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Effect of Potassium Source and Dose on Yield and Quality of Strawberry Fruit

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Abstract

The purpose of this research is to investigate the effect of potassium fertilization source and dose on productivity and quality parameters of strawberry. The trial was conducted in 2016-2017 at the experimental greenhouse of Hassan II Institute of Agronomy and Veterinary Sciences in Rabat. Strawberry plants of the cultivar "San Andreas" were planted on November 6th in 12 liter pots equipped with a gravity fertigation system. The experimental design was a split-plot with eight treatment combinations of two potassium fertilizer sources: 1) Potassium Sulphate for the whole growing cycle (PS/PS); 2) Potassium Nitrate during the vegetative period and Potassium Sulfate during the fruit production period (PN/PS) and four potassium fertilizer doses: 100, 200, 300 and 400 kg/ha of K_2O replicated thrice. Potassium sulfate source was superior to potassium nitrate on the improvement of productivity and quality parameters of strawberry fruit. Potassium sulphate improved the number of flowers by 16%, fruit production by 21%, sugar content by 3%, and titrable acidity content by 0.5 g/L. The highest yield was recorded in plants receiving 300 kg/ha K_2O as potassium sulphate. The 300 kg K_2O/ha dose gave also superior results regarding quality parameters of strawberry fruit. This optimum potassium dose enhanced number of flowers by 35%, fruits produced by 44%, sugar content by 25% and titrable acidity content by 0.9 g/L.

Keywords

Strawberry, Fertilization, Potassium, Productivity, Quality

1. Introduction

Strawberry (*Fragaria* × *ananassa* Duch.) is one of the most widespread fruit crops in the world. In Morocco, strawberry cultivation has undergone a significant evolution of cultivated area and production, from 750 ha with 31,000 T harvested in 1995 to 3400 ha with an average production of 102,000 T in 2021 [1]. More than three quarters of strawberry production in Morocco is exported, 22% fresh from November to March and 45% frozen from April to July. The production rest is sold to the local market. During the 2020-2021crop year, exports reached 22,400 T in fresh state and 67,900 T in frozen [1]. This small fruit is grown in the Loukkos-Gharb region, including 83% in the Loukkos perimeter and 17% in that of Gharb and involves 593 farms from 0.2 to 70 ha [1].

To compete in the export market, Moroccan strawberry growers are opting for high performance varieties in terms of earliness, organoleptic qualities and shelf-life. For this, farmers must master appropriate techniques, mainly fertilization, in order to balance productivity, regularity of production and quality of strawberry fruits throughout the cycle. A strawberry marketing is essentially conditioned by quality parameters [2], of which sugar content, acidity content and visual appearance are the main determinants [3].

Potassium is an essential mineral element for strawberries, which require large amounts [4] [5]. It has essential functions within the plant in the production and transfer of proteins and sugars, in regulating water movement within the plant, and in improving plant tolerance to diseases and pests [6]. However, potassium affects significantly growth, production and quality parameters of strawberry plant [7]. During the strawberry fruiting period, potassium requirements increase to meet fruit needs [8] [9], which contains a large proportion of potassium. Potassium is thus considered a determinant of strawberry quality parameters such as sugar content, vitamin C content and fruit acidity [10]. These parameters tend to increase with the potassium fertilization dose [11]. Indeed, a higher potassium concentration in the nutrient solution improved strawberry fruit quality [12].

In addition, potassium plays an essential role in the transfer of assimilates to fruit. Reduced assimilate transport limits strawberry productivity and quality and is often a consequence of potassium deficiency [13].

It is recognized that excess or deficient fertilizers can have a significant impact on yield, quality and profitability of vegetable crops. The strawberry fertilization is particularly challenging since this crop is one of the most sensitive plants in horticultural production due to its shallow root system, pH requirement and sensitivity to salinity of nutrient solution [14] [15]. Choice of fertilizers, timing of their application and appropriate doses remain the key factors ensuring good yield and quality fruits.

In the Loukkos region, the strawberry potassium requirement for a yield of 60 tons/ha, is about 300 kg K_2O/ha [16]. In this region, strawberry fertilization is conducted by fertigation throughout the cycle, as it is a technique that maximizes productivity by reducing environmental impact [17] and increases fertilizer use efficiency [18]. The main fertilizers used by Loukkos strawberry growers under fertigation are potassium nitrate (PN) and potassium sulfate (PS) [19]. Strawberry growers favor the PN source during the early part of the cycle when the average temperature is low and the PS source from flowering onwards.

The aim of the present research is to study the effect of potassium fertilizer source and dose on strawberry productivity and quality through a pot trial conducted under controlled conditions.

