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Influence of foliar application of potassium and its spray schedule on quality, yield and nutrient content of leaf in Citrus

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Abstract

The cultivation of citrus crop is gaining impetus in light textured soils of north western India where rice-wheat is the predominant cropping sequence which urgently needs to be diversified. Studies have revealed that the soils of citrus orchards are highly deficient in potash. Correction of K deficiencies particularly at pre- and post anthesis stage of the crop improved yield and quality of the fruit. Foliar application of K through different sources and combinations and its spray schedule at bloom and early fruit development stage of the crop was found to influence the yield and quality parameters such as average fruit weight, number of fruits/plant, size (diameter and proportion of medium and large fruits), yield, peel content, peel thickness, rag and juice content, TSS, reducing, non-reducing and total sugar, ascorbic acid and acidity of the citrus fruits over control and other treatments. The nutritional status of the leaf was also found to be influenced due to different respective treatments on K. The impact of K and its spray schedule on related parameters in some other fruit crops has also been discussed and compared in the present manuscript. There is lack of information on economically important citrus crops like Kinnow mandarin (*Citrus reticulata*) and Sweet orange (*Citrus sinensis*), the major crops in north western region of the country. The systematic array of the results of different investigations on the aspect compiled in this manuscript may help in formulating and executing the research endeavour in this direction for further improvement.

Keywords: citrus, foliar application, spray schedule, potash, yield, quality, leaf nutrient content

1. Introduction

1.1 Present status of citrus crop

Citrus is one of the most important fruit crop which ranks third in area and production after banana and mango in India (Vijay, 2015) [89]. Citrus belongs to family Rutaceae. Citrus fruits are grown under varying agro-climatic conditions of India except high hilly temperate regions. It is largely grown in Andhra Pradesh, Maharashtra, Tamil Nadu, Punjab, Haryana and Rajasthan. Citrus possesses a share of 12.5% in fruit production of the country with 1.08 million ha area under cultivation and 11.15 mt production with the productivity of 10.3 t/ha (Saxena and Gandhi, 2014) [78]. The cultivation of citrus in the North-Western States of India has steadily increased over the past few years due to its high productivity and adaptability to various agro-climatic conditions (Gill and Mahindra, 2010, Sidhu and Thind, 2015 and Vijay *et al*., 2016a) [42, 80, 90].

1.2 Good source of vitamins and minerals

Citrus fruits are not only delicious and refreshing but also provide vitamins and minerals. Citrus fruit contains considerable amount of vitamin C, dietary fibre (non-starch polysaccharides) that are essential for normal growth and development. Citrus fruits or their products are the part of daily human intake in one or other forms all over the world and hence are recognized as important components in human healthy life. The rind of citrus fruits is rich in pectin and certain essential oils.

1.3 Influence on International trade

Citrus is considered to be the most remunerative fruit crop which has its own influence in international trade and finance. The crop has gained a status of huge industry which would provide nutritional security to the growing population. In India, citrus may be an important

Crop in earning the foreign exchange (Dalal *et al.*, 2014) [24]. There has been an increase of 41.4% (74.1 crores) (Anonymous, 2016) [7] which reflects its potential in international market.

1.4 Viable substitute for diversification
The prevailing situation of water crisis in north western states of India particularly in Punjab where rice-wheat is the dominating cropping sequence is alarming. The conditions concerning the ground water level are quite serious. Punjab underground available water is approximately 21 million cubic meter (MCM) whereas there is net draft of approximately 31 MCM leading to a direct deficit of about 10 MCM. Out of a total of 137 blocks, 103 blocks in Punjab are under over-exploited category where there is not enough recharging. The productivity of citrus in Punjab is one of the highest (about 21 t/ha) which is much higher than rice and wheat productivity (about 7.0 t/ha/annum). In Punjab, citrus crop is grown in 50428 ha out of the total fruit area of 76592 ha under fruit crops (Sidhu and Thind, 2015) [80]. The situation of water crisis is not pleasing in Haryana too. About 55% of the blocks are under over exploited category. Hence, this crop may provide a viable alternate to substitute the water guzzling crops like rice and wheat.

1.5 Superiority of crop under water stress
The overall scenario of horticultural crops has shown its worth under water stress conditions. India have faced three drought years during the first one and half decade of the current century and in each scenario horticulture proved its worth. The years 2002-03, 2009-10 and 2014-15 registered long period average (LPA) rainfall of 81, 77 and 88% resulting in a decline of 38.1, 16.7 and 12.4 mt food grain production, respectively, over the previous year. In contrast, the respective growth in horticulture sector was -1.41, 8.37 and 8.21 mt. Water saving techniques like drip and sprinkler irrigation have been found more effective in horticultural crops than other crops.

