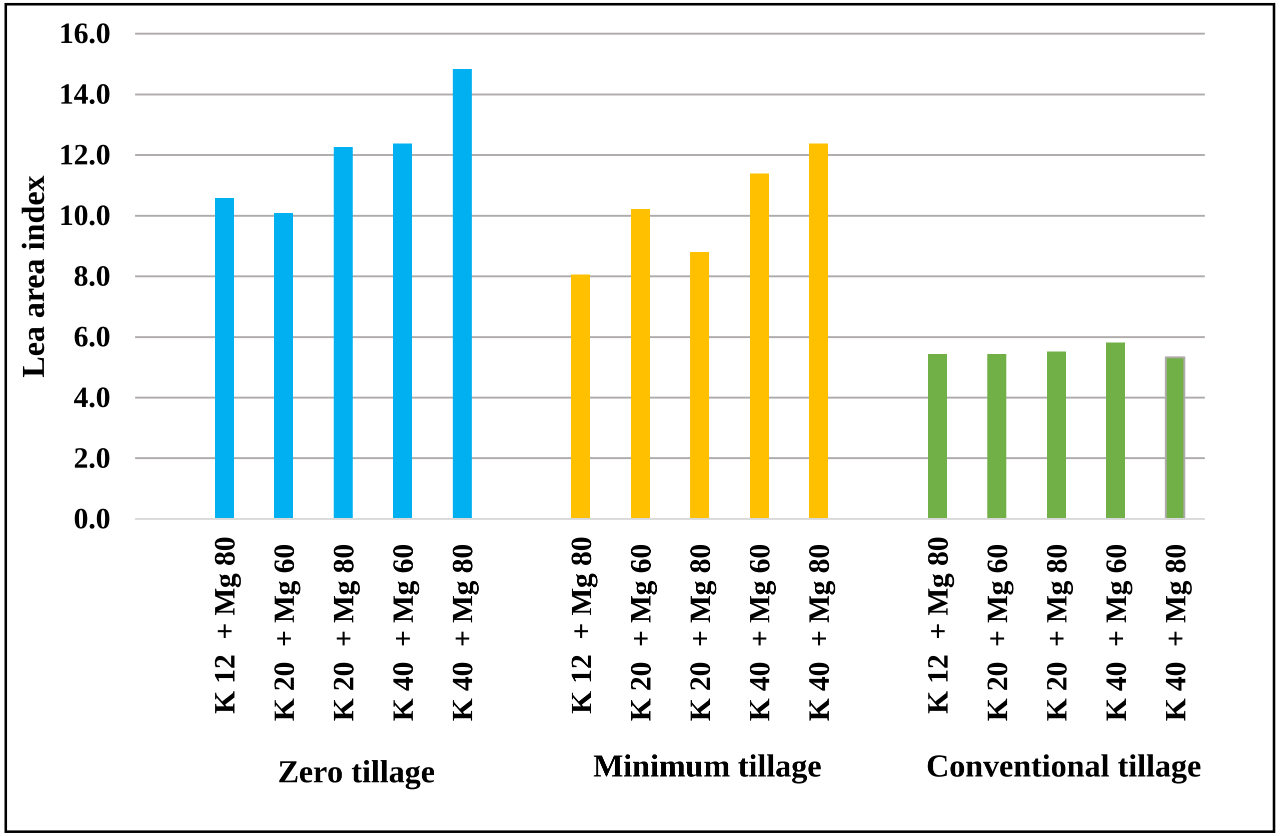


Fig. 8. Leaf area index of cowpea as affected by tillage and K & $MgSO_4$ levels

Application of K: $MgSO_4$ @ 40:80 kg/ha resulted in higher leaf area index (10.8). The next nutrient combination which resulted in higher LAI (9.9) was K: $MgSO_4$ @ 40:60 kg/ha. This might be due to the addition of higher doses of nutrients which in turn might have increased soil fertility and uptake of nutrients as well as in expansion of leaves. Thalooth *et al.* (2006) reported that foliar application of potassium resulted in higher number of leaves, and leaf area of mungbean.

Zero tillage along with K: $MgSO_4$ @ 40:80 kg/ha recorded highest LAI during the study period (14.8). Minimum tillage with K-$MgSO_4$ @ 40:80 kg/ha also indicated higher LAI. Sangakkara *et al.* (2001) observed that increasing K nutrient increased leaf area and shoot dry weights of cowpea and green gram which resulted from better nutrition and growth of plant.

Similarly, Rao *et al*. (2015) reported significant increase in leaf area per plant (390.93 cm^2) with 1% K_2SO_4 spray at pod initiation stage and flowering stage of black gram. According to Kumar *et al.* (2018) application of potassium @ 90 kg/ha improved growth parameters of chickpea.

Chlorophyll content

There was no significant changes in chlorophyll content (chlorophyll a, b, a/b ratio, and total chlorophyll content) due to various tillage practices **(Table 22 & Fig. 9)**. However, the nutrient doses and interaction significantly influenced chlorophyll a, a/b ratio and total chlorophyll content. Highest total chlorophyll content (1.34 mg/g) was noted in application of K: $MgSO_4$ @ 20:60 kg/ha and K: $MgSO_4$ @ 40:80 kg/ha. Magnesium is a constituent of chlorophyll and the role of magnesium in chlorophyll formation is well established. Application of K: $MgSO_4$ @ 40:60 kg/ha resulted in higher chlorophyll a/b ratio (3.84). Teklić *et al*. (2009) reported that foliar application of Mg favoured rate of photosynthesis as magnesium is associated with increase in leaf chlorophyll content.