2. Materials and Methods

2.1. Experimental Site and Substrate

Agronomic trial was installed in the experimental greenhouse of the Hassan II Agronomic and Veterinary Institute in Rabat during the 2016-2017 crop year. The substrate used is a mixture of sandy soil from coastal areas, clay and commercial peat. The substrate has a pH suitable to the requirements of strawberry plant and moderately rich in organic matter and mineral macro-elements (**Table 1**).

2.2. Plant Material and Potassium Treatments

The trial was conducted in 12 liter pots (Length = 60 cm, width = 20 cm, depth = 15 cm). Three bare-root plants, of SAN ANDREAS cultivar, were planted per pot on November 6, 2016. Originally from California, it is one of the three strawberry cultivars widely adopted in the Loukkos region [20].

The treatments tested were two potassium fertilizer sources: 1) Potassium sulfate for all the growth cycle (PS/PS) 2) Potassium nitrate during the vegetative period and Potassium sulfate during the fruit production period (PN/PS) combined with four potassium fertilizer doses: 100, 200, 300 and 400 kg K_2O/ha. The total nitrogen, phosphorus, magnesium and calcium application dose was identical for the eight potassium fertilizer source and dose treatments (179 kg N/ha, 165 kg P_2O_5/ha, 55 kg CaO/ha and 14 kg MgO/ha).

2.3. Fertigation Management

The pots were individually equipped with fertigation tanks, drip irrigation systems and drains with taps to collect the drainage and allow fertigation management.

Fertigation solutions were applied daily by adjusting the irrigation dose based on the drained water volume which is maintained between 10% and 20% of the supplied water volume [21] and by measuring the pH and electrical conductivity of the nutrient solutions and drainate which should meet the specific requirements of strawberry[1].

Table 1. Characteristics of the culture substrate prepared for the trial.

Organic matter content (%)	$N\text{-}NH_4^+$ (mg/kg)	$N\text{-}NO_3^-$ (mg/kg)	P (ppm)	K (ppm)	$CaCO_3$ (%)	Electrical conductivity (mmhos/cm)	pH
2.86	17.22	6.16	31.4	237.2	0.52	0.67	5.7

[1]Electrical conductivity = 1 to 2 dS/m and pH = 5.5 to 6.5 [22] [23].

2.4. Agronomic Measurements

In order to evaluate the effects of potassium fertilizer source and dose and the timing of its application in fertigation on production and quality of strawberry fruit, parameters related to the growth, production and quality of hand harvested strawberries were measured every week.

The growth parameters recorded were:

- Plant water consumption determined by the difference between the volume of water brought to the plants and the volume of water drained from the pots [24];
- Flowering dynamics consisted of counting the number of flowers per plant.

The production parameters measured were:

- Fruiting dynamic recorded as number of fruits per plant and average fruit weight harvested;
- Fruit yield measured through the cumulative weight of strawberry production during the whole harvest period which lasted 13 weeks.

The quality parameters concerned:

- Sugar content (˚Brix) in fruit measured by placing 1 to 2 drops of clear juice fruit on the prism of a digital refractometer (HI 96801, HANNA). The prism of the refractometer was washed with distilled water and dried between samples;
- Titratable acidity of fruit juice determined by titration method using a benchtop pH meter (CONSORT P107) [25]. The titrated volume of 0.1 M NaOH was recorded to an endpoint of pH 8.1;
- Dry matter content of strawberries of which the sampled fresh fruits were weighed and then oven dried at 80 deg C temperature for 48 hours before being weighed their dry weight [25].

2.5. Statistical Analysis

The obtained data were analyzed for significant differences using SYSTAT 13 statistical software. A two-factor analysis of variance was performed for each parameter studied to assess significant differences at the 5% level in treatments and their interaction for all parameters.

Comparison of the treatment means was performed using the Newman-Keuls test at significance level of 5% probability.

3. Results and Discussion

3.1. Strawberry Growth Parameters

Fertilization with potassium sulfate at 300 kg K_2O/ha dose showed the best results of water consumption and flowers produced per plant during the cycle. Indeed, plants receiving 300 kg K_2O/ha of potassium sulfate consumed more water and produced more flowers compared to other treatments (**Table 2**). Analysis of variance did not reveal a significant difference in the combined effect of potassium fertilizer source and dose on plant water consumption ($p = 0.450$) and

Table 2. Effect of potassium fertilizer source and dose on strawberry growth parameters.