1.6 Constraints in citrus production
Variable and small size fruit production is one of the main production problems in citrus industry which results in poor economic return to the grower. To have more consumer acceptability, the fruit must have good quality and proper size (Sangwan *et al.*, 2008) [76]. Medium to large fruit size fetches premium price in the market. There are several reasons for poor size of fruit and lower yield in citrus such as poor management practices, nutritional deficiencies and nutritional imbalance (Dhatt, 1990) [28].

1.7 Relevance of the present study
Foliar application of nutrients have gained importance in recent years to rectify the deficiencies of nutrients as sometimes soil application is not effective because of the fact that some parts of nutrients leach down and some others do not become available to the plants due to complex chemical and biochemical reactions in soil. Secondly, foliar application of nutrients plays a regulatory role in physiological processes of plant and the availability of nutrients is easy and quick to the plants (Miller and Hofman, 1988 and Alwa *et al*., 2006) [64, 5]. Potassium is important in formation and functioning of proteins, fats, carbohydrates and chlorophyll and also in maintaining the balance of salts and water in plant cells (Abd-Allah, 2006) [1].

Most of the citrus orchards (91%) have been found deficient in Potash and thus, quick supply of K through foliar application has been found effective in enhancing yield (Vijay, 2015, Mostafa and Saleh, 2006 and Sangwan *et al*., 2008) [89, 66, 76] and quality (Vijay *et al*., 2016c, Alwa *et al*., 2006 and Hamza *et al*., 2012) [92, 5, 47] of citrus fruit. Hence, foliar application of potash requires due attention in citrus crop. The time and doses of potassium application varies with the agro climatic conditions as well as with citrus cultivars (Erner *et al.*, 1993 and Sangwan *et al*., 2008) [40, 76]. Therefore, K requires good understanding of its requirement under varying doses and time of application and its effect on different quality and yield parameters and nutrient uptake in citrus fruits. Little information is available in citrus crop on this aspect and hence, the effort has been made in this direction.

2. Quality parameters
2.1 Physical parameters
2.1.1 Juice content
In case of lemons, juice content slightly increased in the fruits produced from the trees that received K application compared with those of the trees without K application (Jones and Embleton 1960) [53]. Haggag (1988) [45] reported that spray with 0.5% potassium from different sources i.e. KCl, K_2SO_4 or KNO_3, the juice percentage was not significantly affected in Washington Navel orange. Cicata and Catara (1994) [22] reported that juice content in Torocco Orange decreased with foliar application of 3 % KNO_3. Josan *et al.* (1995) [54] found that highest juice content was recorded with foliar spray of 8% K_2SO_4 at 15th and 30th of May followed by 6% K_2SO_4 treatment. These results are in accordance to the earlier findings of Embleton *et al.* (1969) [38] and Ahmed *et al.* (1988) [4]. Qin (1996) [88], Abd-El-Migeed *et al.* (2000) [2] and Saleh *et al.* (2001) [74] in orange reported that fruit juice percentage was improved by potassium, phosphorus or boron application. Gill *et al.* (2005) [43] conducted an experiment on Kinnow plants using various K formulations sprayed three times a year. First spray was done when leaves attained 2/3rd of their original size, subsequently second spray was done when fruitlets attained a diameter of 2 cm and third spray was done one month after second spray. Juice content was significantly reduced in all foliar application of K treatments as compared to control except urea 1 %. Rattanpal *et al.* (2005) [72] showed that the juice content (45.46%) was minimum in plants sprayed 60 days after full bloom with KNO_3 5% + 2,4-D 20ppm and was maximum in control (51.97%) in Kinnow fruits. Abd-Allah (2006) [1] conducted an experiment to study the effect of spraying some macro and micronutrients (during full bloom stage) on fruit set, yield and fruit quality of Washington Navel orange trees. Treatment significantly increased juice weight in the 1st season only, since boric acid + K_2HPO_4 treatment recorded the highest juice weight. Dudi *et al.* (2007) [30] conducted an experiment to study the effect of P and K application on growth, yield and quality of Kinnow mandarin. Potassium applied in January (210 gm K_2O/plant) increased the juice content from 44.18 to 46.77%. Sangwan *et al.* (2008) [76] found that various K treatments on foliar spray did not significantly influenced juice percentage of Kinnow mandarin. Kundu and Biswas (2009) [61] observed that the juice content was highest 34.90 % in the plant treated with N 400 gm/plant/year followed by K 100 gm/plant/year (juice content 33.90 %) in sweet orange cv. Mosambi. Hamza *et al.* (2012) [47] conducted an experiment to observe the effect of potassium foliar application on fruit

production and quality of Clementine citrus var. *Cadoux.* Experimental treatments consisted of different K fertilization rates (5 and 8% KNO_3 and 2.5 and 4% K_2SO_4) and number of foliar applications (two or three) on 16th of July, 3rd of August and 21st of August. In the low density (6 x 6 m), the increase in the number of foliar application for a given concentration of either KNO_3 or K_2SO_4 is accompanied by an increase in fruit juice content. This increase was 0.5 % between treatments, 5% KNO_3 x 3foliar sprays and 5% KNO_3 x 2 foliar sprays, and 1.8% between 8% KNO_3 x 3foliar sprays and 8% KNO_3 x 2 foliar sprays.

