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Potassium Sources and Rates for Drip Irrigated Polyethylene Mulched Chilli Pepper

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Abstract

Fertigation with drip irrigation is one of the technologies to solve fertilization and irrigation problems in chilli pepper production using polyethylene mulch. Potassium (K) is one of the important macro nutrients that affect plant growth and development due to its roles in the biochemical and the biophysical processes in plants. The objective of this study was to determine the best sources and the optimum rates of potassium for drip irrigated polyethylene mulched chilli pepper field production. The study was conducted in January until July 2018 at Tajur Experimental Farm, Center for Tropical Horticulture Study, Bogor Agricultural University. The experimental design was a split plot with the K sources (KCL, ZK, NPK) as main plots and K rates that consisted of five levels (0, 68, 136, 204, 272 kg $K_2O.ha^{-1}$) as sub-plots. The results showed that the best optimum rate of K to produce fruit is 101.11 kg $K_2O.ha^{-1}$ with a maximum yield of 2.26 $t.ha^{-1}$. Chilli crops fertilized with NPK and KCl had the greatest fruit weight per plant, fruit weight per plot, and fruit weight per hectare.

Keywords: fertigation, fertilizer, optimum fertilizer rate

Introduction

Chilli pepper is one of the most popular types of chilli and one of the most important and strategic vegetables in Indonesia. The demand for chilli pepper has been continuously increasing along with the increasing need of households and industries. Productivity of chilli pepper in Indonesia from 2013 to 2017 ranged from 5.7 to 6.88 $t.ha^{-1}$ (BPS, 2018), which is still relatively low as the potential yield could reach 10 to 14 $t.ha^{-1}$. Some of the major problems that result in low productivity of chilli pepper in Indonesia are poor crop management techniques, low soil fertility, and weather variabilities.

Fertilization plays significant roles in fulfilling plant nutrient requirements that cannot be provided optimally by soil. Potassium (K) is an important macro nutrient that affects plant growth and development; K is required for various biochemical and biophysical processes in plants including photosynthesis, protein synthesis, cell osmotic regulation, enzyme activation, as well as to enhance plant resistance to abiotic and biotic stresses (Szczerba et al., 2009). According to Wuzhong (2002) K fertilizer can increase the quality and yield of fruits of Solanaceae family including eggplant, tomatoes, sweet pepper, and chilli.

Polyethylene mulch is a widely applied technology in the cultivation of chilli pepper. The benefits of using mulch include reducing fertilizer loss and soil compaction, inhibiting weed growth, and increasing leaf photosynthesis rates (Bosland dan Votava, 2012). However, there are technical constraints on the use of plastic mulch occur during the application of fertilization and irrigation. The current method of fertilization for chilli pepper in Indonesia is by applying the fertilizers directly to the planting holes. This technique can be time-consuming and laborious. In addition, mulching using polyethylene mulch often leads to ineffective water absorption by roots with overhead irrigation.

Fertilization through drip irrigation can overcome the difficulties of applying fertilizers and irrigation on polyethylene mulch. Fertigation is the process of applying fertilizer with water through drip irrigation to the crop root zone simultaneously and uniformly. over broadcast fertilization Sivanappan (2015) are higher efficiency of fertilizers and water usages as nutrients were applied directly into the rooting zone, nutrient loss is minimized, and it saves time and labor. Nitrogen (N) and K are easily dissolved and move rapidly within irrigation water (Jat et al., 2011). Cultivation of vegetable crops by Simone et al. (2003) applied 100% P_2O_5, 20-50% N and K_2O before planting, while the remaining 50-80% N and K_2O were applied through drip irrigation. A study by Susila and Gumelar (2010) demonstrated that combination of polyethylene mulch and drip irrigation system using one dripline resulted in the highest yield of eggplant and kangkong (Susila and Gumelar 2010).

The study on K fertilization through drip irrigation for field production of chilli pepper has not been widely explored. Therefore, the objective of this study was to determine the best K source and the optimum rate of K through fertigation with drip irrigation to improve the production of chilli pepper.

Materials and Methods

The research was conducted from January to July 2018 at the Tajur Experimental Garden, Tropical Horticulture Study Center, Bogor (S6^{0}37'21.80784", E106^{0}44, 57.07716) at an altitude of 250 m above sea level. The type of soil is Latosol with moderate soil fertility.
The materials used in this study were chilli pepper seeds of "Santika" F1, Urea (45% N), TSP (46% P_2O_5), KCl (60% K_2O), ZK (50% K_2O), NPK (16 % N: 16% P_2O_5: 16% K_2O). The tools used included installation of drip irrigation.

