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Potassium Fractions, Soil Chemical properties and Water Use Efficiency as influenced by Polyhalite Multi-nutrient Fertilizer and Irrigation Regimes of Bt. Cotton under Inseptisols

Utkarsha V. Amolic[1*], Ritu S. Thakare[2], V.S. Patil[3], B.M. Kamble[4] and B.D. Bhakare[5]

*[1]Ph.D. Scholar, Department of Soil Science and Agril. Chemistry,
Mahatma Phule Krishi Vidyapeeth Rahuri, Dist Ahmednagar (Maharashra), India.*
*[2]Associate Professor , Department of Soil Science and Agril. Chemistry,
Mahatma Phule Krishi Vidyapeeth Rahuri, Dist- Ahmednagar (Maharashtra), India.*
*[3]Soil Chemist, Department of Soil Science and Agril. Chemistry,
Mahatma Phule Krishi Vidyapeeth Rahuri, Dist- Ahmednagar (Maharashtra), India.*
*[4]Head, Department of Soil Science and Agril. Chemistry,
Mahatma Phule Krishi Vidyapeeth Rahuri, Dist- Ahmednagar (Maharashtra), India.*
*[5]Department of Soil Science and Agril. Chemistry,
Mahatma Phule Krishi Vidyapeeth Rahuri, Dist- Ahmednagar (Maharashtra), India.*

(Corresponding author: Utkarsha V. Amolic)*
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ABSTRACT: Polyhalite is a hydrated sulphate evaporate mineral containing potassium, calcium, magnesium and sulphur with chemical formula $K_2Ca_2Mg\ (SO_4)_4.2H_2O$. Field experiments were implemented to explore the coupling effects of various drip irrigation and fertilizer levels on the soil properties, potassium fractions and water use efficiency of cotton during the years 2020 and 2021 at AICRP on Irrigation Water Management farm, Mahatma Phule Krishi Vidyapeeth Rahuri, Dist. Ahmednagar (Maharashtra). The field demonstrations were laid out in split plot design with three replications. Total fifty four treatment combinations comprising three irrigation regimes as main plot treatment *viz.,* I_1-0.8 ETc, I_2-1.0 ETc and I_3-1.2 ETc and six fertilizer doses as sub plot treatments. *viz.,* T_1-Absolute control, T_2 - 100% GRDF (125:65:65 N: P_2O_5: K_2O kg ha^{-1}), Mg, S as per recommendation, T_3-100 % N:P_2O_5 + 100% K_2O through polyhalite, T_4-100 % N: P_2O_5: 25 % K_2O through muriate of potash + 75% K_2O through polyhalite , T_5- 100 % N: P_2O_5: 50 % K_2O through muriate of potash + 50 % K_2O through polyhalite, T_6- 100 % N:P_2O_5: 75 % K_2O through muriate of potash + 25% K_2O through polyhalite. Results of study revealed that, Significantly highest water soluble K (10.0 mg kg^{-1}), exchangeable K (190.46 mg kg^{-1}), non-exchangeable (867.50 mg kg^{-1}) and total K (14014.44 mg kg^{-1}) content in soil was recorded with treatment F_4-100%N:P_2O_5:25%K_2O through MOP+75%K_2O through Polyhalite. The fractions of soil potassium were found to be increased along with increasing level of potassium. Soil chemical properties *viz.*, including pH, EC, organic carbon content, available macronutrients and exchangeable cations showed increased significantly with application of 100% N:P_2O_5:25%K_2O through MOP + 75% K_2O through polyhalite. Whereas the deficit irrigation at 0.8 ETc recorded maximum water use efficiency and percentage of water saving. Study concluded that polyhalite shows potential as a commercial fertilizer to supply K, Ca, Mg, and S nutrients. due to low release properties of polyhalite, if integrated in to the fertilization program, a more balance and stable flow of nutrients can be achieve.

Keywords: Fractions of soil potassium, chemical properties, Bt. cotton, water use efficiency.