2.1.2 Peel content
In Dancy tangerine, Singh and Singh (1981) [82] found that all the treatments including zinc sulphate 0.5% + copper sulphate 0.5% , KNO_3 1%, boric acid (25 and 50 mg 1^{-1}) and calcium hydroxide 2% significantly reduced the peel content. Rattanpal *et al.*(2005) [72] obtained maximum peel content in plants sprayed 60 days after full bloom with KNO_3 5% + 2,4-D 20ppm in Kinnow fruits. Sangwan *et al.* (2008) [76] conducted an experiment to study the effect of foliar application of potassium on fruit yield and quality of Kinnow mandarin. Three foliar sprays, first spray when leaves attained 2/3rd of their original size, subsequently second spray when fruitlets attained a diameter of 2 cm and third spray one month after second spray were done. The peel content increased with all the potassium treatments and manxímum peel content was recorded with KNO_3 @ 2% in Kinnow mandarin.

2.1.3 Rag content
In Dancy tangerine, Singh and Singh (1981) [82] found that all the treatments including zinc sulphate 0.5% + copper sulphate 0.5%, KNO_3 1%, boric acid (25 and 50 mg 1^{-1}) and calcium hydroxide 2% significantly reduced the rag content. Rattanpal *et al.* (2005) [72] studied the effect of potassium and 2, 4-D sprays on physical parameters of Kinnow fruits. Maximum rag content was observed in plants sprayed 60 days after full bloom with KNO_3 5% + 2, 4-D 20ppm. In Kinnow mandarin, Sangwan *et al.* (2008) [76] conducted an experiment to study the effect of foliar application of potassium on fruit yield and quality of Kinnow mandarin. Three foliar sprays, first spray when leaves attained 2/3rd of their original size, subsequently second spray when fruitlets attained a diameter of 2 cm and third spray one month after second spray were done. Rag content increased with all the potassium treatments but the results observed were found to be non-significant.

2.1.4 Peel thickness
Potassium deficiency leads to the production of fruits with thin skin in citrus. Increased K fertilization is associated with thicker rind (Sites, 1950; Deszyck and Koo, 1957; Smith and Rasmussen, 1960) [83, 27, 84]. Qin (1996) [88], Abd-El-Migeed *et al.* (2000) [2], Saleh *et al.* (2001) [74] in orange reported that peel thickness was improved by potassium, phosphorus or boron application. Gill *et al.* (2005) [43] observed the effect of foliar application of K and N on fruit quality of Kinnow mandarin. Various K formulations were sprayed three times a year. First spray was done when leaves attained 2/3rd of their original size, subsequently second spray was done when fruitlets attained a diameter of 2 cm and third spray was done one month after second spray. They showed that maximum peel thickness was recorded with 2% Multi K which was statistically at par with KCl and KNO_3 treatments in Kinnow mandarin. Abd-Allah (2006) [1] reported K_2HPO_4 treatment alone followed by Ca.chelate + K_2HPO_4 (during full bloom stage) gave the higher values in the 1st season while in the 2nd season, boric acid + Ca.chelate (during full bloom stage) treatment followed by the control recorded the higher thickness of peel in Washington Navel orange trees. Omaima and El-Metwally (2007) [68] reported that maximum peel thickness was in Zn + K treatment (sprayed thrice during mid February, mid March and last of April) while minimum was recorded with control in Washington Navel orange. Obreza *et al.* (2008) [67] reported that increasing K foliar fertilization induces an increase in the citrus fruit rind thickness. Sangwan *et al.* (2008) [76] observed that rind thickness was significantly higher in treatment of KNO_3 @ 2%. Hamza *et al.* (2012) [47] observed that there was numerical increase in peel thickness with the increase in K concentration or the number of foliar application.

