Research Article

Potassium Fertilizer Source and Timing Regulate Growth, Flowering and Yield in Trees of Sweet Lime (*Citrus limetta* L.)

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Abstract | Sweet lime has acquired great commercial importance globally particularly in juice and medical industry. However, its poor yield discourage farmers from its cultivation. Plant nutrients particularly Potassium plays critical role in growth and yield of citrus crops. Therefore, for the possible solution the current study Potassium fertilizer source and timing regulate growth, flowering and yield in trees of sweet lime (*Citrus limetta* L.) was conducted during the year 2019. Experiment was laid out in RCBD split plot arrangement with 2 factors and 3 replications. Potassium sources (Potassium chloride (KCl), Potassium sulfate (K_2SO_4) and Potassium nitrate (KNO_3) were applied on different dates i.e., 15th Feb, 25th Feb, 7th March and 17th March. Potassium sources and its time of application significantly affected various attributes of sweet lime. Among different sources, KNO_3 was more effective in increasing leaf chlorophyll content (46.47 mg g^{-1} FW), leaf area shoot^{-1} (135.29 cm^2), fruit weight (85.64 g) number of fruits tree^{-1} (808.75) and fruit yield tree^{-1} (69.48 kg). Potassium sulfate application decreased days to full bloom (33.58). Whereas the application of potassium sources on 17th March significantly increased leaf chlorophyll content (44.31 mg g^{-1} FW), leaf area shoot^{-1} (127.95 cm^2), number of fruits tree^{-1} (739.52), fruit yield tree^{-1} (63.68 kg) and reduced days to full bloom (20). Hence it is recommended that KNO_3 must be applied on 17th March (mid of March) for better growth and yield attributes of sweet lime.

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Introduction

Sweet lime (*Citrus limetta* L.) locally known as Mettah is extremely famous all around the globe because of its excellent nutritional and medicinal properties (Tanaka, 1994). Sweet lime has great demand during Aug-Sept due to its refreshing juice. Along with its importance in juice industry sweet lime is known for its cooling affect in problems like fever and jaundice (Kumar *et al*., 2020). However, growers are facing yield related problems particularly due to poor cultural practices and the use of inappropriate fertilizers. Among various factors plant nutrition is the critical factor which influence vegetative growth, flowering and yield. Fertilization is known as an important tools for the improvement of yield through its vital role in various plant processes like, flowering, sex expression, photosynthesis and transport of assimilate. Regarding the total amount of nutrients required by plant, potassium is required in larger quantity after nitrogen (Zorb *et al*., 2014) and is required in larger amount by fruit than any other nutrient (Lester *et al*., 2006; Mpelasoka *et al*., 2003). Potassium plays a vital nutritional role in determining the yield and quality of citrus (Vijay *et al*., 2016). Potassium application is particularly practiced in the citrus industry to increase yield and to improve fruit quality (Alva *et al*., 2006). Among different essential nutrients K is removed in large amount from soil by citrus fruits than any other nutrient (Alva and Tuker, 1999), hence its deficiency severely affects fruits quality and yield. Potassium helps in fruit setting, enhances fruit size, color and flavor (Obreza, 2003). Citrus orchard should receive potassium almost at the same concentration of Nitrogen for higher yield and quality fruits. Potassium deficiency may lead to poor yield and quality of citrus fruits and also accelerate fruit drop (Amina *et al*., 2018). Potassium application mainly enhance the uptake of other nutrients which then contribute to the enzymes which help in the translocation of sugars to the growing sinks and increases yield and yield components.

Different sources of potash have been used by different scientists on different crops to get more desirable results in term of growth, flowering and yield. It is also demonstrated by various authors that for getting more desirable results of a particular nutrient on particular crop, timing, concentration and source of nutrient are very much important. Application of particular nutrient produce its positive effects only when its right source is applied on most responsive phenelogical stage of the plant. This experiment was therefore designed to find out most appropriate source of potash and its time of application for maximum growth and yield components of sweet lime.