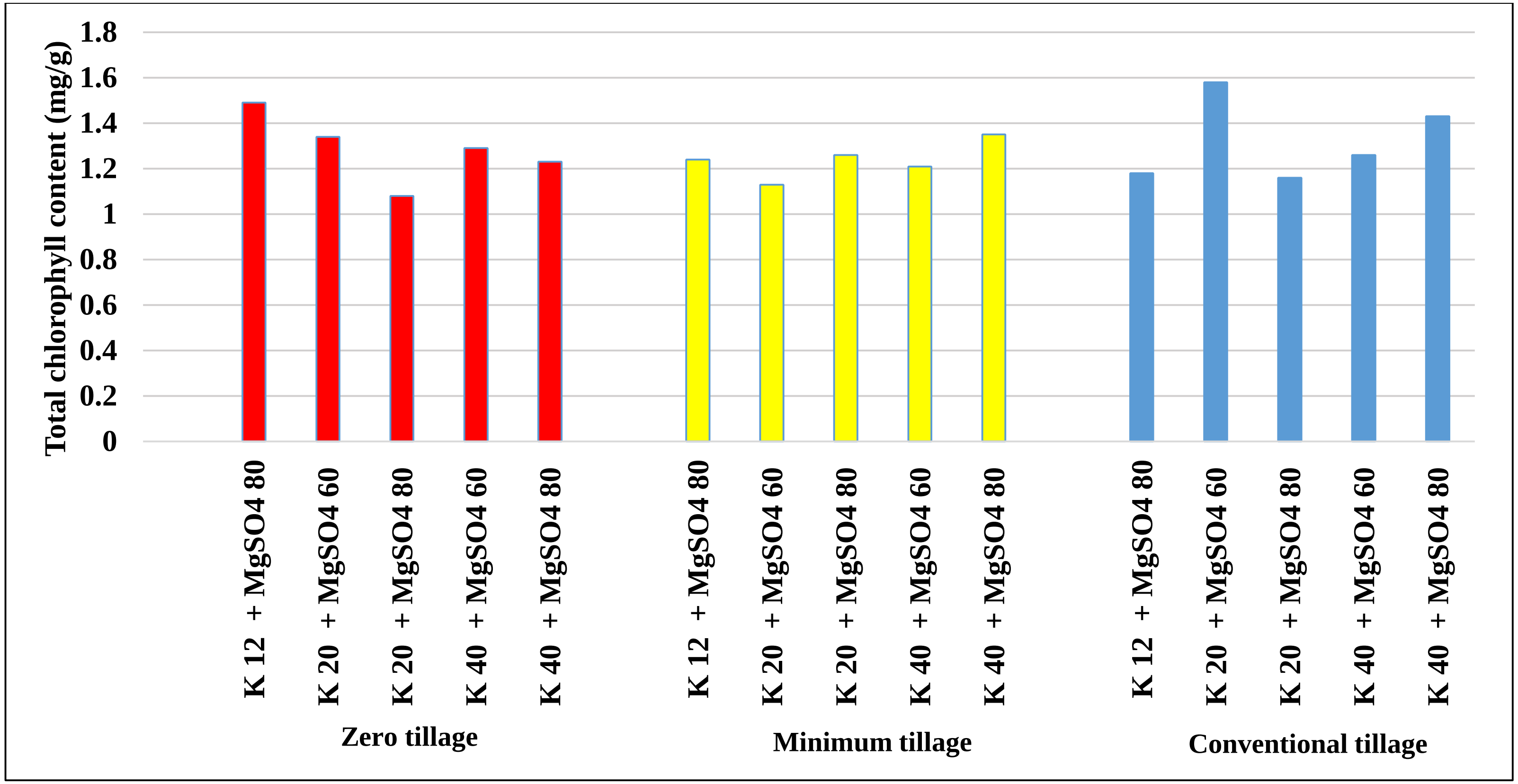


Fig. 9. Total chlorophyll content as affected by tillage and K & $MgSO_4$ levels

Fernández *et al.* (2015) suggested that the reason for higher magnesium content in corn leaves with application of Mg might be due to the rapid absorption of Mg by plants, and another reason might be the high mobility of magnesium in the phloem. These reasons also might have resulted in the higher Mg content in cowpea, with application of K: $MgSO_4$ @ 40:80 kg/ha.

Altarugio *et al.* (2017) also stated that foliar application of magnesium increased leaf Mg content in soybean and there was a significant increase in SPAD index values. Canizella *et al*. (2018) noticed that Mg and Zn fertilization increased the chlorophyll content from 283.4 mg/m^2 to 329.7 mg/m^2 leaf area in soybean cultivars.

Regarding tillage and nutrient interaction effect, higher total chlorophyll content (1.58 mg/g) was noticed in conventional tillage with K: $MgSO_4$ @ 20:60 kg/ha, which was at par to zero tillage with soil test based nutrition (1.49 mg/g). Higher dose of $MgSO_4$ @ 80 kg applied in these treatments might have favourably influenced leaf chlorophyll content. There was no significant difference between the $MgSO_4$ doses tried as all these doses had only a narrow difference of 20 kg/ha with each other. In soil test based nutrition also $MgSO_4$ dose applied was @ 80 kg/ha.

Days to 50% flowering

During both years under study, early flowering (45-46DAS) was observed in conventional tillage. This might be due to the early establishment of plants under conventional tillage due to early germination and growth. Early flowering of safflower under conventional tillage compared to minimum as well as zero tillage as reported by Yau *et al.* (2010). Guzzetti *et al.* (2020) observed early blooming of cowpea under conventional tillage and it was delayed under no tillage. In the present study, both no tillage and minimum tillage condition resulted in delayed flowering (47-49 days to reach 50% flowering).

Dry matter production

Tillage had significant influence on dry matter production throughout the growth stages **(Table 24, 25 & 26)**. Among various tillage practices, higher dry matter was produced under conventional tillage practice till 60 DAS compared to conservation tillage systems (zero and minimum Tillage). However, at 75 DAS, highest dry matter was produced under minimum tillage (3240 kg/ha). Both minimum and conventional tillage resulted in comparable dry matter (2043 kg/ha and 2085 kg/ha respectively) at 90 DAS.

It was found that throughout the crop growth, zero tillage consistently resulted in lowest dry matter accumulation of cowpea. Since, root weight, root length and root spread was highest under zero tillage, the photosynthate partitioning might have concentrated more towards the development of root rather than shoot and pods. Lopez-Bellido *et al.* (2007) observed that conventional tillage practices resulted significantly higher biomass and total dry matter production in pea, than under no-tillage. These findings are in line with the reports of Meena *et al*. (2015) in green gram.

The Mg content of the soil was low and hence response to applied magnesium was good. Evidences on role of Mg on plant revealed that, it plays specific roles in carbon partitioning as well as dry matter production to plant parts which act as sink, Mg deficiency leaves are seen with carbohydrates accumulation (Cakmak *et al.*, 1994). Positive effect of magnesium application in dry matter production in pulses is reported by many workers. In common bean, plant height, total dry matter produced, as well as leaf area were larger when magnesium sulphate was applied @ 324 kg of $MgSO_4$/ha as reported by Oliveira *et al*. (2000).

According to Kurdali *et al.* (2002), highest dry matter in faba bean and chickpea was reported with higher rate of potassium. Ganga *et al.* (2014) reported that application of K_2O @ 60 kg/ha produced significantly higher total dry matter in chickpea which was in line with the findings of Boulbaba *et al.* (2005). Hamid *et al.*

(2010) reported that potassium had an impact on growth parameters of soybean and it increased plant dry matter and LAI of the crop.

Ibrahim *et al*. (2010) found that a significant increase in plant height and dry matter production of french beans due to application of MgO @ 6 kg/ha. Foliar application of Mg-EDTA @ 1mM in pea plants at 25 and 40 DAS resulted in a significant increase in dry matter; leaf area as well as plant height compared no Mg application (Howladar *et al*., 2014). Thalooth *et al.* (2006) reported that, foliar application of Zn, potassium and magnesium resulted in improved growth parameters of mungbean.

At 75 DAS and 90 DAS, higher dry matter production (3996 kg/ha and 2461 kg/ha respectively) was noticed under minimum tillage along with K-$MgSO_4$ @ 40:60 kg/ha. Results indicated that, dry matter production increased gradually till 75 DAS and declined at later stage due to senescence of leaves.

Potassium applied @ 40 kg/ha along with higher level of Mg, *i.e.* 80 kg/ha, produced lower dry matter than K-Mg @ 40:60 kg/ha. This might be due to the antagonistic affect between K and Mg at higher levels. Narwal *et al*. (1985) reported that dry matter yield increased when K was applied up to 150 ppm with Mg up to 20 ppm, and dry weight of roots increased when the Mg level was increased to 40 ppm.

Root growth

Tillage had significant effect on root parameters like root length and root spread, while it failed to create significant influence on root-shoot ratio **(Table 27 & 28)**. Cowpea roots were longest under no tillage (38.5 cm), followed by minimum tillage (36.5 cm) and the shortest roots were noticed under conventional tillage. Similarly root spread (2379 cm^2) and root weight (3.5 g) was recorded highest under zero tillage system. Cowpea, being a legume crop, has typical tap root system which can penetrate to deeper layer of soil and probably tillage is not important in root elongation.