2.2 Chemical parameters
2.2.1 Total soluble solids
The increase in TSS content with foliar application of K is related with role of potassium in translocation of sugars from leaves to fruits (Havlin *et al.*, 2007) [49]. Haggag (1988) [45] found that 0.5% potassium from different sources i.e. KCl, K_2SO_4 or KNO_3 increased TSS of the fruits in Washington Navel orange. Josan *et al.* (1995) [54] found maximum TSS was with foliar spray of 10% K_2SO_4 during 15th and 30th of May followed by Borax and $CaCl_2$ treatments in lemon. Similar findings were reported earlier in different fruits by various workers viz, Koo and Mcornack (1965) [56] in Dancy tangerine; Dube and Ram (1970) [29] in pear; Bar-Akiva (1975) [9] in Valencia orange and Ahmed *et al.* (1988) [4] in Balady lime, while Lee and Chapman (1988) [62] on the contrary did not observed any effect of potassium on TSS of Ellendale mandarin. In Valencia orange, Boman (2001) [16] reported that trees receiving KNO_3 or MPK applications, sprayed thrice in February, April and in summer (July/August) had 25% higher total soluble solids than the control treatment. Gill *et al.* (2005) [43] and Sangwan *et al.* (2008) [76] observed that TSS of fruit was not affected by various K treatments in Kinnow mandarin. Abd-Allah (2006) [1] observed highest value of TSS with K_2HPO_4 (during full bloom stage) in the first season and the same treatment beside boric acid and Ca chelate and the combination of the three nutrient treatment recorded similar higher values in the second season in Washington Navel orange. Shawky *et al.* (1970) [79], El-Deeb (1989) [35], El-Fangary (1998) [36], Mostafa *et al.* (2005) [65] and Mostafa and Saleh (2006) [66] reported that spraying various citrus varieties with different potassium forms enhanced soluble solids content. Dudi *et al.* (2007) [30] found that January application of phosphorus, 320 and 480g P_2O_5/plant and potassium (105 and 210g K_2O/plant) significantly improved the TSS in Kinnow mandarin. In Washington Navel orange, Omaima and El-Metwally (2007) [68] reported highest value of TSS with foliar spray of Zn + K (sprayed thrice during mid February, mid March and last of April). Kundu and Biswas (2009) [61] found significant improvement in TSS under the treatment receiving N 400g/plant/year (9.5^0Brix) and K 100g/plant/year (9.5^0Brix) in sweet orange cv. Mosambi. Sarrwy *et al.* (2012) [77] concluded that foliar spraying (May and July) of both KNO_3 at 1.5% with 0.5% chelated zinc and KTS (potassium thiosulphate) at 1% with 0.5% chelated zinc gave the highest significant percentage of TSS in Balady mandarin. Hamza *et al.* (2012) [47] conducted an experiment to observe the effect of potassium foliar application on fruit production and quality

of Clementine citrus var. *Cadoux.* They found that different K fertilization rates (5 and 8% KNO_3 and 2.5 and 4% K_2SO_4) and number of foliar applications (two or three) on 16th of July, 3rd of August and 21st of August slightly improved total soluble sugar content of the fruit with better efficiency for KNO_3 in comparison to K_2SO_4. TSS was increased as the concentration or number of sprays increased.

2.2.2 Acidity

Haggag (1988) [45] reported that acidity was not affected significantly with foliar potassium applications in Washington Navel orange. Josan *et al.* (1995) [54] recorded maximum acid content with 6 and 8% K_2SO_4 foliar application during 15th and 30th of May in lemon. Similar findings were reported earlier in different fruits by various workers viz, Koo and Mcornack (1965) [56] in Dancy tangerine; Dube and Ram (1970) [29] in pear; Bar-Akiva (1975) [9] in Valencia orange and Ahmed *et al.* (1988) [4] in Balady lime. Gill *et al.* (2005) [43] observed the effect of foliar application of K and N on fruit quality of Kinnow mandarin. Various K formulations were sprayed three times a year. The maximum acid content was recorded in 2% KNO_3 and KCl treatments. Abd-Allah (2006) [1] reported that acidity percentage in the fruit juice was significantly increased by K_2HPO_4 treatment (during full bloom stage) followed by treatments containing K_2HPO_4 in Washington Navel orange. Shawky *et al.* (1970) [79], El-Deeb (1989) [35], El-Fangary (1998) [36], Mostafa *et al.* (2005) [65] and Mostafa and Saleh (2006) [66] reported that spraying various citrus varieties with different potassium forms did not affected acidity significantly. Dudi *et al.* (2007) [30] conducted an experiment to study the effect of P and K application (during January) on growth, yield and quality of Kinnow mandarin. Acidity was not affected significantly by any level of P and K. In Washington Navel orange, Omaima and El-Metwally (2007) [68] found highest acidity content with foliar spray of Zn + K (sprayed thrice during mid February, mid March and last of April) while minimum was found in control. Sangwan *et al.* (2008) [76] in Kinnow mandarin found that maximum acidity (0.90%) was recorded with KNO_3 @ 2% treatment and minimum in control. Kundu and Biswas (2009) [61] studied the effect of different treatment combinations of Nitrogen and Potassium on fruit quality of sweet orange cv. Mosambi. The effect of N and K on acidity of the fruit was found not significant. Sarrwy *et al.*(2012) [77] concluded that least fruit acidity was determined from trees sprayed with KTS (potassium thiosulphate) at 1.5% with 0.5% chelated zinc sprayed in May and July, whereas, the highest value of fruit acidity was determined from control trees in Balady mandarin. Hamza *et al.* (2012) [47], in Clementine citrus var. *Cadoux*, observed that with different K fertilization rates and number of foliar sprays (two or three) acidity was less than 1.1%. Increase in the number of foliar K applications however caused a slight increase in acidity in fruit juice. Similar results were found earlier by Erner and Ya'acoe (2004) [41] and Obreza *et al.* (2008) [67] in citrus.