Materials and Methods

An experiment potassium fertilizer source and timing regulate growth, flowering and yield in trees of sweet lime (*Citrus limetta* L.) was conducted in private farm at Rustam, Mardan, Pakistan during 2019. Trees with the same age (20 years old) and uniform size were selected. Rustam is situated at 34°21'0N 72°17'0E with an altitude of 369m or 1213 feet. The cultivar used in the experiment was Palestine lime. Different potassium sources (potassium chloride (KCl), potassium sulfate (K_2SO_4) and potassium nitrate (KNO_3) were applied as a foliar spray at different dates i.e., 15th Feb, 25th Feb, 7th March and 17th March. The tree phonological stage during time of application were as follow; 15th Feb= Dormant stage, 25th Feb= Dormant stage, 7th March= after 3 days of bud break, 17th March= after 13 days of bud break. The current study was carried out in RCBD split plot arrangement with three replications. The required concentrations of each source of potassium for 1.5 % K were dissolved in four liters of water and was sprayed on each selected tree. Control treatments were sprayed with distilled water.

Preparation of potassium solution

Potassium sources i.e., Potassium Nitrate (KNO_3), potassium chloride (KCl) and Potassium sulfate (K_2SO_4) were selected and the required concentration of potassium which was 1.5% was calculated in each source according to its molecular weight. Detail of each source is given in Table 1.

Table 1: *Calculation of K in different potassium sources.*

Potassium sources	Chemical formula	Molecular weight	Calculation for 1.5 % K (g)
Potassium Nitrate	KNO_3	101.103	3.88 g/100ml
potassium Chloride	KCl	74.5	2.86 g/100ml
Potassium Sulfate	K_2SO_4	174	3.34 g/100ml

Parameters studied

Following parameters were studied during the research study.

Leaf chlorophyll content (mg g^{-1} FW)

Leaf chlorophyll content (a+b) was measured with the help of spectrophotometer by Lichtenthaler (1987).

Leaf area $shoot^{-1}$ (cm^2)

Leaf area meter (CI-202) was used for the measurement of leaf area $shoot^{-1}$ in selected shoots of each tree in each replication and finally their average was calculated.

Days to full bloom

Days were counted from flower bud break to the more than 50 percent bloom on the tree.

Fruit weight (g)

Eight fruits were selected randomly from all direction of tree canopy of each treatment than their weight was taken by using electronic balance.

Number of fruits tree^{-1}

Numbers of fruits tree^{-1} was determined by counting harvested fruits from every treatment of each replication.

Fruit yield tree^{-1} (Kg)

Total number of fruits harvested from each treatment in each replication were weighed and was expressed as fruit yield per tree (kg).

Statistical analysis

For the statistical analysis of the collected data Statistix-8.1 software was used as describe by Steel *et al*. (1997). Recorded data was subjected to analysis of variance (ANOVA) for variations between treatments and their interactions. The LSD test was applied when the difference in data was found significant i.e., $P \leq 0.05$.

Results and Discussion

Leaf chlorophyll content (mg g^{-1} FW)

There were significant variations in leaf chlorophyll content in response to potash sources and time of application. The interaction among potash sources and time of application had non-significant effect (Table 2). Means showed that the highest leaf chlorophyll content (46.47 mg g^{-1} FW) was noted with the application of KNO_3, while control treatment had minimum (41.03 mg g^{-1} FW) leaf chlorophyll content. Time of application showed positive effect in increasing leaf chlorophyll content, where increased leaf chlorophyll content (44.31 mg g^{-1} FW) was produced with 17th March application which was statistically similar to 7th March with leaf chlorophyll content of 43.72 mg g^{-1} FW. However, leaf with less chlorophyll content (42.55 mg g^{-1} FW) was noted when application was practiced on 15th Feb.

