

EFFECTIVENESS OF VARIOUS POTASSIUM SOURCES ON VEGETATIVE GROWTH, FLOWERING, ESSENTIAL OIL PRODUCTIVITY AND SOME CHEMICAL CONSTITUENTS OF YARROW (*ACHILLEA MILLEFOLIUM* L.) PLANT

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ABSTRACT: *Achillea millefolium* is a major medicinal and aromatic herb and has antioxidant, antimicrobial, antispasmodic and antitumor effects in its essential oil. This research was conducted at Floriculture Farm and in the Laboratories of Horticulture Departments, Faculty of Agriculture at Moshtohor, Benha Univ., during 2018/2019 and 2019/2020 seasons to study the effect of foliar spraying at 2000 mg/l with various potassium sources i.e., potassium chloride, potassium citrate, potassium humate, potassium nitrate, potassium silicate, potassium sulphate, monopotassium phosphate and di-potassium hydrogen phosphate on vegetative growth, flowering, essential oil productivity and some chemical constituents of yarrow (*Achillea millefolium* L.) plants. Results showed that various potassium sources scored highly significant effects on vegetative growth and flowering of *A. millefolium* L. plant, particularly potassium nitrate followed potassium humate. Moreover, the richest leaf N% was resulted by potassium nitrate, whereas, spraying *A. millefolium* L. plants with monopotassium phosphate treatment induced the highest values of the percentage of P (%) and total chlorophylls content (%) as well as the maximum K (%), while total carbohydrate content was given by potassium sulphate. In addition, spraying yarrow plant with potassium citrate treatment induced the maximum values of essential oil parameters. Furthermore, the constituents of volatile oil of *A. millefolium* L. showed 13 components have been recognized. The major components were α -bisabolol oxide B, limonene, carvacrol and chamazulene. Consequently, spraying *A. millefolium* L. plants with potassium nitrate or potassium humate is recommended, to boost growth, flowering and some chemical constituents, whereas potassium citrate and potassium silicate treatment induced the richest values of essential oils production.

Key words: *Achillea millefolium*, potassium sources, growth, flowering, chemical composition and essential oil productivity and GLC.

INTRODUCTION

Achillea millefolium L. is an ancient herbaceous medicinal plant belonging to the Asteraceae family, commonly known as Yarrow, thousand-leaf, pepper and thousand-seal. Van Der Kooi *et al.* (2015). *Achillea*

millefolium is 0.2-1 m in height and has a spreading rhizomatous growth shape, growing one to multiple stems. Leaves are spread uniformly around the stem, with the highest being the leaves in the center and bottom of the stem. The leaves have various types of hairiness (pubescence). The leaves

are 5–20 cm long, almost feathery, bipinnate or tripinnate, and spirally arranged on the stems. Cauline, and more or less clasping, are the stems. There are 4 to 9 phyllaries in the inflorescence and ray and disk flowers, which are white to pink. The flowers are normally ovate to circular with 3 to 8 rays. Disk flowers differ between 15 and 40. A flat-topped capitulum cluster produces the inflorescence and many insects frequent the inflorescences with a generalized pollination scheme. Van Der Kooi *et al.* (2015). Yarrow is widely used due to its many pharmacological properties, such as anti-inflammatory drugs, in folk medicine (Goldberg *et al.*, 1969), antispasmodic (Falk *et al.*, 1975), antiseptic (Candan *et al.*, 2003), diaphoretic, anti-swelling, and antihypertensive (Sweetman *et al.*, 2002), diuretic and antidiarrheal (Honda *et al.*, 1996) and emmenagogue (Schulz *et al.*, 2001). Nowadays, common yarrow is used in healing ointments applied to wounds (Sampson *et al.*, 1997) and in modern medicine for reducing ulcer size (Nilforoushadeh *et al.*, 2008). It also has antitumor (Tozyo *et al.*, 1994), antioxidant ingredients (Yaseen *et al.*, 2017), antimicrobial-based (Candan *et al.*, 2003), antifungal officers (Aydin and Sevindik, 2018), anti-mutagenic (Düsman *et al.*, 2013), liver protective (Lin *et al.*, 2002), muscle relaxant (Koushyar *et al.*, 2013), gastric anti-secretory and gastroprotective activities (Baggio *et al.*, 2002). The yarrow flower contains of 0.2–0.5% essential oil, while the leaves and stem parts contain only 0.02–0.07% (Hornok *et al.*, 1974). *Achillea millefolium* L. essential oil contains mostly of mono- and sesquiterpenoids pinenes, sabinene, phellandrene, eucalyptol (1,8-cineol), terpinen-4-ol and alpha-terpineol were the most important compounds in the first class, while β -caryophyllene, bornyl acetate, eudesmol, camazulene and alpha-bisabolol were the most important compounds in the second class. (Tuberoso and Kowalczyk, 2009; Rahimmalek *et al.*, 2009; Bocevskaa and Sovová, 2007; Chalchat *et al.*, 1999).

Potassium (K) is an important nutrient in plants this plays too significant function in plant growth and production. Its function in photosynthesis is all right known, growing the operation of enzymes, enhancing protein, carbohydrate and fat synthesis, translocating photosynthetics, enabling their capacity to withstand pests and diseases. K is often known as an important osmotically active cation in plant cells (Mehdi *et al.*, 2007). Potassium is an essential nutrient for meristematic plant growth and physiological functions, including plant water and gas exchange control, protein synthesis, activation of enzymes, photosynthesis, and translocation of carbohydrates in plants. Potassium has a beneficial influence on the synthesis of nucleic acids, fats, vitamins and growth compounds. (Bisson *et al.*, 1994; Bednarz and Oosterhuis, 1999). In addition, K increases water absorption and root permeability and, in addition to its function in increasing water usage quality, serves as a guard cell controller (Zekri and Obreza, 2009). Potassium has favorable effects on metabolism of nucleic acids, proteins, vitamins and growth substances (Bisson *et al.*, 1994; Bednarz and Oosterhuis, 1999). Furthermore, K foliar applications can boost yield and tuber quality, especially in heavy clay or in sandy soils where K is not readily accessible to plants. (Marchand and Bourrie, 1999). Similar outlets for K in this study such as potassium chloride, potassium citrate, potassium humate, potassium nitrate, potassium silicate, potassium sulphate, monopotassium phosphate and di-potassium hydrogen phosphate are used for plants nutrition (Magen 2004). Jabeen and Ahmad (2011) the beneficial effects of the application of KNO_3 on growth, concentration of nutrients, activity of nitrate reductase and soluble proteins of sunflower and safflower plants were seen regardless of their growth under non-saline or saline conditions. Said-Al Ahl *et al.* (2009) declared that, in conjunction with nitrogen fertilizer levels (0, 0.6 and 1.2 g N pot⁻¹ as ammonium sulphate), potassium-humate as foliar spraying at 1% improved the