The experiment was arranged in a split plot with a randomized complete block design. The main plots are the sources of K fertilizer (KCl, ZK, NPK) and the sub-plots are rates of K fertilizer (0, 68, 136, 204, 272 kg $K_2O.ha^{-1}$) or 225 kg $N.ha^{-1}$, 112 kg $P_2O_5.ha^{-1}$, and 136 kg $K_2O.ha^{-1}$ according to Susila (2006). The size of experiment plots was 1.5x6 m with the size of bed of 1 x 6 m long and 0.3 m in height, and the distance between beds of 0.5 m. Seedlings were planted in a double row with 30x50 cm spacing planted in a zig zag pattern, resulting in 24 plants per bed.

Drip irrigation consisted of a head unit and the infield units. The head unit consisted of a 2000 L reservoir, engine pumps, booster pumps, pressure regulators at 20psi, and 0.75 inches disc filters which are connected to the infield unit components including polyethylene pipes 16 mm and drip tubes (diameter 20 cm and emitter distance 16 mm) according to the treatment of each experimental unit plot. Drip tubes were installed under the polyethylene mulch along the beds and between the planting holes with the emitter facing down. Calibration was conducted to determine the length of time and amount of water applied through drip irrigation to reach a wetting root zone.

The pre-plant basic fertilizers consisted of 100% TSP fertilizer, 40% Urea, and 40% K (KCl, ZK, and NPK) were applied before the installation of polyethylene mulch at one week before planting. The rest of fertilizers (60% Urea and 60% KCl, ZK, and NPK) were applied through drip irrigation (Table 1). Fertigation was applied 10 times weekly at 1-10 weeks after planting (WAP) at the rate of 6%.

The growth parameters measured were plant height (five sample plants per plot, fortnightly), 50% flowering i.e. when 50% plant population per plot had flowered, 50% ripe fruit, i.e. when 50% plant population per plot had ripe fruits (indicated by red color fruits), shoot dry weight (two sample plants per plot, collected at 5 WAP and 18 WAP), marketable and unmarketable fruit weight per plant, fruit weight per plot and fruit weight per hectare, which were calculated cumulatively from eight harvests at one week interval.

Shoot K was measured using HNO_3 and $HClO_4$ method (Eviati and Sulaeman, 2009); shoot K uptake was calculated from shoot dry weight x % of shoot K (Sumarni et al., 2012) where the shoots consist of stem and leaves. Ascorbic acid was measured using iodine titration method developed by AOAC (1995). Fruit capsaicin was determined using high performance liquid chromatography (Al Othman et al. 2011).

The data were analyzed using ANOVA at a 5% level

Table 1. The fertilizer rates for pre-plant and drip irrigation*

Rate of K (kg $K_2O.ha^{-1}$)	Preplant					Drip irrigation			
	TSP (g)	Urea (g)	KCl* (g)	ZK* (g)	NPK* (g)	Urea (g)	KCl* (g)	ZK* (g)	NPK* (g)
0	876	719	0	0	0	1 078	0	0	0
68	876	719	163	195	610	1 078	244	293	915
136	876	719	325	390	1 220	1 078	488	586	1 831
204	876	719	488	586	1 831	1 078	732	879	2 746
272	876	719	651	781	2 441	1 078	976	1172	3 661

Note: Applied to 9 m^2 planting beds and each treatment was replicated four times.

of significance using SAS 9.4 program. Significant differences between means were tested further by orthogonal polynomial test for K rate using Tukey test for K source at a 5% level of significance.

Results and Discussion

Soil Analysis

The results of the soil analysis before the experiment showed that the soil consisted of 51% dust, 38% clay, and 11% sand, pH 6.1 (slightly acidic), had 0.15% N (low), 362 ppm of P (very high), 820 ppm of K (very high), 14.23 ppm of Ca per 100 g of soil (high), 1.86 of Mg per 100 g of soil (Moderate), C:N ratio of 13 (moderate), and CEC of 21.20 (moderate).

Plant Height

The application of different sources of K had significant effects on plant height at 8 and 10 WAP; chilli crops fertilized with KCl and NPK were the tallest compared to those fertilized with ZK (Table 2). K rate and their interaction with K sources from 2 to 10 WAP did not have significant effects on plant height (Table 2). It is possible that this was due to the status of K in the soil that was already high (Table 2).