Studies indicated that roots of some plant species can penetrate compact layer under no tillage system which helps in nutrient absorption (Unger and Kaspar, 1994). Ball-Coelho *et al*. (1998) noted that the distribution of crop roots in different layers of soil can be affected by the type of tillage. It is known that the tap-root system is strong enough for penetrating better in soils with high resistance than fibrous root system.

Similarly, root length of faba bean was significantly higher under the zero tillage system compared with conventional tillage, which could be attributed to an increase in water use efficiency under no tillage with respect to conventional tillage (Lopez-Bellido *et al*., 2007).

Application of K: $MgSO_4$ @ 40:60 kg/ha produced longest roots and higher root spread. Conventional tillage results in loosening of soil, with increased aeration and nutrient availability in the surface layers itself, and supply of higher doses of K and Mg might have favoured the concentration of cowpea roots in surface layers alone. Sangakkara *et al.* (2001) reported significant increase in root growth of cowpea and green gram under higher level of K application, with greater impact in green gram grown under low soil moisture.

Gransee and Fuhrs (2013) reported that combined application of K and Mg improved the rooting depth of crops. Zero tillage with K: $MgSO_4$ @ 40:60 kg/ha resulted in longest roots (45.2 cm) and higher root spread (2695 cm^2) which was comparable in minimum tillage with K: $MgSO_4$ @ 40:60 kg/ha. However, application of K: $MgSO_4$ @ 40:80 kg/ha in conventional tillage registered shortest roots and lower root spread, indicating that conventional tillage is not necessary in root growth of cowpea.

Effect of tillage and nutrients on yield and yield parameters of cowpea

As per recent reports intensive tillage or soil manipulation is actually not needed to obtain good crop yields and in many cases it can lead to the deterioration of soil health. There are many factors that determine the tillage requirements in a cropping system and the major factors are soil, crop and climatic conditions. There are reports that zero tillage and minimum tillage out yielded conventional tillage, thus reducing energy and labour inputs in farming.

In the present study cowpea was raised in a rice fallow and yield varied significantly with the intensity of tillage. The trend in grain yield was different in the two years of study and pooled analysis of data showed that the grain yield was significantly higher and comparable in minimum tillage and conventional tillage. During 2017-18 both zero and minimum tillage registered comparable yields where as in 2018-19 minimum and conventional tillage were comparable in grain yield. This shows the suitability of cowpea to conservation tillage practices especially in crop rotation involving rice fallow cultivation.

Tillage and nutrient interactions had significant effect on number of pods/M_2 and grain yield **(Fig. 10 & 11)**. Minimum tillage along with application of K: $MgSO_4$ @ 40:60 kg/ha resulted in higher number of pods/M_2 as well as highest grain yield (914.8 kg/ha) as number of pods per plant is a major determinant of yield. This can be also be attributed to the increase in number of branches under minimum tillage leading to higher number of flowers and ultimately pods. Increase in number of branches under minimum tillage was 40 per cent over conventional tillage.

Ploughing the strips alone helps in decreasing evaporation and conserving soil moisture, also the undisturbed area near the strips reduced weed density, and hence decreased weed competition in favour of better crop growth. Also it was found that root growth was more in conservation tillage practices compared to normal tillage. All these factors ultimately might have caused increase in crop yields.

Chickpea seed yield under no tillage was higher by 57% and was higher by 27% under reduced tillage while it was 13% higher under minimum tillage than the conventional tillage, as reported by Hemmat and Eskandari (2004).