vegetative growth and essential oil of oregano plants. Abd El-Razik *et al.* (2015) illustrated that, combining the irrigation cycles with the application of potassium silicate, it was evident that the treatments had a marked impact on the quality of essential oil (%) during all cuts of the chervil plant in both seasons. Ghatas and Mohamed (2020) mentioned that, the best for enhancing growth, seed production, fixed oil productivity, chemical constituents and fixed oil components of *Oenothera biennis* L. plant were monopotassium phosphate with EM or phosphorein. Farahani *et al.* (2020) declared that, the foliar application of Si at a concentration of 0.2% in spring and summer of rose plant, particularly under conditions of water stress, is useful for raising the content of essential oils and the concentration of geraniol, citronellol, eugenol and methyl eugenol, which are the key compounds useful for oil therapeutic, cosmetic and wellness applications. Therefore, the current research was intended to investigate the influence of different sources of potassium on vegetative growth, flowering, productivity of volatile oils and some chemical elements of yarrow (*Achillea millefolium* L.) plants.

MATERIALS AND METHODS

Plant material:

This research was conducted at the Experimental Farm and at the Department of

Horticulture Laboratories, Faculty of Agriculture, Moshtohor, Benha Univ. 2018/2019 and 2019/2020 seasons to study the effect foliar spraying with various potassium sources i.e., potassium chloride, potassium citrate, potassium humate, potassium nitrate, potassium silicate, potassium sulphate, monopotassium phosphate and di-potassium hydrogen phosphate on vegetative growth, flowering, essential oil productivity and some chemical elements of yarrow (*Achillea millefolium* L.) plants.

Yarrow seeds have been sourced from Floriculture Farm, Department of Horticulture, Faculty of Agriculture, Benha Univ. Seeds of yarrow were sown in clay loam soils on 20th October in both seasons in plots (1.5 × 1 m) containing two rows (75 cm in between) every row has two hills (50 cm apart) and six weeks later, the plants were thinned, leaving only two seedlings/hill.

Physical and chemical analysis of the experimental soil were determined according to Jackson (1973) and Black *et al.* (1982), respectively. The obtained results of soil analysis are presented in Table (1).

Experimental layout:

A complete randomized block design with one element with three replicates was the architecture of the experiment. Every replication containing 5 plots, included 20

Table 1. The experimental soil mechanical and chemical analysis.

Mechanical properties			Chemical analysis		
Parameters	Values		Parameters	Values	
	2018/2019	2019/2020		2018/2019	2019/2020
Coarse sand (%)	6.88	5.44	Organic matter (%)	1.74	1.77
Fine sand (%)	14.44	12.22	CaCO ₃ (%)	0.72	0.79
Silt (%)	23.01	25.42	Available nitrogen (mg kg ⁻¹)	0.68	0.71
Clay (%)	55.67	56.92	Available phosphorus (mg kg ⁻¹)	0.49	0.56
Textural class	Clay loam	Clay loam	Available potassium (mg kg ⁻¹)	234	241
			pH	7.71	7.66
			EC (dS/m)	0.74	0.81

plants, i.e. 60 plants in each treatment, a consideration including nine separate treatments for potassium sources.

Foliar spray of various potassium sources treatments:

All yarrow plants were given potassium sources at the same concentration as foliar spray (2000 mg/l K₂O). Multiple sources of potassium were sprayed as a foliar spray in five occasions. The 1st application was conducted one month after transplantation. The 2nd and 3rd were applied two weeks after the first and the second, respectively. While the 4th was applied after the first cutting the herbs and finally the 5th was applied two weeks after the fourth. Spraying was performed up to the point of runoff. In all checked solutions, including the control, a surfactant (Tween-20) was applied at a concentration of 0.01 percent.

The potassium sources were calculated as follows:

1. The control treatment (spray with tap water) at 0 mg/l water.
2. Potassium chloride KCl (63.2% K₂O), 3.2 g/l water as foliar spray.
3. Potassium citrate K₃C₆H₅O₇ (48% K₂O), 4.2 g/l water as foliar spray.
4. Potassium humate KH (11% K₂O), 18.1 cm/l water as foliar spray.
5. Potassium nitrate KNO₃ (46.6% K₂O and 13.8% N), 4.3 g/l water as foliar spray.
6. Potassium silicate K₂SiO₃ (60% K₂O), 3.3 cm/l water as foliar spray.
7. Potassium sulphate K₂SO₄ (54% K₂O and 18.4% S), 3.7 g/l water as foliar spray.
8. Monopotassium phosphate (potassium dihydrogen phosphate KH₂PO₄ M.W. 136.09) (34.6% K₂O and 52% P₂O₅), 5.8g/l water as foliar spray.
9. Di-potassium hydrogen phosphate K₂HPO₄ (54% K₂O and 40.8% P₂O₅), 3.7 g/l water as foliar spray.

All potassium sources were obtained from Abou Zaabal for Fertilizers and

Chemical Substances Co. except potassium humate was obtained from Technogene Crop., Dokki, Cairo, Egypt).

In addition, yarrow plants obtained chemical fertilizer at 200 kg/feddan N (using ammonium nitrate (33% N), calcium superphosphate (15.5% P₂O₅) at 150 kg P₂O₅/feddan and potassium sulfate (48% K₂O) at 100 kg/feddan K₂O. A mixture of three fertilizers with a ratio of 1:1:1 (N: P₂O₅: K₂O) Three additions were applied; the first fertilizer after 30 days of transplantation was added. The second was after 1 month from the first, while the third was applied after extracting the herbs. Calcium super phosphate (15 percent P₂O₅) was applied as a single dose during soil preparation during the two seasons of this study. Where appropriate, traditional agricultural practices (irrigation, fertilization, manual management of weeds, etc.) have been introduced.

Harvesting:

In each experimental season, plants were harvested at the time of the full-blooming period. For each crop, the plants were twice trimmed. The first cut was done on 15 February, and on 15 May the second cut was done between the 2019 and 2020 seasons.

Data measurements and recorded:

The vegetative and yield parameters were measured and recorded at harvesting time on 15 February and 15 May 2019 and 2020 seasons as follows: The vegetative parts were cut about 10 cm above the soil surface. Measurements of the following traits were collected:

1. Characteristics of vegetative and flowering:

- Plant height (cm).
- Number of branches/plant.
- Fresh weight of herb (g/plant).
- Dry weight of herb (g/plant).
- Number of inflorescences/plant.
- Fresh weight of flowers (g/plant).
- Dry weight of flowers (g/plant).

- Dry weight of herbs and flowers (g/plant).
- Total dry yield (herb and flowers)/season/feddan (ton).