INTRODUCTION

Polyhalite is a hydrated sulphate evaporate mineral containing potassium, calcium, magnesium and sulphur with chemical formula $K_2Ca_2Mg\ (SO_4)_4.2H_2O$ (Tiwari *et al.,* 2015). Polyhalite is a single complex crystal (triclinic, pseudo-orthorhombic). It is water soluble with precipitation of gypsum and syngenite which is also soluble, leaving behind a precipitate of gypsum. Polyhalite serves as a suitable fertilizer to supply four nutrients, is less water soluble than the more conventional sources and may conceivably provide a slower release of nutrients (Yermiyahu *et al*., 2017). The polyhalite typically consist of K_2O: 14%, SO_4: 48%, MgO: 6% and CaO: 17%. As a fertilizer providing four key plant nutrients polyhalite offers attractive solutions to crop nutrition. An important benefit of using polyhalite as a fertilizer, when compared to the equivalent salts, is the rate at which it releases minerals to the soil profile. The leaching of Ca, Mg, K and S from polyhalite appears to be slower than the leaching of these ions from the commonly used soluble salts (Vale, 2016). In this regard, polyhalite has the potential for longer term effects compared to commercial fertilizers.

Cotton is an important commercial crop in the world. Indian economy continues to receive great support from the most important commercial fibre crop. However, the cotton productivity is still below the potential mainly, because of high evaporative conditions, scarcity of groundwater, deficient rainfall and poor water management practices like poor irrigation scheduling during water scarce conditions, lack knowledge on the frequency of irrigation during low availability of water, low water application efficiencies, water use efficiencies in surface irrigation practices, the traditional management of farms and the climatic conditions characterized by poor and irregular rainfall. Therefore, there is a need for effective on-farm water management, to increase crop yield and save water resources. Adverse environmental conditions coupled with water scarcity intrigued farmers of this region to adopt drip irrigation with mulching in Bt. cotton for mitigating the impact of climatic aberrations. Drip irrigation can reduce input cost, increase yield, give more water productivity than surface irrigation and reduce the risk of yield reduction due to inter-irrigation dry spells (Rajendra *et al.,* 2012). Managing congenial soil moisture in the crop root zone and preventing more productivity per drop of water.

Water is very crucial input in agriculture and hence its efficient utilization is of prime need today in agriculture. Though, the drip irrigation saves almost 40 to 60 per cent of irrigation water, but still there is scope for more precise use of irrigation water hence, the concept of deficit irrigation emerged for use of limited water resources more efficiently for increasing the productivity of crops. Deficit irrigation is a watering strategy that can be applied by different types of irrigation application methods. The correct application of deficit irrigation requires thorough understanding of the yield response to water (crop sensitivity to drought stress) and of the economic impact of reductions in harvest. In regions where water resources are restrictive it can be more profitable for a farmer to maximize crop water productivity instead of maximizing the harvest per unit land. The saved water can be used for other purposes or to irrigate extra units of land.

The present study hypothesizes that, due to low release properties of polyhalite, if integrated in to the fertilization program, a more balance and stable flow of nutrients can be achieve. Secondly, polyhalite is at least as effective as MOP as a K source.

MATERIAL AND METHODS

The present study was conducted during *kharif* season in the year 2020 - 2021 at AICRP on Irrigation Water Management Farm, Mahatma Phule Krishi Vidyapeeth, Rahuri, 413722, Dist. Ahmednagar, Maharashtra (India). Geographically the Central Campus of Mahatma Phule Krishi Vidyapeeth, Rahuri is lies between 19°48' N and 19°57'N latitude and 74°19' E and 74°32' E longitude. The altitude varies from 495 to 569 meters above mean sea level. This tract is lying on the eastern side of Western Ghat Zone and falls under rain shadow area. Argo climatically it falls in semi-arid tropics with annual rainfall varying from 307 to 619 mm. The average annual rainfall is 520 mm. Out of the total annual rainfall, about 80 per cent rains received from South-West monsoon in 15-45 rainy days.

The soil of the experimental field was clay in texture. Before laying out the experiment, soil samples were collected from 0-30 cm depth at random spots covering experimental area, a composite soil sample was prepared and analyzed for various physical and chemical properties by using standard analytical methods which indicates that the soil of the experimental field was clay in texture. The seed material of Bt. cotton hybrid Bhakti (BG-II) was procured from the local market of Rahuri. The dibbling method was used for sowing of cotton. The irrigation was scheduled to alternate days for cotton crop. The treatment wise water requirement of cotton crop was worked out on the basis of class 'A' open pan evaporation. The value of pan coefficient was taken as 0.8.

The present investigation was laid out in Split Plot Design with three replications. Data obtained on various variables were analyzed by 'Analysis of Variance' method (Panse and Sukhatme, 1985).