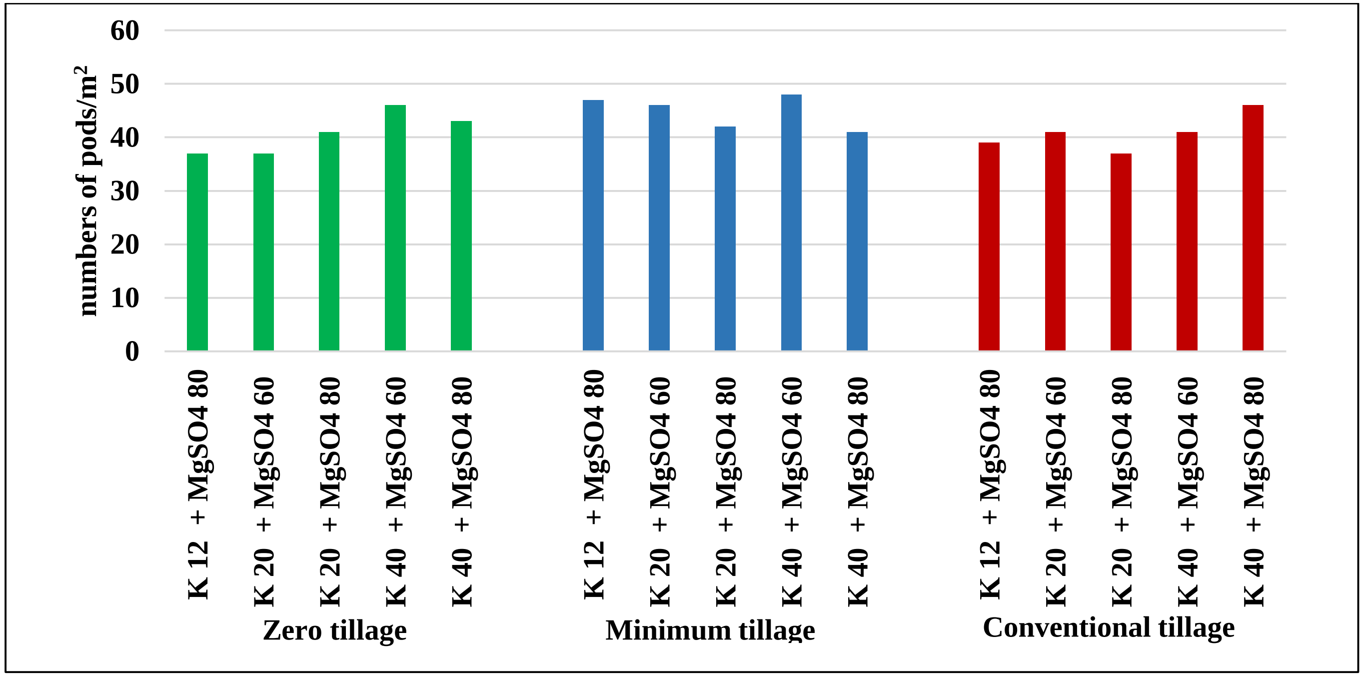


Fig. 10. Number of pods of cowpea as affected by tillage and K & $MgSO_4$ levels

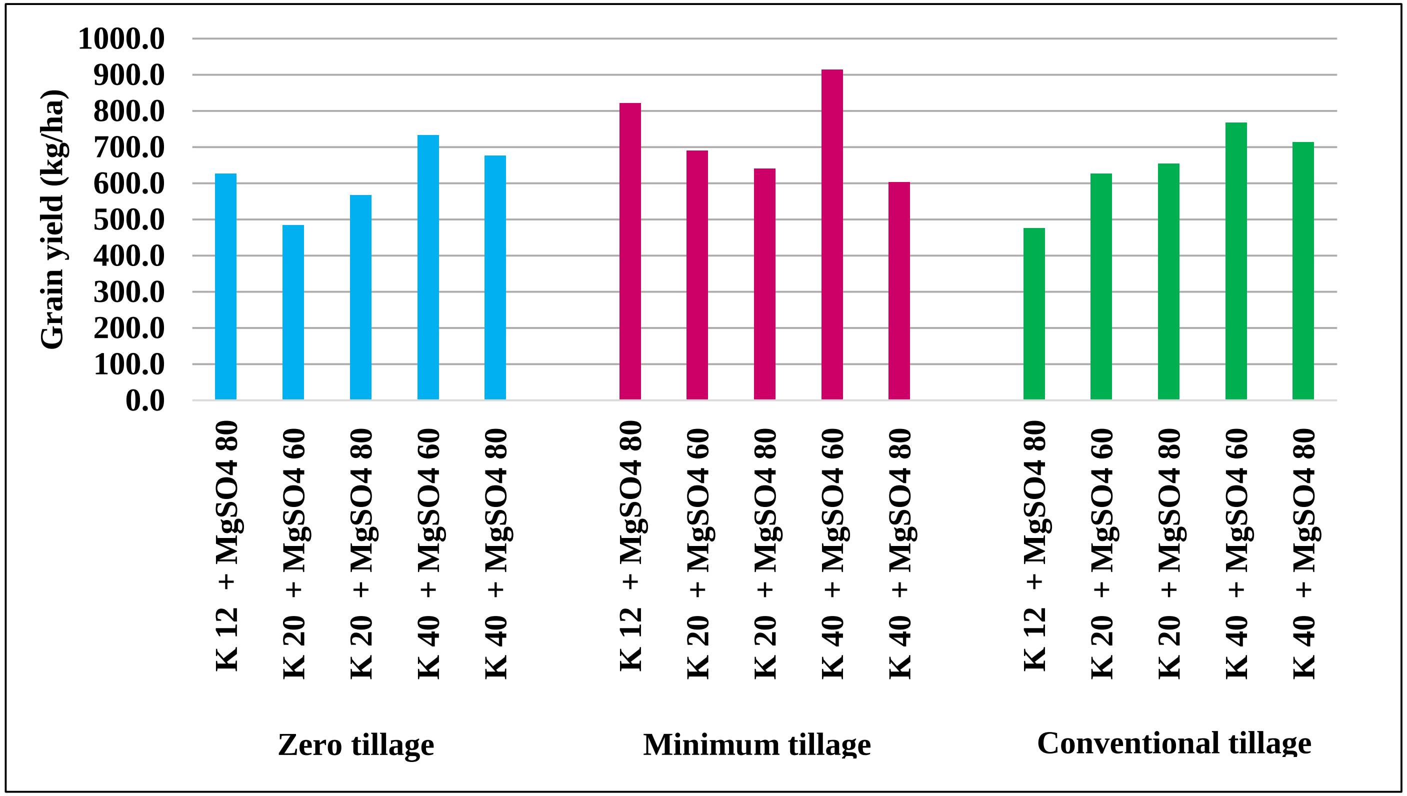


Fig. 11. Grain yield of cowpea as affected by tillage and K & $MgSO_4$ levels

Comparable yields under conventional and no-tillage treatments were reported earlier in legumes like lentil and chickpea by Pala *et al.* (2000). Dry bean yield under zero tillage was higher than the yield recorded under conventional tillage in different places of Canadian prairies (Blackshaw *et al.*, 2007). In chickpea and safflower comparable yields were obtained in zero and conventional tillage, suggesting that the tap root system of chickpea and safflower might be more adapted to zero tillage (Yau *et al*., 2010).

Onyari *et al.* (2010) observed that compared to double digging, furrow tillage, and conventional tillage, highest plant biomass production at reproductive stage, grain yield and number of pods of chickpea was noticed in strip tillage, as the strips helps in conserving soil moisture reducing evaporative loses making it available for consumptive use by this deep rooted crop.

El-Naim and Jabereldar (2010) reported that when plant population was higher, number of pods per plant, number of seeds per pod and hence seed yield per plant was reduced. Similar observations were also reported by Neugschwandtner *et al.* (2015). Seed yield and number of pods per plant of chickpea under reduced tillage was higher than no-tillage and conventional tillage (Chaghazardi *et al.*, 2016).

Application of K @ 40 kg/ha with $MgSO_4$ @ 60 kg/ha might have increased the rate of photosynthesis leading to higher yields. Potassium is fundamental for activating enzymes essential for many metabolic processes, and also for stomatal regulation in plants. Ganga *et al.* (2014) reported that effect of various levels of potassium on yield of chickpea varied significantly and higher yield was noted with 60 kg K_2O/ha and the increase in yield was due to improvement in all the yield parameters.

K deficiency reduced photosynthetic rate and the rate of ATP production (Römheld and Kirkby, 2010). Hence K has a crucial role in deciding yield. This is in line with the findings of Mona *et al.* (2011), where K fertilization in the form of potassium sulphate increased the number of pods in faba bean. Foliar application of K or Mg resulted in higher yields and number of pods in mungbean (Thalooth *et al*., 2006).

Application of $MgSO_4$ @ 60 kg/ha resulted in enhanced chlorophyll content which might be the other reason for higher yields of cowpea. In plant system, magnesium is phloem mobile and gets readily translocated to actively growing sink (White and Broadley 2009). Magnesium is vital in chlorophyll formation and increasing photosynthetic rate. Magnesium plays vital role in physiological processes and its key function is phloem loading, as a co-factor and allosteric modulator for more than 300 enzymes including in Calvin cycle, kinases, RNA polymerases and ATPases (Cowan 2002; Shaul 2002; Verbruggen and Hermans 2013).

Mg is crucial for the transport of assimilates from source to sink, hence Mg deficiency stress in plants disturbs photosynthate partitioning between roots and shoots, leading to accumulate assimilates in leaves, reducing the development of sink (Cakmak and Kirkby 2008; Cakmak 2013).

Increase in crop yield was observed in soybean (Vrataric *et al.*, 2006), as well as in fava bean (*Vicia faba*) (Neuhaus *et al.*, 2014) as a result of foliar application of magnesium. Application of Mg had positive effect on the translocation of photosynthate in plants (Cakmak & Yazici, 2010). Hence its application might have increased grain filling and yield. These findings are in line with Altarugio *et al*. (2017) in soybean and corn.

K: $MgSO_4$ @ 40:80 kg/ha registered lower yields probably because of antagonistic effect of higher levels of K on availability of Mg. These findings are in line with Guiet-Bara *et al.* (2007) who found that fertilization with high potassium levels can also result in Mg deficiency as K inhibits Mg absorption by plants.

Kumar *et al.* (2018) reported that application of K_2O @ 90 kg /ha produced significantly higher grain and straw yield in chickpea followed by application of 60 kg potassium and reduction in yields under no potassium was attributed to reduction in growth and yield parameters.

C. Effect of tillage and nutrients on protein content

Different tillage systems such as zero tillage, minimum tillage and conventional tillage, as well as the interaction between tillage and nutrients had no significant effect on protein content in grains **(Table 31).** In general, conventional tillage along with various levels of K: $MgSO_4$ resulted in higher protein content in grains.

Among various nutrient doses, K: $MgSO_4$ @ 40:80 kg/ha registered higher protein content (26.2%). This might be due to application of higher level of K, leading to higher K content in grains (1.72%) which might have favoured in protein synthesis. Potassium is associated with quality of grains in pulses including protein content and higher concentration of potassium helps in more protein synthesis. Evans and Sorger (1966) reported that in higher plants, a characteristic physiological symptom for potassium deficiency is the accumulation of the protein precursors, amino acids and amides in the tissues. As per the reports of Blevins (1985), low K concentrations in plants inhibited protein synthesis.