2. Chemical constituents :

- Photosynthetic pigments: total chlorophylls in the fresh leaves were calorimetrically estimated according to the method defined by the A.O.A.C (1990) and fresh weight, measured as mg/100 g.
- Nitrogen, phosphorus, potassium and total carbohydrates: the dried yarrow leaves were calculated according to the methods mentioned by Horneck and Miller (1998), Hucker and Catroux (1980), Horneck and Hanson (1998) and Chaplin and Kennedy (1994), respectively.

3. Essential oil parameters:

- Essential oil percentage. the volatile oil percentage was calculated as ml of oil/100 grams of herbs and flowers using the following equation:

Essential oil percentage = Oil volume in the graduated tube/dry weight of samples × 100.

- Essential oil yield/plant (ml).
- Essential oil yield/plant of two cuts (ml).
- Essential oil yield/feddan (l).

Essential oil percentage of yarrow herbs and flowers was determined by hydro distillation according to the method of Guenther, (1961), the oil percentage was used to calculate essential oil yield/plant (ml), essential oil yield/ plant of two cuts (ml) and essential oil yield/feddan (l).

4. GLC analysis of essential oil:

GLC research was performed at the medicinal and aromatic plant laboratory for oil samples from the second season only after the first trial. Dokki Study of gas liquid chromatography was conducted by Guenther (1961) and British Pharm. (1963).

Statistical analysis:

The design of the experiment as simple experiments in a complete randomized block design at $p \leq 0.05$. The discrepancies between the mean values of different therapies. Duncan's multiple range test (Duncan, 1955) was compared. Using the MSTAT-C statistical program package as given by (Snedecor and Cochran, 1989).

RESULTS AND DISCUSSION

Vegetative growth parameters:

Tables (2 and 3) demonstrated that, foliar spraying with a various of potassium sources, i.e. potassium chloride, potassium citrate, potassium humate, potassium nitrate, potassium silicate, potassium sulphate, monopotassium phosphate and di-potassium hydrogen phosphate, showed highly significant results at 2000 mg/l of plant height, number of branches, and fresh and dry weight of *Achillea millefolia* herbs (g/plant) particularly potassium nitrate, with plant height exception in both cuts and in the 1st and 2nd seasons. The tallest yarrow plant was recorded by the treatment of potassium humate followed by potassium nitrate. Moreover, the treatment of potassium sulphate significantly enhanced the parameters mentioned above. Irrespective control, the minimum values of these parameters were achieved by potassium chloride in the two cuts and seasons.

The rise in yarrow plant vegetative growth which sprayed with potassium sources may be due to it the role of potassium in plant nutrition, i.e. the promotion of the function of enzymes and the improvement of assimilate translocation and protein synthesis. With regard to this relation, Sangakkara *et al.* (2000) the increase in yarrow plant growth has been due to the role of K in biochemical pathways in plants, increasing photosynthetic rates, CO₂ assimilation and promoting carbon movements. Marschner (2012) reported that

Table 2. Effect of foliar application of different potassium sources on plant height (cm), number of branches/plant and fresh weight of herb (g/plant) of *Achillea millefolium* L. plant during 2018/2019 and 2019/2020 seasons.

Treatments	Plant height (cm)		Number of branches/plant		Fresh weight of herb (g/plant)	
	1 st cut	2 nd cut	1 st cut	2 nd cut	1 st cut	2 nd cut
First season (2018/2019)						
Control (tap water) at 0 mg/l	68.22 h	64.31 f	30.33 g	61.67 g	367.6 i	391.3 i
Potassium chloride at 2000 mg/l	71.44 g	73.31 e	32.33 f	64.67 f	421.4 h	480.3 h
Potassium citrate at 2000 mg/l	75.29 ef	77.05 d	36.67 e	69.33 e	568.0 g	631.9 f
Potassium humate at 2000 mg/l	91.46 a	89.50 a	46.67 b	77.67 b	630.2 b	744.3 b
Potassium nitrate at 2000 mg/l	89.31 b	85.65 b	49.33 a	80.67 a	640.2 a	761.4 a
Potassium silicate at 2000 mg/l	74.74 f	71.96 e	36.33 e	69.33 e	579.0 f	620.6 g
Potassium sulphate at 2000 mg/l	81.74 c	77.97 cd	40.00 d	70.33 e	619.4 d	660.0 e
Monopotassium phosphate at 2000 mg/l	79.56 d	79.14 c	39.67 d	73.33 d	615.7 e	689.9 d
Di-potassium hydrogen phosphate at 2000 mg/l	76.66 e	79.39 c	43.67 c	75.67 c	623.4 c	710.2 c
Second season (2019/2020)						
Control (tap water) at 0 mg/l	69.33 g	63.39 f	33.67 h	63.67 g	371.3 i	411.4 i
Potassium chloride at 2000 mg/l	72.33 f	71.59 e	36.67 g	67.33 f	461.3 h	510.3 h
Potassium citrate at 2000 mg/l	75.97 e	73.54 e	39.00 f	69.67 e	609.9 f	660.3 f
Potassium humate at 2000 mg/l	92.29 a	90.35 a	48.67 b	79.33 b	673.7 b	761.7b
Potassium nitrate at 2000 mg/l	89.38 b	88.67 a	51.00 a	82.33 a	681.3 a	778.9 a
Potassium silicate at 2000 mg/l	75.33 e	73.56 e	39.33 ef	70.00 e	604.2 g	650.9 g
Potassium sulphate at 2000 mg/l	85.45 c	83.10 b	40.33 e	73.33 d	629.6 e	689.5 e
Monopotassium phosphate at 2000 mg/l	81.55 d	80.52 c	43.67 d	74.67d	631.7 d	706.2 d
Di-potassium hydrogen phosphate at 2000 mg/l	79.97 d	77.15 d	46.67 c	76.67 c	640.9 c	720.5 c

Means accompanied by numerous letters are considerably different at the stage at $P \leq 0.5$ level according to Duncan's multiple range test (Duncan, 1955).

Table 3. Effect of foliar application of different potassium sources on dry weight of herbs (g /plant), dry weight of herbs and flowers (g /plant) and total dry yield (herb and flowers) /season /feddan (ton) of *Achillea millefolium* L. plant during 2018/2019 and 2019/2020 seasons.