RESULT AND DISCCUSION

A. Forms of potassium fractions

The different forms of potassium are quite important in assessing K availability in the soil. As such potassium is not rapidly available to plants but it is an important reservoir of slowly available K, if released gradually to more available forms. About 1 to 10 per cent of total K is present in non-exchangeable form which is slowly available because of its fixation by soil colloids. The data on the various fractions of K *viz*., water soluble, exchangeable, nonexchangeable and total K under the respective treatment plots as influenced by potassium application at harvest stage of cotton are presented in Table 1.

(i) Water soluble. The water-soluble potassium is the fraction of soil potassium that can be readily absorbed by plants. Nevertheless, this is very small fraction of total potassium and even in the fertile soil this form cannot fulfil the major requirements of the plants.

The water soluble K in Inceptisols under study (Table 1) revealed that the water soluble potassium at treatment F_4- 100% $N:P_2O_5$:25% K_2O through MOP + 75% K_2O through Polyhalite showed significant result among all treatments (10.05 mg kg^{-1}) at harvest stage. The readily available or water-soluble K has been reported to be a dominant fraction in the initial stage while exchangeable and non-exchangeable contribute more in the later stages of plant growth (Sharma *et al.,* 2009). Similar values of water soluble potassium have been recorded for soils of Sayala and Barshi series in Maharashtra (Patil and Sonar 1993).

(ii) Exchangeable potassium (mg kg^{-1}). Exchangeable K has been generally regarded as reliable index of K removal by crops. It is held by virtue of the negative charges of clay minerals in soil. It is easily exchanged with other cations and is relatively easily available to plants. The exchangeable K constitutes the K adsorbed on soil colloidal complex and is replaceable with neutral salt solution in relatively short time.

The Exchangeable K in Inceptisols under study (Table 1) revealed that treatment F_4-100% $N:P_2O_5$:25% K_2O through MOP + 75% K_2O through Polyhalite showed significant result among all treatments (190.46 mg kg^{-1}) at harvest stage whereas it was significantly lower under control (147.58 mg kg^{-1}). It was observed that the exchangeable potassium was increased along with the increase in potassium fertilization, K^+ may get into the expanded interlayer space and become fixed, by reversing the weathering process. In soil solution the dominant cation is generally Ca^{2+} whose hydrated form is bigger than K^+, it enlarges the interlayer spaces, releasing more K^+, therefore, when exchange place with K^+, in the process when the potassium is removed from soil solution consequent to crop and plant uptake, more potassium continues to be released from clay minerals by cation (including proton) exchange and a gradient created which diffuses out K^+ from within the structure of clay particles to their surface (Sekhon, 1999).

Increase in exchangeable potassium under continuous application of NPK by 21 to 27 percent over control has been recorded by Dhanokar *et al*. (1994) under long term fertilizer experiment study.

(iii) Non exchangeable potassium. Non exchangeable potassium is held between adjacent tetrahedral layers of dioctahedral and trioctahedral micas, vermiculites and intergrade clay minerals. It is also found in wedge zones of weathered micas and vermiculites. Non exchangeable K is moderately to sparingly available to plants. Release of non-exchangeable K to the exchangeable form occurs when levels of exchangeable and soil solution K are depleted by crop removal or by leaching. The release of non-exchangeable K depends upon a number of factors such as nature and amount of clay minerals, level of K reserves, addition of fertilizers, cropping intensity, crop species and root expansion, crop rotation, etc.

Data pertaining to non-exchangeable K is presented in (Table 1) revealed that non-exchangeable potassium was increased along with increasing levels of potassium fertilizer. There was significant increase under application of treatment F_4- 100% $N:P_2O_5$:25% K_2O through MOP + 75% K_2O through Polyhalite over the potassium under control treatment (F_1).

The similar findings were obtained by the non-exchangeable K varied from 130 to 830 mg kg^{-1} in Vertisols of Maharashtra (Pharande and Sonar 1996).

Table 1: Effect of polyhalitemultinutrient fertilizer and irrigation levels on forms of potassium at harvest of Bt. Cotton.