Treatment		Water consumption (L/plant)	Number of flowers/plant
Source	PS	7.77	23.4^{a}
	PN	7.08	19.4^{b}
Dose	D1	7.41	16.4^{b}
	D2	7.08	21.8^{a}
	D3	8.32	25.3^{a}
	D4	6.89	22.3^{a}
Source x Dose	D1-PS	7.16	17.3^{b}
	D2-PS	7.40	24.1^{a}
	D3-PS	9.21	29.2^{a}
	D4-PS	7.32	23.1^{a}
	D1-PN	7.66	15.6^{b}
	D2-PN	6.76	19.4^{a}
	D3-PN	7.42	21.4^{a}
	D4-PN	6.46	21.4^{a}
Probability	Source	0.172^{NS}	0.051*
	Dose	0.212^{NS}	0.030*
	Source × Dose	0.450^{NS}	0.630^{NS}

PS: Potassium sulfate; PN: potassium Nitrate; D1: 100 Kg K_2O/ha; D2: 200 Kg K_2O/ha; D3: 300 Kg K_2O/ha; D4: 400 Kg K_2O/ha. *Significant effects at threshold P: 0.05; NS: Non-significant effects.

number of flowers produced during the strawberry cycle ($p = 0.630$), but our results show that potassium sulfate at 300 kg K_2O/ha increased nutrient solution consumption by 19% and improved flowering by 27% compared to potassium nitrate at the same potassium fertilizer dose.

The improvement in strawberry growth parameters could be attributed to the observed increase in water use in the PS treatment which is explained by the optimal effect of the applied potassium dose. Indeed, the application of potassium at optimal dose has a positive impact on water use efficiency of maize [26] thus improving its growth [27] and allows vigorous growth and early flowering of tomato [28]. Kering and Broderic [29] showed that millet plant growth was maximal around 80 kg K_2O/ha and above this dose the plants were shorter.

Our results are in agreement with the literature that demonstrates the functional role of potassium in the plant growth [30] and the improvement of crop water supply [6] [31] [32], which improves nutrient uptake of plant and increase photosynthesis rate needed for flower induction [33].

3.2. Strawberry Production Parameters

Strawberry fruit production was significantly increased by fertilizing with potassium sulfate, an increase of 22% over potassium nitrate. Indeed, the highest number of fruits was recorded in plants receiving potassium sulfate as a source of potassium fertilizer during the cycle (Table 3). Potassium sulfate improved yield by 19% compared to potassium nitrate, but this difference was not statistically significant.

An optimum effect of D3 dose corresponding to 300 kg K_2O/ha was observed on the production parameters. This effect is demonstrated by the analysis of variance which confirms that this dose of potassium fertilization significantly increased number of fruits by 45% and yield by 50% compared to the lowest dose D1 (Table 3).

The highest yield of 14 T/ha was recorded in plants receiving potassium sulfate as a source of potassium fertilizer at 300 kg K_2O/ha dose. PS-D3 improved fruit number by 14% and yield by 8% compared to potassium nitrate at the same dose (PN-D3), but these differences were not statistically significant.

Table 3. Effect of potassium fertilizer source and dose on strawberry production parameters.

Treatment		Number of fruits/plant	Average fruit weight (g)	Fruit yield (T/ha)
Source	PS	13.7^a	15.8	11.9
	PN	10.7^b	15.3	9.6
Dose	D1	8.3^b	14.5	6.9^b
	D2	12.8^a	15.8	11.0^a
	D3	15.0^a	16.5	13.9^a
	D4	12.7^a	15.8	11.1^a
Source x Dose	D1-PS	9.2^b	13.5	7.4^b
	D2-PS	14.9^a	15.3	12.6^a
	D3-PS	16.1^a	16.4	14.5^a
	D4-PS	14.4^a	16.3	13.0^a
	D1-PN	7.4^b	15.6	6.4^b
	D2-PN	10.7^a	16.1	9.4^a
	D3-PN	13.9^a	16.7	13.4^a
	D4-PN	10.9^a	17.7	9.2^a
Probability	Source	0.038*	0.737^{NS}	0.099^{NS}
	Dose	0.0163*	0.174^{NS}	0.013*
	Source x Dose	0.9^{NS}	0.275^{NS}	0.802^{NS}

PS: Potassium sulfate; PN: potassium Nitrate; D1: 100 Kg K_2O/ha; D2: 200 Kg K_2O/ha; D3: 300 Kg K_2O/ha; D4: 400 Kg K_2O/ha. *Significant effects at threshold P: 0.05; NS: Non-significant effects.

These results are consistent with our previous observations regarding the positive effect of potassium sulfate at an optimal fertigation dose on growth parameters. Indeed, the improvement of strawberry production parameters by potassium sulfate at 300 kg K_2O/ha are attributed to the increase in flower number [5] [7] [34].

In an experimental trial comparing two sources of potassium fertilizer, it was observed that potassium sulfate improved pepper yield more than potassium nitrate [35].

The positive effect of potassium sulfate as a source of potassium fertilizer on yield has also been observed in tomato [36] and fruit trees such as apple [37] in soil fertilization trials and in passion fruit [38] and strawberry [39] conducted in hydroponic systems. The same trend was noted in chili crop where Medhi *et al.* [40] reported that potassium application maximize the number of fruits per plant and Ananthi *et al.* [41] showed that potassium sulfate application improves fruit number per plant, fruit weight and thus yield.