Treatments	Dry weight of herbs (g /plant)		Dry weight of herbs and flowers (g /plant)		Total dry yield (herb and flowers) /season /feddan (ton)
	1 st cut	2 nd cut	1 st cut	2 nd cut	
First season (2018/2019)					
Control (tap water) at 0 mg/l	97.53 i	102.7 i	104.2 h	110.0 g	2.40 i
Potassium chloride at 2000 mg/l	106.3 h	113.0 h	114.0 g	121.2 f	2.63 h
Potassium citrate at 2000 mg/l	129.2 g	146.1 g	138.6 f	157.1 e	3.31 g
Potassium humate at 2000 mg/l	157.6 b	175.3 b	172.5 b	192.3 b	4.09 b
Potassium nitrate at 2000 mg/l	161.2 a	183.8 a	177.8 a	202.8 a	4.26 a
Potassium silicate at 2000 mg/l	132.9 f	148.1 f	141.4 e	158.2 e	3.36 f
Potassium sulphate at 2000 mg/l	146.9 d	154.2 d	156.9 d	165.6 d	3.61 d
Monopotassium phosphate at 2000 mg/l	144.9 e	151.8 e	155.8 d	164.0 d	3.58 e
Di-potassium hydrogen phosphate at 2000 mg/l	152.0 c	164.0 c	164.1 c	177.9	3.83 c
Second season (2019/2020)					
Control (tap water) at 0 mg/l	101.1 h	109.3 h	107.5 h	116.6 i	2.51 i
Potassium chloride at 2000 mg/l	112.3 g	122.8 g	119.8 g	131.4 h	2.81 h
Potassium citrate at 2000 mg/l	134.0 e	152.1 e	144.9 e	165.2 f	3.47 f
Potassium humate at 2000 mg/l	160.2 b	181.9 b	175.8 b	199.6 b	4.21 b
Potassium nitrate at 2000 mg/l	165.2 a	188.7 a	182.5 a	208.3 a	4.38 a
Potassium silicate at 2000 mg/l	129.3 f	149.7 f	139.3 f	161.0 g	3.36 g
Potassium sulphate at 2000 mg/l	151.5 d	160.2 d	162.7 d	172.0 e	3.75 e
Monopotassium phosphate at 2000 mg/l	150.5 d	160.4 d	162.1 d	174.6 d	3.77 d
Di-potassium hydrogen phosphate at 2000 mg/l	156.8 c	171.1 c	169.5 c	188.0 c	4.00 c

Means accompanied by numerous letters are considerably different at the stage at $P \leq 0.5$ level according to Duncan's multiple range test (Duncan, 1955).

during stomatal activity, K leads a key role in the control of turgor beyond, within, guard cells. Potassium is an essential nutrient for meristematic plant growth and physiological functions, including plant water and gas exchange control, protein synthesis, activation of enzymes, photosynthesis and translocation of carbohydrates in plants. In addition, K is also important for the success of multiple functions of plant enzymes and controls higher plant metabolite trends, gradually changing metabolite concentrations. (Mengel and Kirkby, 2001 and Marschner, 2012). Foliar supply of KNO_3 to the improve K and N status of salt treated plants. The role of potassium in ionic balance is reflected in nitrate metabolism (Jeschke and Wolf, 1985). A necessary factor for plant growth is nitrogen, which is an active component of chlorophyll and protein. Potassium spray results in an increase in the content of leaf potassium, followed by increased amounts of photosynthesis, photorespiration and carboxylase activity of RuBP. Therefore, in the latest inquiry, there was a substantial increase in development and under the saline strata. Ebert *et al.* (2002) found that supplying of $Ca(NO_3)_2$ at 10 mM had a beneficial effect on growth and metabolism of NaCl treated guava seedlings. Akram *et al.* (2009) declared that, improvement in sunflower development due to foliar spray of K_2SO_4 and KNO_3 was observed at 1.25% under saline concentrations of 150 mM NaCl. The improving effect of potassium humate or potassium silicate on vegetative growth traits at different concentrations may be due to the beneficial effect of potassium and silicon or potassium and humic acid being mixed.

Where potassium plays an important role in osmoregulation, photosynthesis, transpiration, stomatal opening and closing, protein synthesis, assimilates are converted into sink organs and enzymes are formed. (Mengel and Kirkby, 2001; Cakmak, 2005; Milford and Johnston, 2007). In addition, silicon's successful function in the plant is to enhance the architecture to reveal more erect

leaves that intercept higher solar luminosity, increasing photosynthetic efficiency and higher chlorophyll material. (Braga *et al.*, 2009), Besides its role in plant forbearance, several stress factors are associated with it. The strengthening effect of humic acid on pea vegetative growth may be due to the introduction of plant hormones that have a beneficial effect on plant nutrition. (Martinez *et al.*, 1983) and enhance the uptake of minerals through the stimulation of microbiological activity (Akinremi *et al.*, 2000). The obtained results are in harmony with those reported by Said-Al Ahl *et al.* (2009) on oregano plants, Jabeen and Ahmad (2011) on sunflower and safflower plants, Matin *et al.* (2015) on *Narcissus tazetta* plants, Basiouny (2020) on *Taxodium disticum* plant and *Swietenia mahagoni* plant, Ghatas and Mohamed (2020) demonstrated that, monopotassium phosphate with EM or phosphorein were the best for improving growth parameters of *Oenothera biennis* L. plant and Moghith *et al.* (2020) reported that the maximum growth parameters of the chia (*Salvia hispanica* L.) plant have been shown to be preferred for cultivation under saline water irrigation at (0.68 dSm^{-1}) and potassium silicate spray at 2000 ppm.

K foliar feeding has shown that supplementary feeding at critical stages of growth will increase performance and quality. Compared to both K-applied as KCl and power, foliar-applied K in the form of KNO_3 showed more yield compared to K-applied as KCl (Oosterhuis *et al.*, 1993).

Flowering parameters:

Various potassium sources had significant effects on number of inflorescences, fresh weight of flowers (g/plant), dry weight of flowers (g/plant), dry weights of herbs and flowers (g/plant) and total dry yield (herbs and flowers)/season/ feddan (ton) of yarrow plant (Tables, 3 and 4). The maximum values of parameters mentioned afore were observed for potassium nitrate followed by potassium humate as compared with the control. Moreover, di-potassium hydrogen phosphate

Table 4. Effect of foliar application of different potassium sources on number of inflorescences, Fresh weight of flowers (g /plant) and dry weight of flowers (g/plant) of *Achillea millefolium* L. plant during 2018/2019 and 2019/2020 seasons.