Treatment	Forms of Potassium (mg kg^{-1})				
	Water soluble	Exchangeable	Non exchangeable	Lattice	Total
Irrigation regimes – I					
I_1 : 0.8 ETc	9.25	171.88	811.92	11476.39	12469.44
I_2 : 1.0 ETc	9.11	172.49	806.50	11574.11	12562.22
I_3 : 1.2 ETc	8.83	168.78	787.11	11411.37	12376.11
S.Em (±)	0.10	0.91	6.28	71.56	73.91
CD at 5%	NS	1.92	NS	NS	290.22
Fertilizer Treatment – P					
F_1: Absolute Control	7.77	147.58	741.16	10254.57	11151.11
F_2: 100% GRDF	8.72	163.71	747.03	11040.53	11960
F_3 : 100%$N:P_2O_5$:100 %K_2O through Polyhalite	9.66	180.75	836.87	12100.48	13127.78
F_4 : 100%$N:P_2O_5$:25%K_2O through MOP+75%K_2O through Polyhalite	10.0	190.46	867.50	12946.42	14014.44
F_5 : 100%$N:P_2O_5$:50%K_2O through MOP+50%K_2O through Polyhalite	9.16	171.72	814.17	11153.82	12148.89
F_6: 100%$N:P_2O_5$:75%K_2O through MOP +25%K_2O through Polyhalite	9.0	172.08	804.33	11427.91	12413.33
S.Em (±)	0.23	1.92	10.49	219.14	219.34
CD at 5%	0.67	5.55	30.30	632.93	633.50
Interactions					
I × F	NS	NS	NS	NS	NS

(iv) Lattice potassium. The mineral potassium is bounded within the crystal structure of soil mineral particles but it holds between adjacent tetrahedral layer of micas, Vermiculites and integrate clay minerals (Sparks, 1987). It is moderately to sparingly available to plants, when levels of exchangeable and soil solution K decreased by crop removal or leaching and perhaps by large increasing microbial activities. Data pertaining to lattice K is presented in (Table 1) revealed there was significant increase under application of treatment F_4 - 100% $N:P_2O_5$:25% K_2O through MOP + 75% K_2O through Polyhalite over the potassium under control treatment (F_1). Similar results were also noted by Vaidya (1995); Arbindar Dhar *et al.* (2009); a substantial release of lattice bound potassium during the period of plant growth could take place especially when no potassium or an inadequate amount of it was supplied, in order to fulfil the demand of the crop (Pati Ram and Prasad 1984).

(v) Total potassium. Potassium concentration in plants is the highest and therefore, the amount needed for optimum growth is relatively high, hence the knowledge of K fertility status is of prime importance as it indicates the total reserve of K which may become available to plants. More than 90 per cent of total K in soil is within the crystal lattice of silicate minerals, which on weathering slowly released K in soil for plant utilization.

Data pertaining to total K is presented in (Table 1) revealed there was significant increase under application of treatment F_4-100% $N:P_2O_5$:25% K_2O through MOP + 75% K_2O through Polyhalite over all other treatments . Similar results have been reported that the total potassium increased with the increasing levels of potash inducing building up of K in soil (Amrutsagar and Sonar 1999). Srinivasarao *et al*. (2007) observed that total K was generally higher in Inceptisols followed by Aridisols, Vertisols and Vertic intergrades, while it was low in Alfisols and Oxisols. Whereas, the total K was higher in surface soils and it decreased with depth in all the Inceptisols and unlike Inceptisols, total K decreased with depth in most of the Vertisols.

B. Soil chemical properties of Bt. Cotton

Higher nutrient availability may be attributed to the fact that polyhalite enhances the properties of the soil, supplies multiple nutrients in a slow-release pattern, reduces leaching, and also fosters synergy between the soil, microbes, and plants. It has also been reported by Yermiyahu *et al*. (2017) that using polyhalite as a fertilizer material has improved the soil's fertility. Further increased nutrient availability might be attributed to fact that K, Ca, Mg and SO_4S in polyhalite are more freely available rather than the nutrients of MOP in clay and sandy soils. The use of polyhalite fertilizer is considered harmless, with the development of green agriculture. Previous research Mello *et al*. (2018) has shown that polyhalite fertilizer application improves different soil quality parameters. Similar results were obtained in the present study were discussed under foregoing headings

(i) Physicochemical properties. The pH, EC and Organic carbon content in, soil after harvest of crop as influenced by different treatments are presented in Table 2.

Irrigation regimes. In *kharif* 2020 and 2021 experiment, the pH, EC and Organic carbon content in soil were not influenced significantly due to the different irrigation regimes through dripirrigation method during both years and pooled mean.