Shoot Dry Weight, Shoot K Content, and Shoot K Uptake

The application of KCl and NPK resulted in a higher shoot dry weight and shoot K uptake (measured at 18 WAP) than application of ZK (Table 3, Figure 1). Dry weight reflects the translocation of photosynthesis products to the plant organs during plant growth and development (El-Bassiony et al., 2010). El-Bassiony et al. (2010) and Amisnaipa et al. (2016) also reported that K fertilizer application could increase all growth parameters including plant height, leaf number, branch number per plant, as well as fresh and dry weight of sweet pepper leaves. Similarly, Izhar et al. (2013) reported in increase of tomato dry weight with K fertilization.

The shoot K at 5 and 18 WAP were not influenced by the K sources, but the response to the K rates showed a linear pattern (Table 3). This shows that the higher the rate of K applied, the higher the shoot K content. This is in accordance with the nature of nutrient K as it tends to be absorbed excessively by crops. However, the increase in shoot K content was not followed by an increase in shoot dry weight.

The K sources had significant effect on shoot K uptake at 18 WAP. As with shoot dry weight, shoot K uptake in the crops fertilized with KCl and NPK was higher than those fertilized with ZK (Table 3). The shoot K uptake was influenced by the shoot dry weight, thus showing the same response pattern with the shoot dry weight, which was quadratic (Figure 1 A).

The optimum rate of K to obtain the maximum shoot dry weight of 116.32 g per plant was 115.94 kg $K_2O.ha^{-1}$ (Figure 1 A), whereas the optimum rate of K

Table 2. The height of chilli pepper fertilized with various sources and rates of K at 2 to 10 weeks after planting

Treatment	Plant height (cm)				
	2 WAP	4 WAP	6 WAP	8 WAP	10 WAP
Source of K					
KCl	19.10 a	36.67 a	74.83 a	92.34 a	93.78 a
ZK	18.91 a	37.27 a	70.75 a	83.70 b	84.23 b
NPK	18.54 a	36.18 a	71.07 a	88.51 a	92.45 a
F	ns	ns	ns	**	**
Rate of K (kg $K_2O.ha^{-1}$)					
0	18.21	36.13	72.92	87.98	89.79
68	18.88	36.52	71.50	87.66	90.29
136	18.88	36.88	71.65	87.39	91.08
204	18.92	36.70	73.88	88.42	90.28
272	19.36	37.29	71.13	89.47	89.31
F	ns	ns	ns	ns	ns
K sources x rates	ns	ns	ns	ns	ns

Note: The values followed by the same letters within the same column is not significantly different at the 5% level of Tukey test; ns: not significant; *P < 0.05, **P < 0.01. Response pattern was determined by orthogonal polynomial test. L: linear; Q: quadratic; WAP: week after planting.

Table 3. The chilli pepper shoot dry weight, shoot K content, and shoot K uptake at various sources and rates of K at 5 and 18 weeks after planting

Treatment	5 WAP			18 WAP		
	Shoot dry weight (g)	Shoot K content (%)	Shoot K uptake (g)	Shoot dry weight (g)	Shoot K content (%)	Shoot K uptake (g)
Source of K						
KCl	5.33 a	5.26 a	0.28 a	112.61 a	0.60 a	0.67 a
ZK	5.86 a	5.19 a	0.31 a	98.66 b	0.61 a	0.60 b
NPK	5.63 a	5.27 a	0.30 a	112.20 a	0.62 a	0.69 a
F	ns	ns	ns	**	ns	**
Rates of K (kg $K_2O.ha^{-1}$)						
0	5.73	5.08	0.29	102.07	0.58	0.59
68	6.00	5.17	0.31	122.64	0.60	0.74
136	5.67	5.22	0.30	111.69	0.61	0.67
204	5.51	5.31	0.30	105.72	0.62	0.65
272	5.11	5.43	0.28	96.99	0.64	0.62
Response pattern	L*	L*	ns	Q**	L**	Q**
K sources x rates	ns	ns	ns	ns	ns	ns

Note: The values followed by the same letters within the same column are not significantly different according to Tukey test; ns: not significant; *P < 0.05; **P < 0.01. Response pattern was determined by orthogonal polynomial test; L: linear; Q: quadratic; WAP: week after planting.