Treatments	Number of inflorescences		Fresh weight of flowers (g /plant)		Dry weight of flowers (g /plant)	
	1 st cut	2 nd cut	1 st cut	2 nd cut	1 st cut	2 nd cut
First season (2018/2019)						
Control (tap water) at 0 mg/l	23.0 i	43.33 h	40.89 i	49.57 g	6.64 i	7.30 h
Potassium chloride at 2000 mg/l	28.33 h	50.00 g	48.66 h	59.40 f	7.68 h	8.17 g
Potassium citrate at 2000 mg/l	32.67 g	63.67 f	65.85 f	70.67 e	9.45 f	11.03 e
Potassium humate at 2000 mg/l	49.67 b	82.67 b	77.48 b	87.89 a	14.95 b	17.00 b
Potassium nitrate at 2000 mg/l	57.00 a	88.67 a	83.77 a	89.81 a	16.59 a	18.95 a
Potassium silicate at 2000 mg/l	35.67 f	69.67 e	64.14 g	68.66 e	8.58 g	10.07 f
Potassium sulphate at 2000 mg/l	37.67 e	75.0 c	68.37 e	75.26 d	10.0 e	11.36 e
Monopotassium phosphate at 2000 mg/l	39.67 d	72.0 d	70.07 d	79.47 c	10.89 d	12.21 d
Di-potassium hydrogen phosphate at 2000 mg/l	43.67 c	76.33 c	74.22 c	84.64 b	12.07 c	13.91 c
Second season (2019/2020)						
Control (tap water) at 0 mg/l	25.67 h	46.67 h	43.88 i	50.57 i	6.47 g	7.26 h
Potassium chloride at 2000 mg/l	31.67 g	54.67 g	49.33 h	60.61 h	7.43 f	8.57 g
Potassium citrate at 2000 mg/l	35.67 f	63.67 f	69.74 f	78.00 f	10.98 d	13.17 e
Potassium humate at 2000 mg/l	54.33 b	86.67 b	83.96 b	90.75 b	15.59 b	17.78 b
Potassium nitrate at 2000 mg/l	60.33 a	90.0 a	89.45 a	94.25 a	17.29 a	19.52 a
Potassium silicate at 2000 mg/l	37.00 f	69.67 e	68.52 g	74.0 g	10.0 e	11.30 f
Potassium sulphate at 2000 mg/l	40.67 e	74.67 d	73.97 e	81.11 e	11.25 d	11.77 f
Monopotassium phosphate at 2000 mg/l	43.33 d	76.33 d	76.55 d	84.22 d	11.59 d	14.26 d
Di-potassium hydrogen phosphate at 2000 mg/l	49.00 c	80.67 c	80.40 c	86.88 c	12.71 c	16.94 c

Means accompanied by numerous letters are considerably different at the stage at $P \leq 0.5$ level according to Duncan's multiple range test (Duncan, 1955).

was ranked the third values in most cases in this concern.

Chemical composition:

1. N, P, K, total chlorophylls and total carbohydrate content:

Data in Tables (5 and 6) state that N, P, K, total chlorophylls and total carbohydrate content in *Achillea millefolium* L. were increased by all different treatments for potassium sources. In this respect, the richest leaf N was resulted by potassium nitrate followed by potassium humate as compared with the control. Whereas, spraying *Achillea millefolium* L. plants with monopotassium phosphate treatment induced the highest values of the percentage of P and total chlorophylls content followed by di-potassium hydrogen phosphate. Moreover, the maximum K % and total carbohydrate content were given by potassium sulphate followed by potassium silicate as compared with the other ones in most cases. The minimum values of these traits were the untreated plants.

The beneficial effect on chemical constituents in the leaves of various sources of potassium at different rates may be due to the same factors that have triggered vegetative growth, yields and their components as previously described. These findings are in harmony with those of Said-Al Ahl *et al.* (2009) on oregano plants, Jabeen and Ahmad (2011) on sunflower and safflower plants, Basiouny (2020) on *Taxodium disticum* plant and *Swietenia mahagoni* plant. Ghatas and Mohamed (2020) mentioned that, monopotassium phosphate with EM or phosphorein were the best for improving chemical constituents of *Oenothera biennis* L. plant. Moghith *et al.* (2020) It was shown that the combination therapy reported maximum N, P and K content values of the chia (*Salvia hispanica* L.) plant between 0.68 dSm⁻¹ salinity concentration and 2000 ppm potassium silicate.

2. Oil yield parameters:

According to the data referred to in Tables (7 and 8) it can be shown that, essential oil %, essential oil yield/plant (ml), essential oil yield/plant of two cuts (ml) and essential oil yield/feddan (l) of yarrow plant were more affected by using various potassium sources treatments as compared to control plants in the two cuts and seasons. In this respect, spraying *Achillea millefolium* L. plants with potassium citrate treatment induced the maximum values of parameters mentioned afore. However, the second and the third values of these parameters were recorded by the silicate phosphate and di-potassium hydrogen phosphate in 1st cutting and 2nd cutting as well as the first and second seasons, respectively in most cases. The lowest value of essential oil parameters was produced by control plants at both cuts and in the two seasons.

The enhanced impact of treatment with potassium silicate and potassium citrate may be attributed to the function of potassium in osmoregulation, photosynthesis, transpiration, stomatal opening and closing, protein synthesis, assimilate translocation, and enzyme activation (Mengel and Kirkby, 2001; Cakmak, 2005 and Milford and Johnston, 2007). In addition, the beneficial effects of silicon in facilitating plants live under conditions of water scarcity, reducing transpiration, development of plants, stable and competitive growth and productivity (Gao *et al.*, 2006; Regina and Katarzyna, 2011). Obtained findings are in compliance by those reported by Abd El-Razik *et al.* (2015) illustrated that, combining the irrigation cycles with the application of potassium silicate, it was evident that the treatments had a marked impact on the quality of essential oil (percent) during all cuts of the chervil plant in both seasons. Miri *et al.* (2015) demonstrated that, the foliar application of citric acid greatly increased the vegetative properties of the thyme plant as well as the content of pigments (chlorophyll a and carotenoids) and essential oil output. Moghith (2019) declared that the

Table 5. Effect of foliar application of different potassium sources on N, P and K% of *Achillea millefolium* L. plant during 2018/2019 and 2019/2020 seasons.

Treatments	N %		P %		K %	
	1 st cut	2 nd cut	1 st cut	2 nd cut	1 st cut	2 nd cut
First season (2018/2019)						
Control (tap water) at 0 mg/l	1.96 h	2.14 h	0.231 h	0.239 h	1.70 g	1.72 i
Potassium chloride at 2000 mg/l	2.14 g	2.29 g	0.240 g	0.245 g	1.80 f	1.89 h
Potassium citrate at 2000 mg/l	2.39 e	2.41 f	0.249 f	0.254 e	2.24 d	2.13 g
Potassium humate at 2000 mg/l	3.0 b	3.12 b	0.253 e	0.260 d	2.18 e	2.23 f
Potassium nitrate at 2000 mg/l	3.09 a	3.20 a	0.260 d	0.262 d	2.30 c	2.35 c
Potassium silicate at 2000 mg/l	2.33 f	2.41 f	0.249 f	0.249 f	2.38 b	2.40 b
Potassium sulphate at 2000 mg/l	2.44 e	2.59 e	0.269 c	0.277 c	2.40 a	2.45 a
Monopotassium phosphate at 2000 mg/l	2.60 d	2.71 d	0.282 a	0.290 a	2.23 d	2.31 d
Di-potassium hydrogen phosphate at 2000 mg/l	2.79 c	2.88 c	0.276 b	0.286 b	2.19 e	2.25 e
Second season (2019/2020)						
Control (tap water) at 0 mg/l	1.82 i	2.08 h	0.231 g	0.239 f	1.72 i	1.76 i
Potassium chloride at 2000 mg/l	2.03 h	2.30 g	0.240 f	0.246 e	1.89 h	1.95 h
Potassium citrate at 2000 mg/l	2.41 f	2.53 f	0.260 cd	0.265 cd	2.25 f	2.19 g
Potassium humate at 2000 mg/l	2.98 b	3.04 b	0.258 de	0.261 d	2.22 g	2.25 f
Potassium nitrate at 2000 mg/l	3.14 a	3.22 a	0.263 c	0.266 c	2.38 c	2.37 c
Potassium silicate at 2000 mg/l	2.35 g	2.50 f	0.254 e	0.260 d	2.40 a	2.39 b
Potassium sulphate at 2000 mg/l	2.49 e	2.70 e	0.276 b	0.286 b	2.39 b	2.48 a
Monopotassium phosphate at 2000 mg/l	2.71 d	2.82 d	0.290 a	0.296 a	2.30 d	2.31 d
Di-potassium hydrogen phosphate at 2000 mg/l	2.88 c	2.92 c	0.287 a	0.290 b	2.27 e	2.29 e