2.2.3 Ascorbic acid

Potassium may activate the synthesis of ascorbic acid somewhere between D-Glucose to L-Ascorbate (Harold and George, 1966) [48]. Increased Vitamin C content with foliar application of K might be related with improved sugar metabolism (Mengal, 1997). In Washington Navel orange, Haggag (1988) [45] reported that ascorbic acid content was not significantly affected by potassium application. Josan *et al.* (1995) [54] found maximum ascorbic acid content in the fruits sprayed with 4% K_2SO_4 during 15th and 30th of May followed by Borax and $CaCl_2$ treatments in lemon. Gill *et al.* (2005) [43] observed the effect of foliar application of K and N on fruit quality of Kinnow mandarin. Various K formulations were sprayed three times a year. He observed that vitamin C content of fruits was enhanced by all the treatments as compared to control, except 1% urea that reduced the vitamin C content. Among the various K sources, KCl proved better in improving the Vitamin C content. Shawky *et al.* (1970) [79], El-Deeb (1989) [35], El-Fangary (1998) [36], Mostafa *et al.* (2005) [65] and Mostafa and Saleh (2006) [66] reported that spraying various citrus varieties with different potassium forms did not affect the ascorbic acid content. Sangwan *et al.* (2008) [76] observed maximum ascorbic acid with KNO_3 @ 2% treatment. Kundu and Biswas (2009) [61] studied the effect of different treatment combinations of Nitrogen and Potassium on fruit quality of sweet orange cv. Mosambi. Application of potassium 100gm/plant/year recorded maximum vitamin C content of 70.06 mg/100ml of juice. Sarrwy *et al.* (2012) [77] found that chelated Zn and KNO_3 at 1.5% with 0.5% chelated Zn sprayed in May and July recorded the highest significant values of vitamin C percentages compared with other treatments in Balady mandarin.

2.2.4 Sugar

Tisdale and Nelson (1966) [86] reported that higher sugar content can be explained by the role of K in carbohydrates synthesis, breakdown and translocation and synthesis of protein and neutralization of physiologically important organic acids in mango. Gill *et al.* (2005) [43] observed in Kinnow mandarin that various K formulations and spray schedule did not influence the total sugar, reducing sugar and non-reducing sugar content of juice. Similarly, Sangwan *et al.* (2008) [76] found that sugar content of the juice did not vary significantly with various potassium treatments. Kundu and Biswas (2009) [61] studied the effect of different treatment combinations of nitrogen and potassium on fruit quality of sweet orange cv. Mosambi. Application of N 400 gm/plant/year resulted in maximum total sugar content (8.1%) and reducing sugar (4.6%) of fruit, whereas, application of K 100gm/plant/year recorded total sugar (8%) and reducing sugar (4.4%).

3. Yield parameters

3.1 Average fruit weight

Potassium plays a vital role in enhancing fruit weight. Increase in fruit weight with potassium application may be due to the fact that enhanced photosynthesis leads to the accumulation of more carbohydrate (Harold and George, 1966) [48]. Dhatt (1990) [28] found that fruit weight in Kinnow increased from 130 to 150 g with the increase in the leaf K content from 0.68 to 1.30 %. Erner *et al.* (1993) [40] obtained higher fruit weight in plants sprayed 6-8 weeks after flowering with KNO_3 5% + 2,4-D 20 ppm in citrus fruits. Lee and Chapman (1988) [62] reported a significant increase in fruit weight of Ellendale Mandarin with increasing rate in K fertilization. Koller and Schwarz (1995) [55] reported that highest level of K increased average weight of Murcott tangerine fruits. Josan *et al.* (1995) [54] noticed an increase in average fruit weight of lemon fruits receiving foliar spray of 10 % K_2SO_4 at 15th and 30th of May. Similar findings have also been reported earlier by various workers in various fruits, viz, Valancia Late (Bar-Akiva, 1975) [9]; Temple Orange (Koo and Reese, 1977) [57]; Lemon (Embleton *et al.*, 1980) [39]; Balady lime (Ahmed *et al.*, 1988) [4]. Saleh *et al.* (2001)

[74] in orange reported that average fruit weight was improved by potassium, phosphorus or boron application. Gill *et al.* (2005) [43] observed that maximum fruit weight was recorded with 2% Multi K followed by KNO_3 (2%) in Kinnow mandarin. Rattanpal *et al.* (2005) [72] observed that fruit weight of Kinnow increased over control when sprayed at 60 days after full bloom with KNO_3 5% + 2,4-D 20 ppm. Sangwan *et al.* (2008) [76] obtained maximum fruit weight (185.5 g) with KNO_3 @ 2% and the minimum fruit weight (161.2g) in control in Kinnow mandarin. Similar results have been reported earlier by Bazelet *et al.* (1980) [10] in Shamouti oranges, Desai *et al.* (1986) in coorg mandarin and Lee and Chapman (1988) [62] in Ellendale mandarin. Hamza *et al.* (2012) [47] found that treatment with 8 percent KNO_3 in two or three foliar applications, proved most effective in improving average fruit weight.