Increased K supply enhanced quality characteristics including protein content in grains, N fixation, water use efficiency, reduced pest and disease incidence as well as improved yield of pulses (Srinivasarao *et al.*, 2003). Thalooth *et al.* (2006) reported that foliar application of potassium registered highest protein content in mungbean seeds, followed by protein content in foliar application of Mg, which might be attributed to influence of K and Mg on metabolic and biological activity as well as stimulating effect on enzyme and photosynthetic pigments which in turn favoured growth, yield and protein content of mungbean.

Various studies on K fertilization reveals that potassium has direct as well as indirect role in major plant processes like photosynthesis, respiration, osmoregulation, synthesis of protein synthesis, activation of enzyme, water uptake, and thus overall growth and yield of crop.

B. Effect of tillage on nutrient uptake

The uptake of nutrients by plants mainly depends upon its dry matter production as well as the nutrient content. The data on nutrient uptake at harvest revealed that various levels of K and Mg under different tillage systems had significant influence on uptake of primary and secondary nutrients **(Table 44-49).**

Results indicated that minimum tillage practices registered higher N and P uptake as well as highest uptake of Ca and Mg. However, potassium uptake was highest under conventional tillage. Zero tillage system resulted in lowest uptake of N, P, K, and Mg. However, highest sulphur uptake was registered under zero tillage and the lowest uptake was noticed under conventional tillage. Data showed that available sulphur was also lower under conventional tillage, and this indicates the loss of sulphur to deeper layers under intensive ploughing making it unavailable for plant absorption.

Higher nutrient uptake by leguminous crops under conservation tillage is reported elsewhere. In soybean growth and nutrient uptake by plants under reduced tillage containing surface residue were better than conventional tillage (Deibert and Utter, 1989) Deibert and Utter (2002) also reported strip tillage resulted in higher dry matter production and N-P-K uptake by beans

Highest uptake of Ca, Mg and S was noticed under soil test based nutrition where K was applied @ 12 kg/ha. The lower rate of potash might have increased magnesium, and sulphur absorption by plant. Higher availability of cations such as K, Ca, and Mn, decreased the uptake of Mg (Marschner, 2012)

Application of K: $MgSO_4$ @ 40: 60 kg/ha registered higher uptake of N and K. This is due to the fact that the increase in level of K with Mg @ 60 kg/ha increased nutrient content in grain and stover which contributed to higher uptake. Kurdali *et al.* (2002) observed that K fertilizer application significantly enhanced nitrogen content in faba bean. Singh *et al.* (2002) and Chavan *et al.* (2012) reported that higher K levels resulted in higher K content in grains and increased the uptake of nitrogen, phosphorus, and potash by cowpea grain and stover.

Rady and Osman (2010) observed that foliar spray of Mg-EDTA @ 30 mg/L resulted in higher uptake of N, P, K, Ca, Mg, and Zn in beans. Thesiya *et al.* (2013) revealed that applying K @ 20 kg/ha resulted in higher nutrient uptake by black gram. Kumar *et al.* (2014) also observed that, higher doses of potassium resulted in higher N content in green gram seeds. Venkatesh *et al*. (2018) indicated that there is a positive and significant correlation between soil available Mg, its uptake and magnesium content in green gram plants

D. Effect of tillage and nutrients on soil parameters

Results reveals that, various tillage and nutrient application had no significant effect on soil chemical properties like pH, EC, and organic carbon and available phosphorus content **(Table 50)**. Tillage practices can alter only the physical properties of soil and change in chemical properties is a long term effect of organic matter addition, liming as well as nutrient application. Sharma and Acharya (2000) have noticed that short term conservation tillage had no significant effect on soil organic carbon content, however, they opined that practicing conservation tillage for a longer period may have a significant effect on many soil physical properties, including water holding capacity leading to higher crop productivity. Sharma *et al.* (2010) observed that tillage practices did not influenced organic carbon content of soil significantly. In this experiment also as the growth of cowpea was comparable in different tillage treatments, organic matter addition by the crop to the soil also would have been similar to comparable values in organic carbon. It can be seen that there was a decrease in soil organic carbon to 0.78 % compared to initial status.

The lowest N, P, and K were noticed under zero tillage **(Table 53).** This is probably due to the fact that applied fertilizers were not incorporated into the soil and hence losses of applied fertilizers might have taken place. It can be seen that the available potassium, calcium and magnesium were high in conventional tillage compared to zero or minimum tillage. Ball-Coelho *et al*. (1998) reported that methods of tillage followed in crop production can change nutrient distribution in various soil layers. Available magnesium noticed under conventional tillage was highest and the lowest was noted under minimum tillage. This might be due to the fact that uptake of Mg was more under minimum tillage whereas the uptake under conventional tillage was less

Effect on soil microbial population

Results indicated that, total bacteria, total fungi, and biological nitrogen fixers count were the highest under zero tillage and lowest was noticed under conventional tillage. Stubble retention and undisturbed soil might have favoured higher population of microbes under zero tillage. However, rhizobium population was not present in any of the treatments and population of actinomycetes were recorded only under zero tillage systems **(Table 55 & 56)**. El-Titi, (2003) reported that, reducing intensity of tillage can increase the abundance and diversity of soil microbial communities. Mycorrhizal population is found to be more stable in zero tillage (Souza-Andrade *et al.,* 2003).

Feng *et al.* (2003) reported that zero tillage practices along with residue retention, cover crops, and/or crop rotations retains soil nutrients and water, leading to enhanced microbial population and microbial activity. Soon and Arshad (2004) noted enhanced soil microbial N in legume-based cropping system under no-tillage compared to conventional tillage. Zero tillage helps in increasing soil microbial population and their activity, increasing soil organic carbon, (Jain *et al*., 2007). In agricultural fields, continuous tillage causes negative impact on physico-chemical and biological properties of soil by causing soil degradation which in turn may cause changes in the soil microbial fauna and flora. (Dorr de Quadros *et al.*, 2012).

E. Effect of tillage and nutrients on weeds

The weed spectrum constituted mainly the broad leaved weeds which included, *Melochia corchorifolia, Commelina diffusa, Aeshynomene indica, Ludwigia parviflora, Cyanotis axillaris, Elephantopus scaber, Mollugo pentaphylla, Mollugo* *disticha, Emilia sonchifolia, Scoparia dulcis, Cleome burmanii, Ageratum conyzoiides, Centrosema pubescens, Passiflora foetida, Digitaria sanguinalis, Alternanthera sessilis, Phyllanthus niruri and Ipomoea pes-tigridis.*

Melochia corchorifolia was the major weed species observed **(Table 32).** Total number of *Melochia corchorifolia* recorded was highest under conventional tillage (32/M_2) which was four times higher than that in zero tillage (8/M_2). This might be due to good tilth which favoured germination of Melochia seeds in conventional tillage. Sowing cover crops in zero tillage helped in decreasing population of annual weed species due to reduced germination of weed seeds from existing seed bank (Bilalis *et al,.* 2001). Chauhan *et al.* (2006) suggested that effectiveness of zero tillage on weed control varies in accordance with weed and crop species as well as with herbicide used, hence one should choose appropriate herbicide and right timing and dose and it is critical in conservation agriculture approach.