Means accompanied by numerous letters are considerably different at the stage at $P \leq 0.5$ level according to Duncan's multiple range test (Duncan, 1955).

Table 6. Effect of foliar application of different potassium sources on total chlorophylls (mg/100 g f.w.) and total carbohydrates (%) of *Achillea millefolium* L. plant during 2018/2019 and 2019/2020 seasons.

Treatments	Total chlorophylls (mg/100 g f.w.)		Total carbohydrates (%)	
	1 st cut	2 nd cut	1 st cut	2 nd cut
First season (2018/2019)				
Control (tap water) at 0 mg/l	161.2 h	170.9 i	13.78 f	14.17 e
Potassium chloride at 2000 mg/l	173.5 fg	175.4 h	14.07 f	14.71 e
Potassium citrate at 2000 mg/l	174.2 f	177.7 g	14.97 e	15.65 d
Potassium humate at 2000 mg/l	184.3 d	180.8 e	15.23 e	16.13 d
Potassium nitrate at 2000 mg/l	180.8 e	184.0 d	17.88 c	17.26 c
Potassium silicate at 2000 mg/l	172.4 g	179.2 f	19.87 b	19.19 b
Potassium sulphate at 2000 mg/l	187.5 c	189.9 c	20.98 a	21.95 a
Monopotassium phosphate at 2000 mg/l	198.5 a	201.0 a	16.47 d	17.27 c
Di-potassium hydrogen phosphate at 2000 mg/l	190.9 b	196.1 b	15.34 e	15.90 d
Second season (2019/2020)				
Control (tap water) at 0 mg/l	163.4 h	165.7 i	13.32 f	14.46 h
Potassium chloride at 2000 mg/l	170.3 g	173.4 h	14.26 f	15.17 gh
Potassium citrate at 2000 mg/l	175.5 f	180.2 g	15.66 e	16.49 ef
Potassium humate at 2000 mg/l	178.6 e	185.9 e	16.09 de	15.92 fg
Potassium nitrate at 2000 mg/l	181.0 d	188.2 d	18.87 b	19.14 c
Potassium silicate at 2000 mg/l	179.1 e	182.1 f	19.94 b	20.70 a
Potassium sulphate at 2000 mg/l	194.1 c	198.1 c	21.25 a	22.99 a
Monopotassium phosphate at 2000 mg/l	201.1 a	202.4 a	17.54 c	18.04 d
Di-potassium hydrogen phosphate at 2000 mg/l	197.6 b	200.7 b	16.90 cd	16.77 e

Means accompanied by numerous letters are considerably different at the stage at $P \leq 0.5$ level according to Duncan's multiple range test (Duncan, 1955).

Table 7. Effect of foliar application of different potassium sources on essential oil (%) and essential oil yield/plant (ml) of *Achillea millefolium* L. plant during 2018/2019 and 2019/2020 seasons.

Treatments	Essential oil (%)		Essential oil yield/plant (ml)	
	1 st cut	2 nd cut	1 st cut	2 nd cut
First season (2018/2019)				
Control (tap water) at 0 mg/l	0.34 i	0.39 i	0.35 f	0.43 i
Potassium chloride at 2000 mg/l	0.37 h	0.43 h	0.43 e	0.53 h
Potassium citrate at 2000 mg/l	0.70 a	0.81 a	0.96 a	1.28 a
Potassium humate at 2000 mg/l	0.47 f	0.57 f	0.82 cd	1.10 c
Potassium nitrate at 2000 mg/l	0.45 g	0.52 g	0.79 d	1.06 f
Potassium silicate at 2000 mg/l	0.60 b	0.79 b	0.85 bc	1.24 b
Potassium sulphate at 2000 mg/l	0.49 e	0.60 e	0.76 d	0.99 g
Monopotassium phosphate at 2000 mg/l	0.57 c	0.65 c	0.89 b	1.07 e
Di-potassium hydrogen phosphate at 2000 mg/l	0.50 d	0.61 d	0.82 cd	1.09 d
Second season (2019/2020)				
Control (tap water) at 0 mg/l	0.36 h	0.43 h	0.39 i	0.50 h
Potassium chloride at 2000 mg/l	0.43 g	0.45 g	0.52 h	0.60 g
Potassium citrate at 2000 mg/l	0.74 a	0.84 a	1.07 a	1.39 a
Potassium humate at 2000 mg/l	0.53 e	0.61 e	0.94 e	1.21 d
Potassium nitrate at 2000 mg/l	0.50 f	0.52 f	0.91 f	1.09 e
Potassium silicate at 2000 mg/l	0.69 b	0.83 b	0.96 d	1.34 b
Potassium sulphate at 2000 mg/l	0.53 e	0.60 e	0.87 g	1.04 f
Monopotassium phosphate at 2000 mg/l	0.59 d	0.62 d	0.97 c	1.09 e
Di-potassium hydrogen phosphate at 2000 mg/l	0.61 c	0.65 c	1.03 b	1.23 c

Means accompanied by numerous letters are considerably different at the stage at $P \leq 0.5$ level according to Duncan's multiple range test (Duncan, 1955).

Table 8. Effect of foliar application of different potassium sources on essential oil yield/plant of two cuts (ml) and essential oil yield/feddan (l) of *Achillea millefolium* L. plant during 2018/2019 and 2019/2020 seasons.