Fertilizer treatments. In *kharif* 2020 and 2021 experiment, the pH, EC and Organic carbon content in soil were influenced significantly due to the application of polyhalitemultinutrient fertilizer in combination with MOP as a source of potassium are discussed as follows;

Soil pH. The data reported in Table 2 indicated that the pH of soil was influenced non significantly due to various treatments and it ranged from 8.06 to 8.15 which indicated that the soil was slightly to moderately alkaline in reaction. Numerically higher value (8.12, 8.15, 8.14) during both years and pooled mean respectively of pH was recorded with the treatment F_4-100%$N:P_2O_5$:25%K_2O through MOP+75% K_2O through Polyhaliteas compared to other treatments. The slight increase in soil pH in polyhalite treatments is attributed to the fact that polyhalite is rich in K, Ca, Mg, S, and other mineral elements. The cations, of these minerals, such as Ca^{2+}, Mg^{2+}, and K^+, replace Al^{3+} on soil colloids and neutralize H^+ in the soil solution, thereby improving the soil pH.

Such improvement in soil pH was also reported by Zhao *et al.* (2022).

Soil EC. The electrical conductivity is a measure of soluble salt concentration in soil. Higher amounts of salts in soils restrict the nutrient uptake and thus, affect the plant stand. Status of EC of soil is given in Table 2.

The electrical conductivity after harvest of crop was statistically influenced due to application of fertilizer and ranged from 0.39 to 0.43 dS m^{-1}. There was narrow variation in EC due to various treatments. The values of electrical conductivity showed that the soils are free from the hazardous effect of salts *i.e.* salinity and sodicity. The numerically higher EC value was observed with treatment F_4-100%$N:P_2O_5$:25%K_2O through MOP+75%K_2O through Polyhalite during both years and pooled mean.

Similar results were also reported by Gadhiya *et al.* (2009).

Organic carbon (%). The soil organic carbon is one of the crucial parameters in substantial agricultural productions and soil health. Carbon is the chief element present in soil organic matter comprising about 56 to 58 per cent of its total weight.

The data pertaining to organic carbon are presented in Table 2. The organic carbon content influenced by potassium application has been studied. The significantly highest (0.69, 0.67, 0.68%) organic carbon was recorded under treatment F_4-100% $N:P_2O_5$:25%K_2O through MOP+75%K_2O through Polyhalite during both years and pooled mean. The lowest value of organic carbon was observed under the treatment of control (F_1). The increase in organic carbon in these treatments may be due to these plots produced higher dry matter which resulted into higher leaf biomass as well as below ground biomass. Similar result was also reported by Krishnan and Loweduraj (1997).

Interaction. The interaction effect between irrigation regimes, fertilizer treatments through fertigation was found non-significant in respect of pH, EC and Organic carbon of soil during both the years.

(ii) Macronutrients (kg ha^{-1}). The available nitrogen, phosphorus and potassium content in soil after harvest of crop as influenced by different treatments are presented in Tables 2.

Available Nitrogen (kg ha^{-1}). Nitrogen is the most important major nutrient required by plant which promotes rapid plant growth and improves yield and growth attributes. Perusal of data presented in Table 2 indicates that available N in soil was significantly increased with different fertilizer treatments and Irrigation regimes.

In *Kharif* season 2020, 2021 and pooled mean, higher available N in soil at harvest stage were noticed in application of treatment F_4-100%$N:P_2O_5$:25%K_2O through MOP+75%K_2O through Polyhalite (177.58, 179.58 and 178.58 kg ha^{-1}) which was at par with treatment F_3-100% $N:P_2O_5$:100% K_2O through Polyhalite (174.62, 175.73, 175.17 kg ha^{-1}) whereas treatment F_1 (control) observed significantly lowest value of available N. This might be due to increased N availability with F_4 treatment is attributed to the fact that polyhalite enhances the properties of the soil, particularly, physical and biological. This transformation enhances the N mineralization processes in soils, thereby increasing the availability. Furthermore, improved soil physical condition reduces the leaching losses of N. These results are in agreement with Yermiyahu *et al*. (2017) who reported that using polyhalite as a fertilizer material improved the soil's fertility. Also, synergetic effect of K application resulted in increasing N availability in soil Ghosh *et al*. (2001) also reported the favourable effect of potassium application on available nitrogen status of the soil.

Available Phosphorous(kg ha^{-1}). Perusal of data presented in Tables 1 indicates that available P in soil was significantly increased with different fertilizer treatments and Irrigation regimes.