Echinochloa colona, Brachiaria mutica, and *Isachne miliacea* were the grass species observed. Species diversity was more under conventional tillage with various levels of K and Mg. Zero tillage resulted in comparatively lower weed diversity. Grasses like *Brachiaria mutica*, were low in number under conventional tillage but was noticed higher under minimum tillage. Similarly, number of *Isachne miliacea* was higher under minimum tillage as compared to zero and conventional tillage. However, conservation tillage (minimum tillage and zero tillage) along with various nutrient doses resulted in comparatively lower number of weeds and diversity.

As in the case of weed density, weed dry matter was highest (9.7 g/m^2 and 17.1 g/m^2 at 30 and 60 DAS respectively) under conventional tillage which was followed by minimum tillage. The lowest weed dry matter was obtained under zero tillage (2.7 g/m^2 and 3.2 g/m^2 respectively) which can be due to the application of glyphosate without much soil disturbance. Moreover, cowpea grows quickly and smothers the ground reducing weed infestation.

Application of K: $MgSO_4$ @ 40:80 kg/ha and soil test based nutrition registered higher weed dry matter at 30 DAS. At 60 DAS, soil test based nutrition produced highest weed dry matter (11.7 g/m^2). Studies indicated that fertilizers benefit weeds more than crops and the application of fertilizers increased weed density and their biomass.

Results also indicated that application of various doses of nutrients under conventional tillage resulted in comparable weed dry matter at initial growth stages of crop while at 60 DAS, K: $MgSO_4$ @ 20:60 and 20:80 kg/ha produced higher weed dry matter. This might be due to more availability of nutrients along with loose soil under conventional tillage. Contradictory to this, Khan *et al.* (2017) reported that tillage practices significantly affected weed density and fresh weight while K sources and levels and all interactions had no significant influence. Yang *et al*. (2018) studied maize-wheat-soybean/common vetch under tilled and untilled conditions either with or without stubble retention, and observed that number of weed species and weed density in all three crops had been affected by crop growth stage and tillage. Yadav *et al*. (2018) also reported higher total weed density and biomass in conventional tillage over no-tillage with 100 per cent residue retention

In conservation tillage, either no or less soil disturbance might have resulted in late emergence of weed seeds and hence weed competition to the crop was less. Besides, under minimal disturbance to the soil, most of the weed seeds would remain on the soil surface even after sowing of the crop which made them vulnerable to surface-dwelling granivores, like birds and insects. Many studies showed that, under zero tilled conditions, newly dispersed weed seeds remained on the soil surface itself, while conventional tillage exposed weed seed bank inducing weed seed germination.

G. Economics of rice fallow cowpea production under conservation tillage

Highest cost of cultivation was noticed under zero tillage along with K: $MgSO_4$ @ 40:80 kg/ha (Rs. 24,476/ha) followed by zero tillage with K: $MgSO_4$ @ 40:60 kg/ha (Rs. 24,156/ha). The high cost in this treatment was contributed by the labour charges for dibbling seeds which took more time compared to dibbling in a tilled soil. In conventional tillage formation of ridges and furrows after tractor ploughing resulted in a cost of Rs. 6000/ha whereas cost was lowest is for minimum tillage **(Table 58)**.

Gross return calculated was highest in minimum tillage with K: $MgSO_4$ @ 40:60 kg/ha (Rs. 45,738/ha) followed by minimum tillage with soil test based nutrition (Rs. 41,073/ha). This is due to more grain yield in these treatments. A similar trend could be observed with respect to net returns also and a net return of Rs. 23,982/ha was realized with the application of K: $MgSO_4$ @ 40:60 kg/ha under minimum tillage, and this treatment also resulted in highest B: C ratio of 2.1.

Akinyemi *et al*. (2003) found that there is economic benefit by raising cowpea under ridge tillage system over zero and flat tillage systems with the highest benefit: cost ratio of 3.8. Hobbs and Gupta (2003) reported that under zero tillage, there is seasonal savings in use of diesel for land preparation and it is in the range of 15–60 L/ha, leading to a savings of 60–90% in rice-wheat systems. Buman *et al.* (2004) noticed that in crop production of maize under long-term varying tillage practices, profit from maize under no-tillage and strip-tillage was highest in four out of five years. According to Dodwadia and Sharma (2012), green gram cultivated in summer season, under zero tillage was more profitable as it involved lower cost of production and produced similar yields as in normal tillage which resulted in higher net returns and B: C ratio.

Labour requirement for land preparation under minimum tillage was reduced by 31%, as there was a single ploughing instead of two (Pradhan *et al.*, 2015). Yedukondalu *et al*. (2007) concluded that soil application of $MgSO_4$ @ 50 kg/ha along with recommended dose of fertilizers resulted in higher B: C ratio (4.9) in soybean.

According to Asgar-Ali *et al.* (2007), application of K @150 kg/ha gave higher net returns of Rs.49431/ha in chickpea which was 76.2 % higher than control, followed by net returns recorded in application of K_2O @ 125 kg/ha.

Summary

VI. SUMMARY

A study on effect of nutrients and tillage interactions in rice-fallow cowpea production was conducted in Department of Agronomy, College of Horticulture, Vellanikkara during 2017-19, with main objective of assessing the response of cowpea to various levels of potassium and magnesium sulphate application under conservation tillage systems. A preliminary pot culture study was conducted with 14 treatments to assess the response of cowpea to various K and $MgSO_4$ doses. Bush type variety Anaswara released from KAU was used for the study. Treatments consisted of three levels of potassium, 10, 20, and 40 kg/ha along with four levels of magnesium sulphate i.e. 40, 60, 80, and 100 kg/ha. Apart from this KAU package of practices (K: $MgSO_4$ @ 10:80 kg/ha) and soil test based nutrition (12:80 kg/ha) were also included. Based on yield, five best treatments selected were, K: $MgSO_4$ @ 40:80, 40:60, 20:80, and 20:60 kg/ha, as well as soil test based nutrient management. These treatments were included in the field trial.

Field experiments were conducted in rice-fallow during November 2017- April 2018 and October 2018- April 2019 and the design was RBD. Treatment consisted of factorial combination of three tillage practices; herbicide based zero tillage (zero tillage), minimum tillage (minimum tillage) and five doses of K and $MgSO_4$ @ 20:60, 20:80, 40:60, 40:80 and 12:80 kg/ha. The soil of the experimental field was sandy loam, with an acidic pH of 4.6. Soil was high in organic carbon, available nitrogen, but deficient in available P K, and Mg. Seeds were dibbled at spacing of 30 cm x 15 cm. In zero tillage, herbicide glyphosate was sprayed @ 0.85 kg/ha two weeks before sowing. In minimum tillage, strip tillage was adopted at a spacing of 30 cm. Land was ploughed twice followed by formation of small ridges and furrows at a spacing of 30 cm in conventional tillage.

The results indicated that, conventional tillage resulted in highest germination percentage as compared to no tillage and this directly influenced crop density. Conventionally tilled plots provided loose soil with good aeration, and favoured germination. In conservation tillage good growth of individual plants.

However, tillage and K-$MgSO_4$ application had no significant effect on plant height of cowpea, average height at 60 DAS was 47.5 cm, 52.9 cm and 48.4 cm under zero tillage, minimum tillage and conventional tillage. Tillage systems influenced number of branches per plant significantly; at 45 DAS, zero tillage resulted in highest number of branches (8.5) which was at par with minimum tillage (8.2). At 60 DAS, number of branches noted under minimum tillage was significantly higher (14) followed by zero tillage (12). The lower branching in conventional tillage might be due to more number of plants per unit area due to higher seed germination percentage leading to higher plant density per unit area.