Treatments	Essential oil yield/plant of two cuts (ml)	Essential oil yield/feddan (l)
First season (2018/2019)		
Control (tap water) at 0 mg/l	0.78 g	8.77 g
Potassium chloride at 2000 mg/l	0.95 f	10.60 f
Potassium citrate at 2000 mg/l	2.24 a	25.13 a
Potassium humate at 2000 mg/l	1.92 cd	21.50 cd
Potassium nitrate at 2000 mg/l	1.86 d	20.78 d
Potassium silicate at 2000 mg/l	2.09 b	23.49 b
Potassium sulphate at 2000 mg/l	1.75 e	19.62 e
Monopotassium phosphate at 2000 mg/l	1.96 c	21.95 c
Di-potassium hydrogen phosphate at 2000 mg/l	1.91 cd	21.35 cd
Second season (2019/2020)		
Control (tap water) at 0 mg/l	0.89 h	9.95 h
Potassium chloride at 2000 mg/l	1.12 g	12.48 g
Potassium citrate at 2000 mg/l	2.46 a	27.50 a
Potassium humate at 2000 mg/l	2.15 c	24.07 c
Potassium nitrate at 2000 mg/l	2.0 e	22.36 e
Potassium silicate at 2000 mg/l	2.30 b	25.79 b
Potassium sulphate at 2000 mg/l	1.91 f	21.34 f
Monopotassium phosphate at 2000 mg/l	2.06 d	23.02 d
Di-potassium hydrogen phosphate at 2000 mg/l	2.26 b	25.28 b

Means accompanied by numerous letters are considerably different at the stage at $P \leq 0.5$ level according to Duncan's multiple range test (Duncan, 1955).

richest percentage of oil and oil yield chia plant (*Salvia hispanica* L.) seeds were graded with a concentration of 0.68 dSm⁻¹ saline water irrigation and potassium silicate spray at 2000 ppm, Farahani *et al.* (2020) declared that, the foliar application of Si at a concentration of 0.2 percent in spring and summer has been shown to be useful for increasing the essential oil content of rose oil, especially under conditions of water stress and Ghatas and Mohamed (2020) mentioned that, monopotassium phosphate with EM or phosphorein were the best for improving fixed oil productivity of *Oenothera biennis* L. plant.

Essential oil constituents of *Achillea millefolium* L. plant:

Table (9) and Figs. (1, 2, 3 and 4)

illustrated that data foliar spraying with some potassium sources i.e. potassium nitrate, potassium silicate and potassium citrate at the same rates at 2000 mg/l in addition control treatment (tap water) at 0 mg/l, the qualitative effects of the essential oil constituents of yarrow were greatly impacted. (*Achillea millefolium* L.) herbs and flowers. The essential oil constituents of *Achillea millefolium* L. thirteen components were recognized, produced, i.e., α -pinene, myrcene, limonene, 1,8-cineole, V-terpinene, linalool, camphor, borneol, carvacrol, thymol, linalyl acetate, chamazulene and α -bisabolol oxide B. Hence, the main component was α -bisabolol oxide B (34.41 to 50.10%). The major components were α -bisabolol oxide B (34.41 to 50.10%),

Table 9. Effect of foliar application of different potassium source on essential oil constituents of *Achillea millefolium* L. plant during the second cut and the second season 2019/2020.

Peak No.	Components	Area %			
		Control (tap water) at 0 mg/l	Potassium nitrate at 2000 mg/l	Potassium silicate at 2000 mg/l	Potassium citrate at 2000 mg/l
1	α -Pinene	2.44	0.10	0.68	3.32
2	Myrcene	1.55	1.80	0.10	0.70
3	Limonene	8.45	21.01	1.66	10.43
4	1,8-Cineole	5.15	9.11	3.59	6.73
5	V-Terpinene	-	0.23	0.59	0.91
6	Linalool	-	0.87	1.44	0.83
7	Camphor	1.98	1.55	3.45	2.04
8	Borneol	3.78	3.31	4.77	2.75
9	Carvacrol	11.77	9.04	10.99	6.70
10	Thymol	2.44	1.49	2.55	1.17
11	Linalyl acetate	3.68	3.73	9.88	3.92
12	Chamazulene	5.98	3.88	14.95	3.74
13	α -Bisabolol oxide B	34.41	35.46	37.27	50.10
	Total identified	81.63	91.58	91.91	93.34
*	Unknown	18.37	8.42	8.09	6.66
	Total	100.00	100.00	100.00	100.00

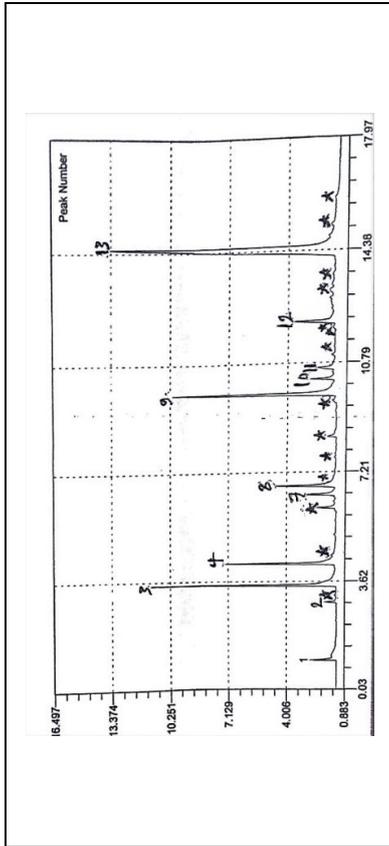


Fig. 1. Influence of control treatment of essential oil constituents on *Achillea millefolium* L.

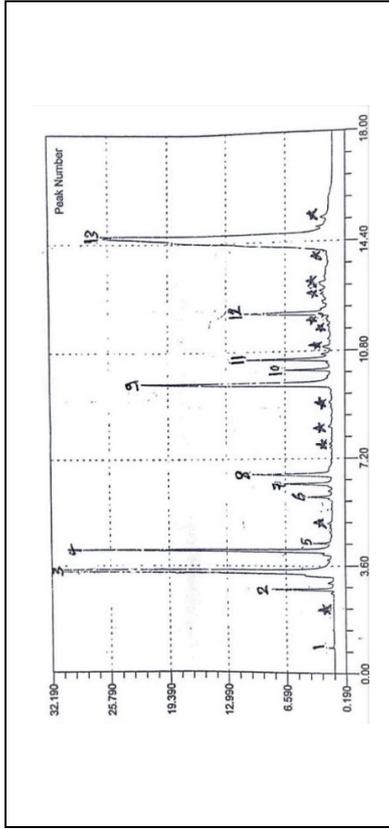


Fig. 2. Influence of potassium nitrate at 2000 mg/l treatment of essential oil constituents on *Achillea millefolium* L.