In *Kharif* season 2020, 2021 and pooled mean higher available P in soil at harvest stage was noticed in application of treatment F_4-100% N:P_2O_5:25%K_2O through MOP+75%K_2O through Polyhalite (14.07,17.98,16.02 kg ha^{-1}) which was at par with treatment F_3- 100% N:P_2O_5:100% K_2O through Polyhalite (13.90, 17.65, 15.78 kg ha^{-1}) whereas treatment F_1 (control) observed significantly lowest value of available P. This might be due to increased P availability with F_4 treatment is attributed to the fact that polyhalite is attributed to the beneficial effects of polyhalite in improving soil properties, specifically, soil biological activity and root growth. Further, the improved soil structural properties and water availability may help increase the P availability in soil. The improved root growth may also help to influence soil properties in the rhizosphere, thereby helping increase soil P availability.

The results are close line with Harish *et al*. (2017) who reported that there is decreased P availability in the soil after 90 DAS may be due to higher uptake of P by plants in square formation, boll formation and boll maturation stage. The levels of fertilisers also influenced the P availability in soil up to some extent.

Available Potassium (kg ha^{-1}). Perusal of data presented in Table 2 indicates that available K in soil was significantly increased with different fertilizer treatments and Irrigation regimes .

In *Kharif* season 2020, 2021 and pooled mean higher available K in soil at harvest stage was noticed in application of treatment F_4-100%N: P_2O_5:25%K_2O through MOP+75%K_2O through Polyhalite (455.05, 459.66, 457.35 kg ha^{-1}) which was at par with treatment F_3-100% N:P_2O_5:100%K_2O through Polyhalite (443.12, 455.62, 449.37) whereas treatment F_1(control) observed significantly lowest value of available K. The increased K availability with F4 treatment might be attributed to the fact that K in polyhalite is more freely available rather than the nutrients of MOP in clay soils. These results are analogous with the findings of Tan *et al*. (2022). Furthermore, the use of polyhalite fertilizer is considered harmless, with the development of green agriculture. Previous research of Mello *et al*. (2018) has shown that polyhalite fertilizer application improves soil potassium availability.

Interaction. The interaction effect between irrigation regimes, fertilizer treatments through fertigation was found non-significant in respect available nitrogen, phosphorous and potassium of soil during both the years.

(iii) Exchangeable cations. The exchangeable cations (Ca and Mg) content in soil after harvest of crop as influenced by different treatments are presented in Table 2.

Exchangeable calcium (cmol(p^{+})kg^{-1}). Perusal of data presented in Table 2 indicates that exchangeable calcium in soil was significantly increased with different fertilizer treatments and Irrigation regimes.

In Kharif season 2020, maximum exchangeable calcium in soil at harvest stage were noticed in application with irrigation regime I_2- 1.0 ETc (37.45cmol(p+)kg^{-1}) and it was at par with irrigation regime I_1-0.8 ETc (36.59cmol(p+) kg^{-1}) whereas, treatment F_4-100%N:P_2O_5:25%K_2O through MOP+75%K_2O through Polyhalite (39.33cmol(p+)kg^{-1}) which was at par with treatment F_3-100% N:P_2O_5:100% K_2O through Polyhalite (38.74 (cmol(p+) kg^{-1}), F_5-100% N:P_2O_5:50% K_2O through MOP + 50% K_2O through Polyhalite (37.67 cmol(p+) kg^{-1}) and F_6-100% N:P_2O_5:75% K_2O through MOP + 25% K_2O through Polyhalite (37.34cmol(p+) kg^{-1}).

In Kharif season 2021, higher exchangeable calcium in soil at harvest stage were observed in application with irrigation regime I_2- 1.0 ETc (36.1cmol(p+)kg^{-1}) and it was at par with irrigation regime I_1-0.8 ETc (35.8cmol(p+)kg^{-1}) whereas, treatment F_4-100%N:P_2O_5:25%K_2O through MOP+75%K_2O through Polyhalite (39.0cmol(p+)kg^{-1}) which was at par with treatment F_3- 100% N:P_2O_5:100% K_2O through Polyhalite (37.3 cmol(p+)kg^{-1}).

While, in calculated pooled mean data the statistically more exchangeable calcium were observed in application with irrigation regime I_2-1.0 ETc (36.79 cmol(p+)kg^{-1}) coupled with treatment F_4-100%N:P_2O_5:25%K_2O through MOP+75%K_2O through Polyhalite (39.16 cmol(p+)kg^{-1}) however irrigation regime I_1-0.8 ETc (36.17 cmol(p+)kg^{-1}) coupled with treatment F_3- 100% N:P_2O_5:100%K_2O through Polyhalite (38.02 cmol(p+)kg^{-1}).This is because, in addition to being a K fertilizer, polyhalite can also be a source of Ca, Mg as it contains $CaSO_4$, $MgSO_4$, and K_2SO_4. The increase in Ca^{2+} content in polyhalite amended treatment is attributed to higher content of these nutrients in polyhalite. Such improvement in Ca with Polyhalite fertilizer application were reported by Mello *et al.* (2018) and Ma *et al.* (2021).