Similarly, highest LAI of 12 was also recorded in zero tillage. This was due to better growth and branching of individual plants in this treatments. On the contrary, due to more number of plants under conventional tillage resulted in low LAI (5.5). Addition of higher doses of K and Mg increased soil fertility, uptake of nutrients and expansion of leaves and hence application of K: $MgSO_4$ @ 40:80 kg/ha also resulted in higher LAI (10.8). Hence zero tillage along with K: $MgSO_4$ @ 40:80 kg/ha (M_1S_5) recorded highest LAI (14.8).

Application of K: $MgSO_4$ @ 20:60 kg/ha and K: $MgSO_4$ @ 40:80 kg/ha resulted in higher as well as comparable total chlorophyll content. Root growth was higher under zero tillage and application of K: $MgSO_4$ @ 40:60 kg/ha produced longest roots and higher root spread. Conventional tillage results in loosening of soil, with increased aeration and nutrients availability in the surface layers itself, along with supply of higher doses of K and Mg might have favoured the cowpea roots to concentrate in surface layers alone and hence registered shortest roots and lower root spread. Zero tillage with K: $MgSO_4$ @ 40:60 kg/ha (45.2 cm) resulted in longest roots and higher root spread (2695 cm^2).

With respect to dry matter production of cowpea, higher dry matter was produced was under conventional tillage 60 DAS, whereas, at 75 DAS, highest dry matter was produced under minimum tillage (3240 kg/ha). However, at 90 DAS, both minimum and conventional tillage resulted in higher dry matter (2043 kg/ha and 2085 kg/ha) and it was at par. It was also noticed that, since, root weight, root length and root spread was highest under zero tillage, the photosynthates partitioning might have concentrated more towards the development of root rather than shoot and pods, throughout the crop growth, plants under zero tillage consistently produced lowest dry matter.

At 75 DAS and 90 DAS, higher dry matter production was noticed under minimum tillage along with K-$MgSO_4$ @ 40:60 kg/ha (3996 kg/ha and 2461 kg/ha). Results indicated that, dry matter production increased gradually till 75 DAS and declined at later stage due to senescence of leaves. Potassium applied @ 40 kg/ha along with $MgSO_4$ @ 80 kg/ha, produced lower dry matter than K-Mg @ 40:60 kg/ha.

Conventional tillage led to early flowering and 50% of plants came to flowering in 45-46 days which can be attributed to the early establishment of plants under conventional tillage due to early germination and growth.

Tillage and nutrient interactions had significant effect on grain yield and number of pods/M_2. Minimum tillage with application of K: $MgSO_4$ @ 40:60 kg/ha resulted in higher number of pods/M_2 (48) as well as highest grain yield (914.8 kg/ha). Application of K @ 40 kg/ha with $MgSO_4$ @ 60 kg/ha increased grain yield of cowpea.

Higher yields under minimum tillage and higher plant nutrient content resulted in higher uptake of N, P, Ca, and Mg which might be the higher root length and root spread. Among nutrient doses, highest uptake of Ca, Mg and S was noticed under soil test based nutrition where K was applied @ 12 kg/ha. The lower rate of potash might have prevented antagonistic effect on Mg and might have increased magnesium, and sulphur absorption by plant. While, application of K: $MgSO_4$ @ 40: 60 kg/ha registered higher uptake of N and K. The increase in level of K with Mg @ 60 kg/ha increased nutrient content by grain and stover resulting in higher uptake.

Soil chemical properties like EC, pH, organic carbon and available phosphorus content were not affected by various tillage and K and $MgSO_4$ doses.

However, available nitrogen was observed highest under minimum tillage, while conventional tillage resulted in highest available potassium Soil Ca and Mg recorded highest under conventional tillage meanwhile, zero tillage recorded highest soil sulphur.

Available N was recorded highest with the application of K2O @ 20 kg/ha + $MgSO_4$ @ 80 kg/ha under minimum tillage. Whereas conventional tillage with K_2O @ 40 @ kg/ha + $MgSO_4$ @ 80 kg/ha recorded higher available K content. Available magnesium noticed under conventional tillage was highest and the lowest was noted under minimum tillage.

Population of total bacteria, total fungi, and biological nitrogen fixers' were highest under zero tillage, and the lowest was noticed under conventional tillage. Stubble retention, undisturbed soil surface, and nutrient application as well as presence of cowpea favoured highest population of microbes under zero tillage. However, rhizobium population was not present in any of the treatments, which can be attributed to the acidic pH of soil, and population of actinomycetes were recorded only under zero tillage systems

The highest cost of cultivation was noticed under zero tillage along with K: $MgSO_4$ @ 40:80 kg/ha (Rs. 24,476/ha) which might be due to higher labour requirement for dibbling of seed under zero tillage. Gross return (Rs. 45,738/ha), net returns (Rs. 23982/ha) and B: C ratio were the highest in minimum tillage with K: $MgSO_4$ @ 40:60 kg/ha.

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Appendix

APPENDIX-I

Month-year	Rain (mm)	Temperature (^{0}C)		Wind	Sun shine	Mean relative humidity
	Past 24 Hrs. ending 08.30	Max	Min	Past 24 Hrs (km/hr)	Hrs on previous day	%
March '17	13.2	36.1	24.7	2.2	7.4	67
April '17	19.1	35.7	26.0	2.1	6.5	70
May '17	167.5	34.6	24.9	1.8	5.5	72
June '17	630.2	30.4	23.5	1.1	2.0	87
July '17	385.5	30.8	22.8	1.2	2.9	85
Aug '17	478.0	30.1	23.3	1.0	3.1	87.0
Sept '17	413.9	31.5	22.9	0.7	4.2	84
Oct '17	183.4	31.7	22.3	0.2	4.9	81
Nov '17	58.3	33.0	21.8	1.9	6.4	73
Dec '17	11.5	32.4	21.1	5.1	7.3	63
Jan '18	0	33.5	20.9	5.4	8.2	53
Feb '18	5.2	35.7	22.5	5.7	9.5	47
Mar '18	33.2	36.7	24.0	3.3	8.0	59
April '18	28.9	36.1	24.8	2.2	7.3	69
	320.5	34.2	22.5	3.4	7.4	63.6
Oct '18	273.4	35.7	22.5	5.4	8.2	53
Nov '18		36.7	24.0	5.7	9.5	47
Dec '18		36.1	24.8	3.3	8.0	59
Jan '19	0	33.0	20.5	2.2	7.3	69
Feb '19	0	35.6	23.8	3.4	7.4	63.6
Mar '19	0	36.8	25	2.2	7.3	69
April '19	0	35.9	25.4	3.4	7.4	63.6

Nutrients and tillage interactions in rice fallow cowpea (*Vigna unguiculata* L. Walp.) production

By

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ABSTRACT OF THE THESIS

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ABSTRACT

An experiment entitled "Nutrients and tillage interactions in rice fallow cowpea production" was conducted during 2017-2019 at College of Horticulture, Vellanikkara of Kerala Agricultural University, Thrissur. The study consisted of two experiments. Experiment-1 was a pot culture study undertaken during 2017, to find out optimum dose of potassium and magnesium sulphate for cowpea. The experiment was laid out in CRD with 14 treatments and three replications. The treatments included three levels of K_2O (10, 20 and 40 kg/ha), and four levels of $MgSO_4$ (40, 60, 80 and 100 kg/ha). Apart from K: $MgSO_4$ @ 10:80 kg/ha (KAU package of practices) and soil test based nutrition (K: $MgSO_4$ @12:80 kg/ha) were also included. Nitrogen and P_2O_5 were applied at the rate of 20 and 30 kg/ha, respectively, uniformly to all pots. A bush type variety of cowpea Anaswara released from Kerala Agricultural University was used in the study.