3.2 Fruit diameter

Potassium plays a vital role in the cell wall construction, therefore application of K enhance size of fruit (Boman and Hebb, 1998) [15]. Increased K fertilization is associated with larger fruit size (Sites, 1950; Deszyck and Koo, 1957; Smith and Rasmussen, 1960) [83, 27, 84]. Reported that K application increased the fruit size in citrus. Miller and Hofman (1988) [64] found that foliar application of K two months after flowering increases the fruit size of Valancia Oranges. Josan *et al.* (1995) [54] reported an increase in fruit diameter of lemon fruits receiving foliar spray of 10% K_2SO_4 at 15th and 30th of May. Boman (1997) [14] reported increased fruit diameter i.e. 11.4 % for KNO_3 sprayed (during September and October) versus 8 % for control treatment in grapefruit. Boman and Hebb (1998) [15] reported that post-bloom K application to Florida grapefruit increased average size of both white and coloured grapefruit. Saleh *et al.* (2001) [74] reported that fruit size improved by potassium, phosphorus or boron application in orange. Boman (2002) [17] observed the effect of foliar spray of KNO_3 on Sunburst tangerine in February, April and July. He observed that KNO_3 treated fruits had larger diameter as compared to that of control. Wei *et al.* (2002) [93] and Obreza *et al.* (2008) [67] reported that increasing the rate and frequency of foliar application of K is accompanied by an increase in citrus fruit size. Gill *et al.* (2005) [43] observed that all the K treatments significantly increased the fruit diameter with highest in Multi K 2% treatment I Kinnow mandarin. El-Fangary (1998) [36] and Mostafa and Saleh (2006) [66] reported that spraying potassium using different forms had a positive effect on fruit diameter of Balady Mandarin. Omaima and El-Metwally (2007) [68] reported increase in Washington Navel orange fruit diameter with foliar application of potassium and in combination with zinc (sprayed thrice during mid February, mid March and last of April). Stander *et al.*(2012) [85] reported an increase in fruit diameter of mandarin after 2,4-D 10 ppm foliar sprays, as well as in combination with K(5%). Sarrwy *et al.* (2012) [77] observed that KTS (potassium thiosulphate) at 1.5% with 0.5% chelated Zn sprayed twice during May and July gave the highest significant diameter in mandarin fruits. Hamza *et al.* (2012) [47] found that K fertilization treatments in three foliar applications showed the best percentage of extra size class (57-63 mm) in Clementine citrus var. *cadoux* irrespective of the source of K or plant density. The treatment 8 % KNO_3 (three sprays) gave best results.

3.3 Grading of fruits

Potassium deficiency leads to the production of small fruits. Calvert (1974) [19] reported that increased rates of K fertilization on grapefruit trees produced fruits that were larger and heavier. Boman (2002) [17] studied the effect of foliar application of KNO_3 on 'Sunburst' Tangerine. He suggested that foliar application of KNO_3 at key times in fruit development cycle can be effective in increasing fruit size. Gill *et al.*(2005) [43] found that various K formulations sprayed three times a year in Kinnow mandarin increased the proportion of A grade fruits (>7.0 cm diameter) and correspondingly decreased the percentage of C grade fruits (<6.5 cm diameter). Significantly higher percentage of A grade fruits was observed in Multi K (2%) treatment compared to all other treatments except KNO_3 2%. Sangwan *et al.* (2008) [76] observed that all the potassium treatments significantly increased the ratio of large size fruits and correspondingly decreased proportion of small size fruits in Kinnow mandarin. Maximum number of large sized fruits was observed with treatment KNO_3 @ 2% significantly higher over other treatments. Similar findings have been reported earlier by Chapman (1982) [21] in Imperial mandarins and Boman (1995) [13] in grapefruit.