The production and content of pigments depends on nutrient availability particularly nitrates and phosphates (Yudiati *et al*., 2021). Potassium nitrate (KNO_3) considerably increased chlorophyll content as compared to other potassium sources because it contains nitrate which plays important role in vegetative growth of plants by improving chlorophyll content (Zhang and Shangguan, 2007). Potassium facilitates structural organization of grana and lamellae, hence it will also improve chloroplast integrity, the efficiency of light absorption, Rubisco diffusion and, as a result carbon assimilation (Tranknera *et al*., 2018). Similarly, under K deficiency decline in chlorophyll content has been reported (Zhao *et al*., 2001). Increase in net photosynthesis rate, stomatal conductance and chlorophyll content is associated with potassium content (Zhang *et al*., 2002; Lin and Danfeng, 2003). Similar result was found by Elhindi *et al*. (2016) who stated that chlorophyll content was significantly enhanced with Potassium Nitrate application. Increase in leaf chlorophyll content with potassium application were also reported by El-Mogy *et al*. (2019) in pepper, Adhikaria *et al*. (2020) in soyabean, Kazemi (2014) in tomato and Meinhardt and Baliga (2013) in Cacao. In case of time of application, the highest chlorophyll content was noted when potash was applied on 17th March. This may be the right phenological stage to affect chlorophyll formation. Variation in vegetative parameters with different times of application was also reported by Iqbal *et al*. (2015).

Leaf area shoot^{-1} (cm^2)

Statistical significant variations in leaf area shoot^{-1} were found in response of potassium sources and time of application, whereas interaction was non-significant (Table 2). Fruit trees treated with KNO_3 resulted in maximum leaf area shoot^{-1} (135.29 cm^2), while minimum (109.57 cm^2) was noted from untreated trees which was followed by KCl with 117.56 cm^2 leaf area per shoot. Leaf area shoot^{-1}was significantly increased with different time of application. Increased leaf area shoot^{-1} (127.95 cm^2) was recorded when application was practiced during 17th March which was statistically at par with 7th March (124.86 cm^2) and 25th Feb (122.58 cm^2). The least (108.85 cm^2) leaf area shoot^{-1} was noted on 15th Feb application.

For photosynthetic efficiency of the plants leaf area is used as indicator because light is captured by it, hence enhancement in leaf area improves photosynthetic rate (Nazli *et al*., 2018). Amongst the essential plant nutrients potash plays critical role in growth and developmental processes of plants (Tang *et al*., 2015). Potassium is also known to affect cell growth (Hepler *et al*., 2001) and cell expansion (Xu *et al*., 2020) which in turn increase leaf area (Hu *et al*., 2020). Improvement in leaf area with potash could be related with increase in photosynthetic rate that is related with high amount of CO_2 fixation due to improved stomatal conductance and ribulase bisphosphate carboxylase activity (Cakmak and Engels, 1999). Among different sources, maximum leaf area shoot^{-1} was obtained with KNO_3 which could be the presence of nitrate that plays critical role in vegetative growth. Potassium nitrate also increased chlorophyll content in the present study (Table 2) which may be the possible reason for enhancement in leaf area. Gerardeaux *et al.* (2010) reported that potassium deficiency during vegetative growth of cotton plant reduced leaf area, internode size and dry matter production which resulted in overall growth reduction in plant. Similar result was found by Elhindi *et al.* (2016) who reported increased leaf area with potassium nitrate application. In case of time of application, the highest leaf area shoot^{-1} was noted when potash was applied on 17th March, this may be related with maximum chlorophyll production on the same stage (Table 2). Lovatt (2013) reported that for desirable results, it is necessary to identify the most appropriate phenological stage for application. Iqbal *et al.* (2015) and Ali *et al.* (2019) reported similar results.

Table 2: *Influence of potassium sources and its time of application on leaf chlorophyll content, leaf area shoot^{-1} and days to full bloom of sweet lime.*

Potassium sources (S)	Leaf chlorophyll content (mg g^{-1} FW)	Leaf area shoot^{-1} (cm^2)	Days to full bloom
Control	41.03 c	109.52 c	36.08 a
KCl	42.88 b	117.56 bc	34.75 b
K_2SO_4	43.76 b	121.86 b	33.58 c
KNO_3	46.47 a	135.29 a	35.16 ab
LSD (P≤0.05)	1.117	9.568	1.119
Time of application (TA)			
15th Feb	42.55 b	108.85 b	50.25 a
25th Feb	43.56 ab	122.58 a	39.83 b
7th March	43.72 a	124.86 a	29.50 c
17th March	44.31 a	127.95 a	20.00 d
LSD (P≤0.05)	1.024	10.225	1.982
S x TA	NS	NS	NS

Means with same letters in column are statistically not different at 5 % level of significance. NS. = Non-significant; KCl = Potassium chloride, K_2SO_4 = Potassium Sulfate, KNO_3 = Potassium nitrate.