Exchangeable Magnesium (cmol(p+)kg^{-1}). Perusal of data presented in Table 2 indicates that exchangeable magnesium in soil was significantly increased with different fertilizer treatments and Irrigation regimes.

In *Kharif* season 2020, maximum exchangeable magnesium in soil at harvest stage were noticed in application with irrigation regime I_2-1.0 ETc (18.4cmol (p+)kg^{-1}) and it was at par with irrigation regime I_1-0.8 ETc (17.9cmol(p+)kg^{-1}) whereas, treatment F_4-100%N:P_2O_5:25%K_2O through MOP+75%K_2O through

Polyhalite (20.4cmol(p+)kg^{-1}) which was at par with treatment F_3-100% $N:P_2O_5$:100% K_2O through Polyhalite (19.9cmol(p+)kg^{-1}).

In *Kharif* season 2021, higher exchangeable magnesium in soil at harvest stage were observed in application with irrigation regime I_2- 1.0 ETc (17.7cmol(p+)kg^{-1}) and it was at par with irrigation regime I_1-0.8 ETc (17.3 cmol(p+)kg^{-1}) whereas, treatment F_4-100%$N:P_2O_5$:25%K_2O through MOP+75%K_2O through Polyhalite (17.8cmol(p+)kg^{-1}) which was at par with treatment F_3-100% $N:P_2O_5$:100% K_2O through Polyhalite (16.6cmol(p+)kg^{-1}).

While, in calculated pooled mean data the statistically more exchangeable magnesium were observed in application with irrigation regime I_2-1.0 ETc (18.08cmol(p+)kg^{-1}) coupled with treatment F_4-100%$N:P_2O_5$:25%K_2O through MOP+75% K_2O through Polyhalite (19.08) however irrigation regime I_1-0.8 ETc (19.08cmol (p+)kg^{-1}) coupled with treatment F_3- 100% $N:P_2O_5$:100 % K_2O through Polyhalite (18.25cmol(p+)kg^{-1}), F_5- 100% $N:P_2O_5$:50% K_2O through MOP + 50% K_2O through Polyhalite (17.62cmol(p+)kg^{-1}).

Table 2: Effect of polyhalitemultinutrient fertilizer and irrigation levels on soil chemical properties of Bt. cotton (Pooled mean).

Treatment	pH (1:2.5)	EC (dSm^{-1})	Soil available nutrients: Organic carbon (%)	Soil major nutrients (kg ha^{-1}): N	P	K	Exchangeable Cations (cmol(p$^+$) kg^{-1}): Ca	Mg
Irrigation regimes – I								
I_1 : 0.8 ETc	8.12	0.41	0.67	173.76	14.93	435.15	36.17	17.62
I_2 : 1.0 ETc	8.13	0.41	0.67	174.81	15.81	444.95	36.79	18.08
I_3 : 1.2 ETc	8.12	0.40	0.67	170.20	14.34	423.46	32.89	14.13
S.Em (±)	0.006	0.007	0.003	0.90	0.22	4.31	0.84	1.06
CD at 5%	NS	NS	NS	NS	NS	26.26	2.76	3.45
Fertilizer Treatment – P								
F_1: Absolute Control	8.08	0.36	0.63	162.80	13.49	408.99	30.70	13.11
F_2: 100% GRDF	8.13	0.42	0.68	174.04	14.96	429.74	32.49	17.09
F_3 : 100%$N:P_2O_5$:100 %K_2O through Polyhalite	8.12	0.42	0.69	175.17	15.78	449.37	38.02	18.25
F_4 : 100%$N:P_2O_5$: 25% K_2O through MOP+75% K_2O through Polyhalite	8.14	0.42	0.68	178.58	16.02	457.35	39.16	19.08
F_5 : 100%$N:P_2O_5$: 50% K_2O through MOP+50% K_2O through Polyhalite	8.13	0.41	0.67	173.38	15.00	436.63	37.17	17.20
F_6: 100%$N:P_2O_5$: 75% K_2O through MOP +25% K_2O through Polyhalite	8.13	0.40	0.66	173.57	14.91	425.04	36.12	14.93
S.Em (±)	0.008	0.005	0.006	0.70	0.31	4.37	0.84	1.40
CD at 5%	0.02	0.017	0.018	2.13	0.93	13.17	2.37	3.96
Interactions								
I × F	NS	NS	NS	NS	NS	NS	NS	NS

C. Irrigation studies

The data pertaining to water applied, effective rainfall, total water applied and water use efficiency are presented in Table 3 (a-b).