3.4 Number of fruits per plant

The increase in the number of fruits due to K application can be attributed to the improvement in vegetative growth of plant (Singh *et al.*, 1979) [81]. Abd-Allah (2006) [1] reported that numbers of fruits per tree were significantly increased by application of K in combination with other macro and micro nutrients (during full bloom stage) in Washington Navel orange. Dudi *et al.* (2007) [30] found that maximum value for number of fruits/plant (794) was obtained with application of 480 g P_2O_5/plant in January and corresponding values at highest K level 210 g K_2O/plant was 792 in Kinnow mandarin. Omaima and El-Metwally (2007) [68] reported Zn + K treatment (sprayed thrice during mid February, mid March and last of April) significantly improved number of fruits per tree by 12.35% within the average of two seasons in Washington Navel orange. However applying the Zn and K significantly increased the number of fruits per tree by 7.40 and 10.12% respectively. Sangwan *et al.* (2008) [76] recorded that treatments KNO_3 @ 1% and KNO_3 @ 2% significantly influenced number of fruits per plant in Kinnow mandarin. Hamza *et al.* (2012) [47] conducted an experiment to observe the effect of potassium foliar application on fruit production and quality of Clementine citrus var. *Cadoux.* Experimental treatments consisted of different K fertilization rates (5 and 8% KNO_3 and 2.5 and 4% K_2SO_4) and number of foliar applications (two or three) on 16th of July, 3rd of August and 21st of August. He concluded that raising the K concentration and the number of foliar application increased tree fruit yield. Sarrwy *et al.* (2012) [77] found that foliar spray of KNO_3 at 1.5% with 0.5% chelated zinc sprayed twice in May and July recorded the highest number of fruits (436 and 441 fruits/tree in both seasons, respectively) compared with other treatments in Balady mandarin trees.

3.5 Yield

Foliar application of potassium nitrate increased the yield of various citrus spp. (Erner *et al.*, 1993, Achilea, 2000 and Vijay, 2015) [40, 3, 89]. Mostafa and Saleh (2006) [66] reported that spraying potassium nitrate with girdling has a positive effect on fruit yield of Balady mandarin. In addition, Mostafa *et al.* (2005) [65] and El-Fangary (1998) [36] found spraying potassium using different forms had a positive effect on yield of Balady mandarin. Abd-Allah (2006) [1] reported that K_2HPO_4 with boric acid and calcium chelate (during full bloom stage) gave highest yield in the 1st season while in the 2nd season K_2HPO_4 + calcium chelate (during full bloom stage) gave the highest yield in Washington Navel orange. Dudi *et al.* (2007) [30] conducted an experiment to study the effect of P and K application on growth, yield and quality of Kinnow mandarin. Maximum value of yield 176.2 kg/plant was obtained with the application of 480 g P_2O_5 in January and corresponding values at highest K level 210 g K_2O/plant was 170 kg/plant. Omaima and El-Metwally (2007) [68] reported that Zn + K treatment (sprayed thrice during mid February, mid March and last of April) significantly increased yield by 25.66% within the average of two seasons, however, applying Zn and K significantly increased the yield by 10.93 and 16.26%, respectively in Washington Navel orange. Sangwan *et al.* (2008) [76] conducted an experiment to study the effect of foliar application of potassium on fruit yield and quality of Kinnow mandarin. They found that maximum yield (73.65 kg) was obtained with KNO_3 @ 2% and minimum (61.70 kg) in control. Hamza *et al.* (2012) [47] conducted an experiment to observe the effect of potassium foliar application on fruit production and quality of Clementine citrus var. *Cadoux*. Experimental treatments consisted of different K fertilization rates (5 and 8% KNO_3 and 2.5 and 4% K_2SO_4) and number of foliar applications (two or three) on 16th of July, 3rd of August and 21st of August. They concluded that raising the K concentration and the number of foliar application increased tree fruit yield. Sarrwy *et al.*(2012) [77] conducted an experiment to study the effect of foliar application of different potassium forms that is potassium nitrate, mono potassium phosphate and potassium thiosulphate at different concentrations supported with chelated zinc at 0.5% on yield and fruit quality of "Balady" mandarin trees. Foliar spray of KNO_3 at 1.5% twice in May and July raised the yield per tree significantly in both the seasons compared with other treatments.

4. Leaf Analysis

4.1 Leaf nitrogen content

The highest (1.66%) leaf nitrogen was observed with the foliar application of 4.0% KNO_3 in sweet orange (Vijay *et al*., 2016b) [91]. In Washington Navel orange, Haggag (1988) [45] reported that 0.5% KCl, 0.5% K_2SO_4 and 0.5 % KNO_3 application did not affect the concentration of leaf nitrogen. Abd-El-Migeed *et al.* (2000) [2] reported that mineral status of Hamlin orange trees with respect to N content in the leaves could be markedly enhanced by NPK sprays specially at 0.5% urea + 1 or 1.5% K_2HPO_4. In Washington Navel orange, Abd-Allah (2006) [1] observed that highest nitrogen percentage (leaves) in the 1st and 2nd season was recorded by K_2HPO_4 treatment (during full bloom stage) solely, while lowest was recorded in control. Mostafa *et al.* (2005) [65] and Mostafa and Saleh (2006) [66] in Balady Mandarin concluded that spraying potassium in several forms i.e. KH_2PO_4 or K_2HPO_4 or KNO_3 raised N level in leaves. In Washington Navel orange, Omaima and El-Metwally (2007) [68] reported that highest values of leaf N, P, K and Zn content were obtained by using mixture of Zn + K (sprayed thrice during mid February, mid March and last of April). These results may be due to role of K and Zn in plant such as photosynthesis reaction, nucleic acid metabolism, protein and carbohydrate biosynthesis which increased due to leaf mineral content (Krauss and Jiyun, 2000) [58]. These results are in agreement with those detected by Dawood *et al.* (2000) [25] and El-Saida (2001) [37] in Washington Navel orange and El-Baz (2003) [33] in Balady mandarin trees.