Days to full bloom

Significant variations were recorded in days to full bloom with the influence of potassium sources and time of application, whereas interaction had non-significant affect (Table 2). Less days to bloom (33.58) were recorded with the application of K_2SO_4, while more days to bloom (36.08) were recorded from control treatment, followed by KNO_3 with 35.16 days to full bloom. Less days to full bloom (20) were noted on 17th March application, while maximum (50.25) were noted when application was practiced on 15th Feb.

Potassium helps in photosynthesis and translocation of nutrients which is the critical prerequisite for flower initiation (Swietlik, 2003). Protacio (2000) noted that K play direct role in floral initiation such as in mangoes. Wilfret (1980) reported that potassium improves flowering and its deficiency causes delay in flowering. Among different sources, SOP significantly reduced days to bloom by three days as compare to control. In general early flowering results in early fruits which is of great importance in market point of view. Early fruits in market fetch high price as compare to latter ones. Earliness promoted by K_2SO_4 could be related with the function of sulphur in carbohydrates metabolism (Dalal *et al.*, 2017) which might have promote earliness due to enough food availability. Early flowering with potassium were reported by Saha *et al.* (2017) and Sergent *et al.* (1997) in mango. Least days taken to full bloom were found with 17th March application because 17th March application was done very close to flowering stage.

Fruit weight (g)

Fruit weight was significantly affected by potassium sources and interaction between potassium sources and time of application, while individual effect of time of application was non-significant (Table 3). Maximum fruit weight (85.64 g) was noted with KNO_3 application which was statistically similar with control with 85.52 g fruit weight. Minimum fruit weight (77.93 g) was recorded with the application of KCl which was statistically at par with K_2SO_4 with 78.47 g fruit weight. Analysis regarding interaction showed that fruit weight was declined with SOP and KCl as compare to control treatment. Maximum fruit weight (102.35 g) was obtained when KNO_3 was applied on 17th March, while least fruit weight (71.50 g) was noted when KCl was applied on 15th Feb (Figure 1).

Potassium plays essential role in fruit weight. Enhancement in fruit weight with K could be related with increased photosynthetic activity which leads to more food storage (Havlin *et al*., 2005). Potassium activates many enzymes and involve in ATP production which is critical in regulation of photosynthesis rate, this help plants to store enough food in fruit (Baiea *et al*., 2015). ATP is also used in various plant processes (Van Brunt and Sultenfuss, 1998) like cell division. Final fruit size depends on the number of cells (Lemaire-Chamley *et al*., 2005). Cell volume is mainly occupied by central vacuole and fruit growth and development is mainly related with its enlargement (Ho, 1996). Potassium improves fruit weight by translocation of photosynthate to fruit (Ghourab *et al*., 2000). Increase in fruit weight with potassium application were also reported by Sarker and Rahim (2013) in mango and Aly *et al*. (2015) in Washington navel orange. KNO_3 was followed by control, this might be due to the less number of fruits produced by untreated trees. The highest fruit weight was noted with 17th March application, this could be due to more carbohydrates translocation to the sink on this stage. El-Tanany *et al*. (2011) reported similar trend of results in Washington navel orange.

Table 3: *Influence of potassium sources and its time of application on various fruit weight, number of fruits tree^{-1} and fruit yield tree^{-1} of sweet lime.*

Potassium sources (S)	Fruit weight (g)	Number of fruits tree^{-1}	Fruit yield tree^{-1} (kg)
Control	85.52 a	599.58 d	51.26 c
KCl	77.93 b	756.33 b	59.00 b
K_2SO_4	78. 47 b	706.25 c	55.42 bc
KNO_3	85.64 a	808.75 a	69.48 a
LSD (P≤0.05)	6.879	10.162	5.054
Time of application (TA)			
15th Feb	77.37	696.42 d	53.59 b
25th Feb	79.08	711.42 c	55.87 b
7th March	85.50	723.50 b	62.02 a
17th March	85.58	739.52 a	63.68 a
LSD (P≤0.05)	NS	9.597	4.766
S x TA	*	***	***