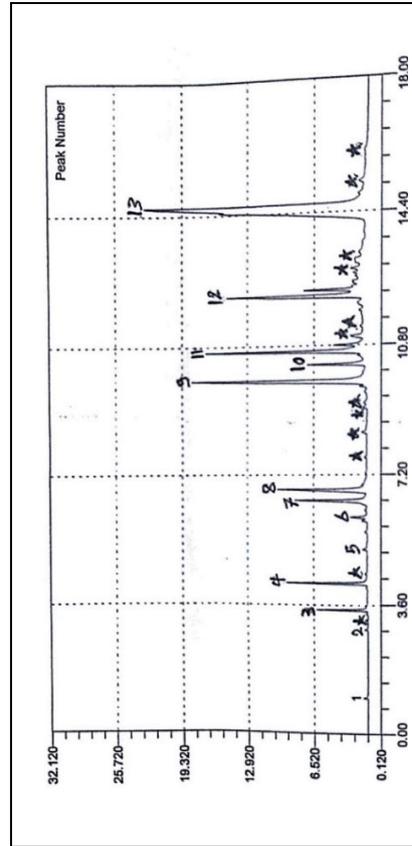


Fig. 3. Influence of potassium silicate at 2000 mg/l treatment of essential oil constituents on *Achillea millefolium* L.

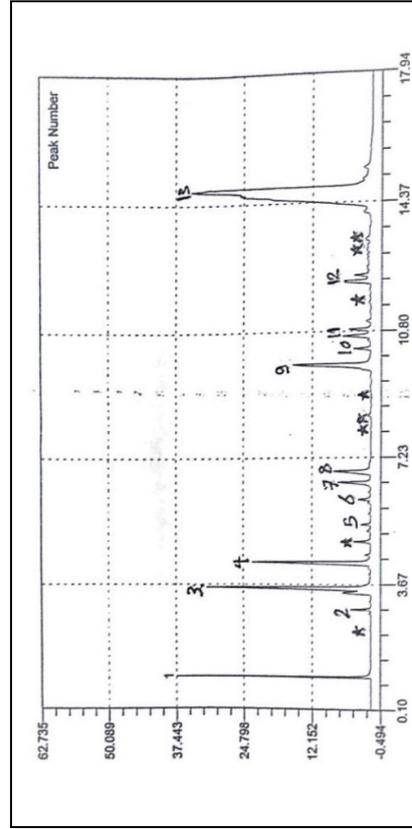


Fig. 4. Influence of potassium citrate at 2000 mg/l treatment of essential oil constituents on *Achillea millefolium* L.

limonene (1.66 to 21.01%), carvacrol (6.70 to 11.77%) and chamazulene (3.74 to 14.95%). The treatment of potassium citrate gave the maximum values of α -bisabolol oxide B (50.10%) followed descendingly by the treatment of potassium silicate as (37.27%) when compared with control (34.41%). Furthermore, the treatment of potassium nitrate scored the richest values limonene (21.01%) followed descendingly by the treatment of potassium citrate as (10.43%) whereas the lowest limonene values (1.66%) by the treatment of potassium silicate. On contrast, various treatments caused decreases in the percentage of carvacrol from (6.70 to 11.77%) in control to 10.99, 9.04 and 6.70% by foliar spray yarrow plant of the treatment potassium silicate, potassium nitrate, and potassium citrate, respectively. Additionally, the highest values of chamazulene (14.95%) of yarrow was achieved by the treatment potassium silicate whereas the minimum values of the same component were recorded by treatment potassium citrate as (3.74%). *Achillea millefolium* L. Mainly, essential oil comprises mono- and sesquiterpenoids. Pinenes, sabinene, phellandrene, eucalyptol (1,8-cineol), terpinen-4-ol and α -terpineol were the most concentrated compounds in the first class, while the most important compounds in the second class were β -caryophyllene, bornyl acetate, eudesmol, chamazulene, and α -bisabololol (Tuberoso and Kowalczyk, 2009; Rahimmalek *et al.*, 2009; Bocevskaa and Sovová, 2007 and Chalchat *et al.*, 1999). In this context, Turkmenoglu *et al.* (2015) demonstrated that the main constituents of the oil *Achillea millefolium* subsp. *Millefolium* α -bisabolol (12%), oxide of caryophyllene (8%), muurolo-410(14)-dien-1-olololoxide (7 %).

Consequently, spraying *Achillea millefolium* L. plants with potassium nitrate or potassium humate is favored, in order to boost growth, flowering and some chemical constituents. Whereas the application of potassium citrate and potassium silicate

induced the highest levels of essential oil content and yield.

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فاعلية مصادر البوتاسيوم المختلفة على النمو الخضري، الإزهار، إنتاجية الزيت العطري وبعض المكونات الكيميائية لنبات الاشيليا (*Achillea millefolium* L.)

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يعتبر نبات الاشيليا أحد النباتات الطبية والعطرية الهامة ويستخدم الزيت الطيار كمضاد للأكسدة، الميكروبات، التشنجات والأورام. أجريت هذه الدراسة بالمزرعة التجريبية والمعمل بقسم البساتين بكلية الزراعة بمشتهر جامعة بنها خلال موسمي ٢٠١٨/٢٠١٩ و ٢٠١٩/٢٠٢٠ لدراسة تأثير الرش الورقي بمعدل ٢٠٠٠ ملجم/لتر بصور البوتاسيوم المختلفة وهي كلوريد البوتاسيوم، سترات البوتاسيوم، هيومات البوتاسيوم، نترات البوتاسيوم، سيليكات البوتاسيوم، كبريتات البوتاسيوم، فوسفات البوتاسيوم أحادي البوتاسيوم وفوسفات هيدروجين ثنائي البوتاسيوم على النمو الخضري، الإزهار، إنتاجية الزيت العطري وبعض المكونات الكيميائية لنبات الاشيليا (*A. millefolium* L.). أظهرت النتائج أن مصادر البوتاسيوم المختلفة سجلت تأثيرات معنوية عالية للنمو الخضري والزهرى خاصة نترات البوتاسيوم ثم هيومات البوتاسيوم. علاوة على ذلك، أعطى استخدام نترات البوتاسيوم أغنى القيم للنسبة المئوية للتروجين، بينما أدى رش نبات الاشيليا بالفوسفات أحادي البوتاسيوم إلى الحصول على أعلى قيم للنسبة المئوية للفوسفور ومحتوى الكلوروفيل الكلي وكذلك أعلى نسبة مئوية للبوتاسيوم، بينما تم الحصول على أعلى قيمة لمحتوى الكربوهيدرات الكلية عند الرش بكبريتات البوتاسيوم. بالإضافة إلى ذلك، أدى رش نبات الاشيليا بسترات البوتاسيوم إلى الحد الأقصى لتقدير الزيت الطيار. علاوة على ذلك، تم تحديد ١٣ مكوناً الزيت العطري المنتجة من *A. millefolium* L. كانت المكونات الرئيسية هي α -camazulene ، carvacrol ، limonene ، bisabolol oxide B. لذلك يفضل رش نبات الاشيليا بنترات البوتاسيوم أو هيومات البوتاسيوم لتعزيز النمو الخضري والزهرى وبعض المكونات الكيميائية. في حين أن الرش بسترات البوتاسيوم وسيليكات البوتاسيوم ادت للحصول على اعلى انتاجية للزيت الطيار.