4.2 Leaf phosphorus content

In Washington Navel orange, 0.5% KCl, 0.5% K_2SO_4 and 0.5% KNO_3 application did not affect the concentration of leaf phosphorus (Haggag, 1988) [45]. In grapefruit, Boman (1995) [13] reported minor differences with respect to leaf mineral content due to fertilization treatment. Leaf P was near the optimum range (0.12-0.16%) during all three years. Abd-El-Migeed *et al.* (2000) [2] reported that mineral status of Hamlin orange trees with respect to P content in the leaves was markedly enhanced by NPK sprays. In Valencia orange, Boman (2001) [16] reported that leaf concentration of P was significantly higher during one of the years for the trees receiving the MKP spray thrice in February, April and in summer (July/August). In Washington Navel orange, Abd-Allah (2006) [1] observed that highest phosphorus content in leaves was recorded by K_2HPO_4 (during full bloom stage) solely and calcium chelate + K_2HPO_4 treatments (during full bloom stage) in the 1st and 2nd seasons respectively while the control gave the lowest value. Mostafa *et al.* (2005) [65] and Mostafa and Saleh (2006) [66] in Balady mandarin concluded that spraying potassium in several forms i.e. KH_2PO_4 or K_2HPO_4 or KNO_3 raised P level in leaves. In Washington Navel orange, Omaima and El-Metwally (2007) [68] reported that highest values of leaf N,P, K and Zn content were obtained by using mixture of Zn + K sprayed thrice. These results are in agreement with those detected by Dawood *et al.* (2000) [25] and El-Saida (2001) [37] in Washington Navel orange and El-Baz (2003) [33] in Balady mandarin. Hamza *et al.* (2012) [47] observed that levels of P were not affected by foliar K applications in Clementine citrus var. *Cadoux.*

4.3 Leaf potassium content

Leaf K concentration of 1.2 % resulted in high fruit yields of good quality in Valencia orange (Reitz and Koo, 1960) [73]. There was significant increase in leaf K content with the foliar application of 4.0% KNO_3 over K_2SO_4 in sweet orange (Vijay *et al*., 2016b) [91]. Haggag (1988) [45] reported that 0.5% KCl, 0.5% K_2SO_4 and 0.5 %KNO_3 application increased the leaf potassium. Abd-El-Migeed *et al.* (2000) [2] reported that mineral status of Hamlin orange trees with respect to K content in the leaves was enhanced by NPK sprays specially at 0.5% urea + 1 or 1.5% K_2HPO_4. In Valencia orange, Boman (2001) [16] reported that Potassium levels were well below the optimum of 1.2% (Tucker *et al.* 1995) [87] in each of the years. However, the addition of 22.8 lb/acre of K_2O per season via foliar spray three times i.e. in February, April and in summer (July/August) through the MKP, KNO_3 and KNO_3 + MKP treatments failed to increase K concentration in leaves above the levels in the control treatment. In Washington Navel orange, Abd-Allah (2006) [1] observed highest percentage of K in leaves recorded by spraying K_2HPO_4 (during full bloom stage) solely. Mostafa *et al.* (2005) [65] and Mostafa and Saleh (2006) [66] in Balady mandarin concluded that spraying potassium from several forms i.e. KH_2PO_4 or K_2HPO_4 or KNO_3 raised K level in leaves. Also Calvert (1969) [18], El-Darier (1991) [34] and Boman (1997) [14] suggested that spraying either K_2SO_4 or KNO_3 is more effective than soil application to correct K problem in Balady mandarin. In Washington Navel orange, Omaima and El-Metwally (2007) [68] reported that highest values of leaf N, P, K and Zn content were obtained by using mixture of Zn + K sprayed thrice. These results are in agreement with those detected by Dawood *et al.* (2000) [25] and El-Saida (2001) [37] in Washington Navel orange and El-Baz (2003) [33] in Balady mandarin. In Balady mandarin, Sarrwy *et al.*(2012) [77]

reported highest value of leaves K content with KNO_3 sprayed at 1.5% i.e. 1.73% on the other hand all treatment showed significant differences in the second season. Hamza *et al.* (2012) [47] reported that the levels of K in the leaves of Clementine var. *Cadoux* increased two weeks after the last foliar K application in all treatments except in control. The increase of K concentration in the leaves of fertilized trees was independent of the source of K (KNO_3 and K_2SO_4) and the number of foliar application.

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