*Means with same letters in column are statistically not different at 5 % level of significance. NS.: Non-significant and *, ***: Significant at P≤0.05 and P≤0.01, respectively. KCl: Potassium chloride, K_2SO_4: Potassium sulfate, KNO_3: Potassium nitrate.*

Number of fruits tree^{-1}

There were significant variations in number of fruits tree^{-1} with the influence of potassium sources, time of application and interaction (Table 3). Maximum number of fruits tree^{-1} (808.75) were recorded with the application of KNO_3, while control had less (599.58) fruits tree^{-1}. Application practiced on 17th March resulted in the highest number of fruits tree^{-1} (739.52), while less (696.42) were noted in trees treated on 15th Feb. Analysis regarding interaction showed that number of fruits tree^{-1} were increased when sources of potassium were applied on different time of application, however maximum number of fruits (834) were produced when KNO_3 was applied on 17th March, while minimum (596.33) were produced in control treatments and 25th Feb application (Figure 2).

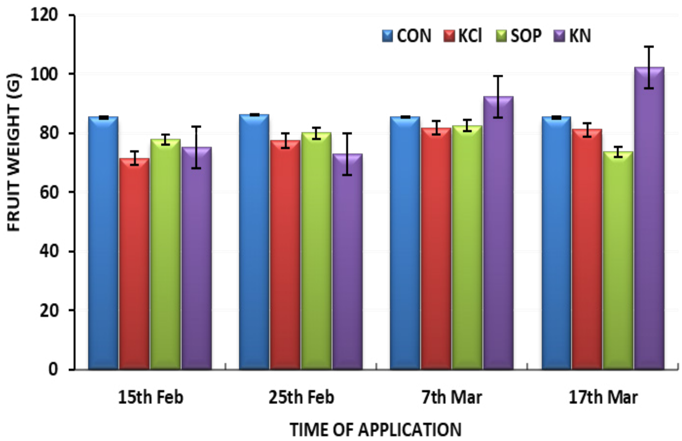

Figure 1: *Influence of potassium sources and time of application on fruit weight (g).*

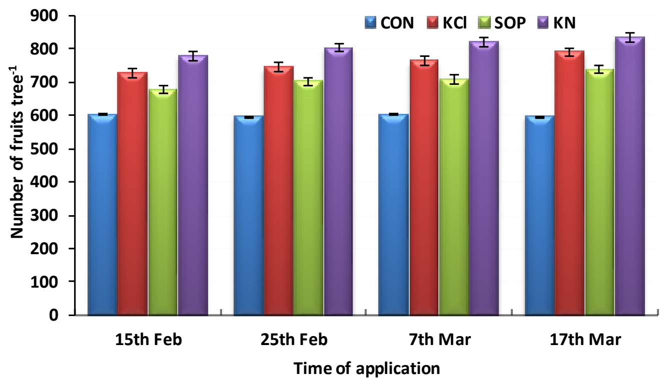

Figure 2: *Influence of potassium sources and time of application on number of fruits tree^{-1}.*

Potassium nitrate positively enhanced leaf chlorophyll content and leaf area per shoot in the current study (Table 2) which is directly related with fruit formation. Shoot with maximum leaf area capture more light which results in translocation of more food to the growing sinks by improving photosynthesis. This relation has been reported by various scientists like Samant *et al*. (2020) reported that there was direct relationship between leaf area and yield in mango, yield was increased with increase in leaf area. Potassium helps in the Hill reaction; it is mainly associated with the NADPH and ATP generation, along with ionic equilibria, electron transport, and proton-motive force. In the Calvin and Benson cycle, it is linked with CO_2 fixation, sugar production and translocation and therefore photoassimilates partitioning (Tighe-Neira *et al*., 2018). Under K deficiency sharp decline in photosynthesis has been noted (Zaied *et al*., 2006), hence optimum photosynthesis rate with potassium may have produced maximum number of fruits per tree. K deficiency can significantly cause loss of yield and quality of crops (Mustafa and Saleh, 2006). Increase in number of fruits tree^{-1} were reported by Quaggio *et al*. (2011) and Omaima and El-Metwally (2007) in sweet orange. Increased number of fruits plants^{-1} were noted with 17th March application. In order to get high yield foliar application must be practiced on right phenological stage. Pre bloom application of urea and potash significantly increased number of fruits plant^{-1} in citrus (Lovatt, 2013).