In the pot culture experiment, application of K_2O: $MgSO_4$ @ 40: 40 kg/ha and 40:100 kg/ha resulted in taller plants. At 60 DAS, POP based nutrient application registered more number of branches (12.7 /plant), which was on par with K_2O: $MgSO_4$ @ 10:60 (T_2), 20:40 (T_5), 20:100 (T_8), 40:40 (T_9), 40:80 (T_{11}), 40:100 (T_{12}) kg/ha as well as to soil test based nutrition (T_{14}). Highest number of root nodules (201) and higher dry matter production at harvest (44 g/plant) was observed in application of K: $MgSO_4$ @ 40:100 kg/ha (T_{12}). An increase in dry matter production of cowpea was observed with magnesium sulphate nutrition. Various levels of K and Mg resulted in significant variation in chlorophyll a and total chlorophyll content. Application of potassium and $MgSO_4$ @ 40:60 kg/ha resulted in higher number of pods and grain yield (40.3 g/plant) and it was statistically comparable to T_{11} and T_{12} (K_2O: $MgSO_4$ @ 40:80 & 40:100 kg/ha). Based on grain yield, treatments K: $MgSO_4$ @ 20:60 kg/ha, 20:80 kg/ha, 40:60 kg/ha, 40:80 kg/ha were selected for field trial along with soil test based nutrition as control.

The second experiment aimed at assessing the effect of various tillage practices, and varied doses of potassium and $MgSO_4$ on growth and yield of cowpea and to work out economic viability. Field experiments were undertaken in rice fallow during 2017 and 2018 (November/December - March/April). Soil of the filed was high in organic carbon, available N, but deficient in available P, K, and Mg. The experiment was laid out in RBD and the treatments were factorial combinations of three types of tillage and varied doses of potassium and magnesium sulphate and it was replicated thrice. Zero tillage (ZT- M_1), minimum tillage (MT- M_2) and conventional tillage (CT- M_3) were the major factors and five nutrient doses (S_1-S_5) were soil test based nutrition (S_1- 11-13 kg K_2O/ha along with 80 kg $MgSO_4$/ha), 20 kg K_2O/ha along with 60 kg/ 80 kg $MgSO_4$/ha (S_2 & S_3) and 40 kg K_2O/ha along with 60 kg/ 80 kg $MgSO_4$/ha (S_4 & S_5). N and P_2O_5 were applied at the rate of 20 kg/ha and 30 kg/ha in all plots. Seeds were dibbled at spacing of 30 cm x 15 cm. In zero tillage, herbicide glyphosate was sprayed @ 0.85 kg/ha two weeks before sowing. In minimum tillage, strip tillage using spade was adopted at a spacing of 30 cm. In conventional tillage, land was ploughed twice followed by formation of small ridges and furrows at a spacing of 30 cm. The plot size was 6 m x 4.2 m.

Germination percentage of cowpea (at 7 DAS) was significantly higher in conventional tillage (79 %), whereas, it was very low in zero till (44 %) and intermediate in MT (58 %). Tillage systems and potassium, magnesium sulphate doses had no significant effect on plant height of cowpea, and at 60 DAS average height was 47.5 cm, 52.9 cm and 48.4 cm under zero tillage, minimum tillage and conventional tillage, respectively. At 45 DAS and 60 DAS minimum tillage resulted in higher number of branches per plant whereas, plants in conventional tillage showed earliness in 50 % flowering.

Significantly higher LAI was recorded in zero tillage, followed by minimum and conventional tillage. Application of K: $MgSO_4$ @ 40:80 kg/ha also resulted in higher LAI. Zero tillage along with K: $MgSO_4$ @ 40:80 kg/ha (M_1S_5) recorded the highest LAI. Tillage had no significant effect on chlorophyll a, chlorophyll b, and total chlorophyll content and on chlorophyll a/b ratio. Whereas, potassium and magnesium sulphate application had significant effect on chlorophyll content. Application of K: $MgSO_4$ @ 20:60 kg/ha and K: $MgSO_4$ @ 40:80 kg/ha resulted in higher as well as comparable chlorophyll a and total chlorophyll content. Among interactions ZT with K: $MgSO_4$ @ 12:80 kg/ha (soil test) and CT along with K: $MgSO_4$ @ 20:60 kg/ha higher chlorophyll a content.

Dry matter production at early growth stage was higher under conventional tillage, followed by minimum tillage and zero tillage. Whereas, at 75 DAS, highest dry matter was registered under minimum tillage (3240 kg/ha). However, at 90 DAS, both minimum and conventional tillage resulted in higher as well as comparable dry matter (2043 kg/ha and 2085 kg/ha). Root length and root spread were higher under zero tillage followed by MT and CT. Application of K: $MgSO_4$ @ 40:60 kg/ha also resulted in higher root spread. Zero tillage with K: $MgSO_4$ @ 40:60 kg/ha (45.2 cm) resulted in longest roots and higher root spread (2695 cm^2). Conventional tillage along with supply of K and $MgSO_4$@ 40 and 80 kg /ha registered shortest roots and lower root spread.

Pooled analysis showed that, among various tillage systems, significantly higher grain yield was realized under minimum tillage (735 kg/ha). This was followed by conventional tillage (648 kg/ha) and zero tillage (618 kg/ha) which were on par. Among varied potassium and magnesium doses, application of K: $MgSO_4$ @ 40:60 kg/ha was found to be the best (grain yield of 806 kg/ha). Hence combination of minimum tillage along with K: $MgSO_4$ @ 40:60 kg/ha resulted in the highest grain yield (915 kg/ha).

Uptake of nutrients at 30 DAS followed the order of CT>MT>ZT. At harvest, higher uptake of potassium, and magnesium was noted in K: $MgSO_4$ @ 40:60 kg/ha under minimum tillage. There was no significant variation with respect to grain protein content of cowpea due to various tillage practices whereas higher content was registered with application of K: $MgSO_4$ @ 40:80 kg/ha (26.2 %).

Diverse weed species were observed in the field among which, dicot weed *Melochia chorchorifolia* was the dominant one. Significant variation in weed dry matter was also observed and significantly higher weed dry matter production was registered under conventional tillage and nutrient doses did not influence weed drymatter production.

Treatments had no significant effect soil pH, EC, organic carbon and available phosphorus content. Conventional tillage along with K: $MgSO_4$ @ 40:60 and 40:80 kg/ha recorded higher available K content. Soil magnesium status was the highest under conventional tillage along with K: $MgSO_4$ @ 20:80 kg/ha. Population of total bacteria, total fungi, and biological nitrogen fixers were highest under zero tillage, and the lowest was noticed under conventional tillage and population of actinomycetes was observed only under zero tillage systems.

Combination of minimum tillage along with application of K: $MgSO_4$ @ 40:60 kg/ha recorded highest grain yield, net returns (23,982 Rs./ha) and B: C ratio (2.1). Hence it can be concluded that the productivity of bush type cowpea varieties can be enhanced with application of a higher level of potassium (40 kg/ha) in soils with low available potassium and there is response to magnesium sulphate application. Also in rice fallow cowpea production, minimum tillage practices would be a better alternative to conventional tillage with respect to grain yield and economics.