(i) Total Water applied (mm). In *kharif* 2020 and 2021 experiment, the maximum quantity of irrigation water through drip was applied in I_3 -1.2 ETc treatment (446.85 mm, 492.05 mm). The minimum quantity of irrigation water was applied at I_1- 0.8 ETc treatment (368.17 mm, 392.35 mm) during both years. The amount of water required for cotton ranges from 660 to 1,145 mm for different places or different varieties, depending upon duration, soil and climatic conditions. Water is applied through drip irrigation method as per evaporative demand of crop directly in the vicinity of root rhizosphere which reduces the water losses. Increase in the level of water application by drip irrigation decreased the water use efficiency, while limited quantity of water applied under lower drip irrigation regime increased seed cotton yield, due to higher moisture content at all stages. These results were in line with the findings of Veeraputhiran and Chinnuswamy (2009).

Table 3 a: Effect of polyhalitemultinutrient fertilizer and irrigation levels on water use efficiency of Bt. cotton (2020).

Treatment	Yield (q ha^{-1})	Water applied (mm)	Effective rainfall (mm)	Total water applied	Water use efficiency (q ha^{-1} mm^{-1})	Percentage of water saving
I_1 : 0.8 ETc	22.06	205.01	163.16	368.17	5.99	33.33
I_2 : 1.0 ETc	22.88	256.26	139.33	395.60	5.78	16.66
I_3 : 1.2 ETc	21.44	307.52	139.33	446.85	4.79	

Table 3b: Effect of polyhalitemultinutrient fertilizer and irrigation levels on water use efficiency of Bt. cotton (2021).

Treatment	Yield ($q\ ha^{-1}$)	Water applied (mm)	Effective rainfall (mm)	Total water applied	Water use efficiency ($q\ ha^{-1}mm^{-1}$)	Percentage of water saving
I_1 : 0.8 ETc	20.62	240.38	151.97	392.35	5.25	20.26
I_2 : 1.0 ETc	21.89	300.48	131.47	431.96	5.06	12.21
I_3 : 1.2 ETc	19.35	360.58	131.47	492.05	3.93	

(ii) Water use efficiency ($q\ ha^{-1}mm^{-1}$). Scheduling of irrigation at 0.8 ETc through drip recorded maximum water use efficiency (5.99, 5.25 $q\ ha^{-1}mm^{-1}$) with maximum saving of irrigation water (33.33, 20.26%) over highest irrigation level *i.e.* I_3 compared to rest of treatments during both the year experimentation. While the minimum water use efficiency (4.79, 3.93 $q\ ha^{-1}\ mm^{-1}$) was observed during both the years. Similarly, Balasubramanian *et al*. (2000); Patil *et al.* (2008) reported higher water use efficiency in fertigation treatments in cotton owing to better crop growth and increased seed cotton yield due to continuous availability of plant nutrients in the root zone throughout the growth stages. Application of irrigation at 0.8 ETc irrigation regimes through drip maintain soil moisture at field capacity throughout crop growth period which enhance the nutrient solubility, moisture and nutrient availability there by increasing the seed cotton yield and ultimately obtained higher monetary returns with minimum quantity of irrigation water during both years (Table 3 a-b).

CONCLUSIONS

From present investigation it can be concluded that the fractions of potassium @100% $N:P_2O_5$:25%K_2O through MOP + 75% K_2O through polyhalite showed increase in soil potassium fractions and improvement in soil fertility. The cultivation of cotton without K application resulted into mining of K reflected in reduction of water soluble, exchangeable and non-exchangeable K due to inability to buffer the various pools of K which ultimately could not fulfill the need of cotton adequately.

Irrigation regimes with scheduling of deficit irrigation at 0.8 ETc is significant among other irrigation levels with 20 percentage of saving cost showed highest water use efficiency. Whereas Soil chemical properties *viz*., including pH, EC, organic carbon content, available macronutrients and exchangeable cations showed increased significantly with application of 100% $N:P_2O_5$:25%K_2O through MOP + 75% K_2O through polyhalite.

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