High potassium levels contribute to vigorous growth of strawberry plant, helping it to support a greater number of fruits per plant. This is justified by the increased chlorophyll content of the foliage, which increases photosynthesis rate [42], carbohydrate synthesis [43] and thus increases fruit production and number of fruits per plant [44]. Indeed, additional potassium fertilization positively influences leaf area development, chlorophyll content, reproductive parameters [4] and increases fruit yield [45] of strawberry crop.

Our results are in agreement with those reported by Yagmur *et al.* [46] who stated that the application of an optimal dose of potassium at 360 kg K_2O/ha significantly increases average fruit weight and results in higher yield in tomato. Others researches also reported that optimal potassium supply maximizes yield of tomato [47] and strawberry [48]. The study results of Zelelew *et al.* [49] showed that potassium had significant effect on potato growth.

3.3. Strawberry Quality Parameters

Potassium fertilizer source had a positive effect on sugar content of strawberry fruit and a significant effect on titratable acidity. Indeed, potassium sulfate improved sugar content (˚Brix) by 4% and titratable acidity by 7% compared to potassium nitrate (**Table 4**).

A dose of 300 kg K_2O/ha significantly influences sugar content of strawberries and thus allows the increase of ˚Brix by 25% compared to the lowest dose.

The optimum effect of D3 (300 kg K_2O/ha) is also observed for acidity content of strawberry fruits. Indeed, the highest results of titratable acidity 7.4 g/L and 6.9 g/L were recorded in the PS-D3 and PN-D3 treatments respectively.

The results of our study showed that potassium sulfate at 300 kg K_2O/ha increased sugar content and titratable acidity of strawberry fruits by 9% and 7% respectively compared to potassium nitrate at the same dose (**Table 4**).

Our results are in agreement with those reported by Ahmad *et al.* [47] that potassium sulfate significantly influences fruit quality. Indeed, in experimental

Table 4. Effect of potassium fertilizer source and dose on strawberry fruit quality parameters.

Treatment		Sugar content (˚Brix)	Titratable acidity (g/L)
Source	PS	5.5	7.0^a
	PN	5.3	6.5^b
Dose	D1	4.1^b	6.2^b
	D2	5.5^a	6.5^a
	D3	5.5^a	7.1^a
	D4	5.4^a	6.4^a
Source x Dose	D1-PS	4.0^b	6.4^b
	D2-PS	5.4^a	6.7^a
	D3-PS	5.7^a	7.4^a
	D4-PS	5.8^a	7.0^a
	D1-PN	4.0^b	6.2^b
	D2-PN	5.8^a	6.6^a
	D3-PN	5.2^a	6.9^a
	D4-PN	5.1^a	6.0^b
Probability	Source	0.140^{NS}	0.032*
	Dose	0.00***	0.0302*
	Source × Dose	0.131^{NS}	0.540^{NS}

PS: Potassium sulfate; PN: potassium Nitrate; D1: 100 Kg K_2O/ha; D2: 200 Kg K_2O/ha; D3: 300 Kg K_2O/ha; D4: 400 Kg K_2O/ha. *Significant effects at threshold P: 0.05; NS: Non-significant effects.

trials comparing two potassium fertilizer sources, it was observed that PS improves fruit quality more than PC (potassium chloride) in cucumber [50], kiwi [51] and other vegetables [52].

The positive effect of potassium sulfate as a source of potassium fertilizer on fruit quality has also been observed in tomato [36] [53] and pepper [54].

Potassium plays an important role in photosynthesis and carbohydrate metabolism [42] [55]. Marschner [42] demonstrated that potassium fertilization increases photosynthesis rate in leaves and thus optimal potassium supply results in higher sugar content in reserve organs [56]. According to Rodas *et al.* [57], the highest sugar contents and the best titratable acidity were obtained in strawberry fruits from plants receiving 344.50 kg K_2O/ha. Indeed, El-Nemr *et al.* [58] confirm that higher potassium concentration in the nutrient solution increases titratable acidity and Awad-Allah *et al.* [59] showed that all quality parameters of garlic bulb increased significantly with increasing K levels.

4. Conclusion

Fertilization of strawberry plants with potassium sulfate at 300 kg K_2O/ha showed superior results in terms of production and fruit quality parameters. In fact, this optimal dose, as PS is a source of potassium, significantly increased number of flowers by 27%, fruit production by 14%, yield by 8%, sugar content by 9% and citric acid content by 7% (0.5 g/L). These effects could be attributed to the increase in nutrient solution consumption observed in the PS-D3 treatment, in the order of 19%, explained by the potassium role in improving crop water supply leading to increased leafs photosynthesis rate, fruits production and sugars translocation to fruit which contributed to improved strawberry fruit yield and quality.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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