Fruit yield tree^{-1} (kg)

Statistical analysis showed significant results regarding influence of potassium sources, time of application and interaction on fruit yield per tree (Table 3). Potassium sources effectively increased yield tree^{-1}, where maximum yield tree^{-1} (69.48 kg) was produced by trees treated with KNO_3, while untreated trees produced minimum (51.26 kg). In time of application the highest yield tree^{-1} (63.68 kg) was produced with 17th March application which was statistically at par with 7th March (62.02 kg), while less (53.59 kg) was produced with 15th Feb application which was followed by 25th Feb with 55.87 kg fruit yield tree^{-1}. Interaction indicated that different sources of potassium when applied on 17th March resulted in increased fruit yield tree^{-1} except SOP application which had highest fruit yield with 7th March application. However, the highest yield tree^{-1} (85.37 kg) was noted when KNO_3 was applied on 17th March, while less (50.87 kg) was noted in control and 17th March application (Figure 3).

Potassium plays major role in physiology of plants like water relations, photosynthesis, sugar translocations and enzyme activation which have direct effects on crop yield (Kazemi, 2014). Sufficient amount of K improve the photosynthetic activity and transport of assimilates from source towards sinks (Patil, 2011; Abd El-Latif *et al*., 2011). Potassium nitrate produced maximum fruits per plant and fruits with maximum weight hence it also resulted in maximum fruit yield tree. Sarker and Rahim (2013) and Woldemariam *et al*. (2018) reported maximum yield of mango and tomato with Potassium application. In case of time of application, maximum fruit yield plant^{-1} was recorded with 17th March application, it may be due to the reason that more number of fruits and fruits with maximum weight were also obtained on this stage. Potassium application improved yield and quality when applied on its more responsive stage (Maksoud *et al*., 2003; Boman, 2001).

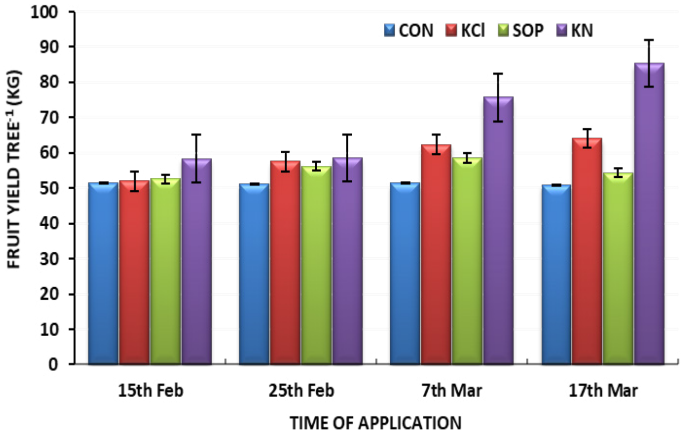

Figure 3: *Influence of potassium sources and time of application on fruit yield tree^{-1}(kg).*

Conclusions and Recommendations

Foliar application of different sources of potassium and its time of application significantly improved growth, flowering and yield attributes of sweet lime. However, among different sources of potassium KNO_3 application was more effective. In case of time of application, sweet lime during active growth stage was more responsive to potassium application than dormant stage. However, 17th March application was more effective in improving majority of parameters. Hence it is recommended that KNO_3 must be sprayed on 17th March (mid of March or 13 days after bud break or 8 days before flowering) for better growth and yield attributes of sweet lime.

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Novelty Statement

The current study is novel because most appropriate source of potassium and more responsive phenological stage of sweet lime to the foliar application of potassium has been identified for the first time.

Author's Contribution

Muhammad Noman Khan: Principal author and this manuscript is part of his PhD work.
Ghulam Nabi: Supervised the study.

Conflict of interest
The authors have declared no conflict of interest.

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