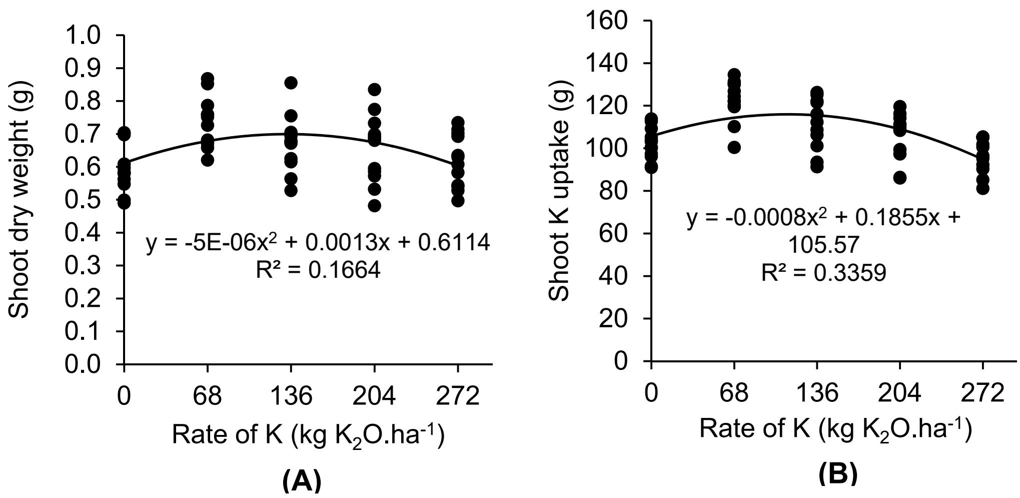


Figure 1. The chilli pepper shoot dry weight (A) and shoot K uptake (B) after treated with different K rates at 18 weeks after planting

fertilizer to get a maximum shoot K uptake (0.69 g per plant) is 130 kg $K_2O.ha^{-1}$ (Figure 1 B).

Time to 50% Flowering and 50% Ripened Fruit

Sources of K and their interaction with the K rates did not significantly affect the time to 50% flowering and 50% ripe fruit. Time to 50% flowering responded linearly with the increasing rates K (Table 4), indicating that the increase in K rates promoted earlier generative phase or flowering time.

Fruit Weight per Plant, Fruit Weight per Plot, and Fruit Weight per Hectare

NPK fertilizer resulted in the greatest fruit weight per plant, marketable fruit weight per plot and fruit weight per hectare, even though there were not significantly different from those treated with KCl (Table 5). NPK has an additional element of phosphorus (P) compared to KCl. According to Marschner (2012) P is an important component of compounds for energy transfer as adenosine triphosphate (ATP) and phospholipids. The study by Amisnaipa (2014)

Table 4. The age of 50% flowering and 50% ripe fruit at various K sources and rates

Treatment	Days to 50% flowering (DAP)	Days to 50% fruit ripening (DAP)
Source of K		
KCl	28.85 a	68.55 a
ZK	28.40 a	67.90 a
NPK	28.80 a	68.60 a
F	ns	ns
Rates of K (kg $K_2O.ha^{-1}$)		
0	29.17	68.75
68	28.67	68.17
136	28.92	68.25
204	28.50	68.33
272	28.17	68.25
Response pattern	L*	ns
K sources x rates	ns	ns

Note: The values followed by the same letters within the same column are not significantly different according to Tukey test at 5%; ns: not significant; *P < 0.05; **P < 0.01. Response pattern was determined by orthogonal polynomial test; L: linear; Q: quadratic; DAP: day after planting.

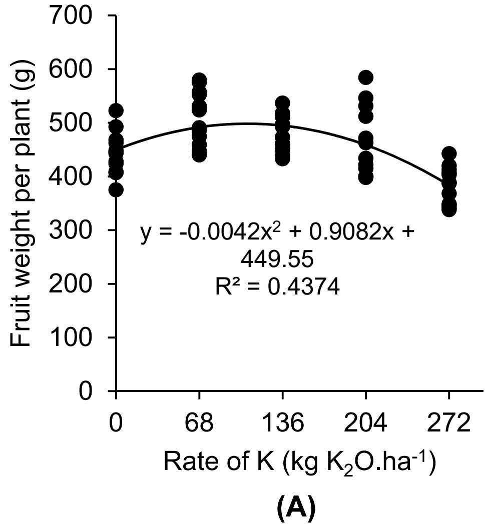
Table 5. Chilli pepper fruit weight per plant, fruit weight per plot, and fruit weight per hectare at different sources and rates of K

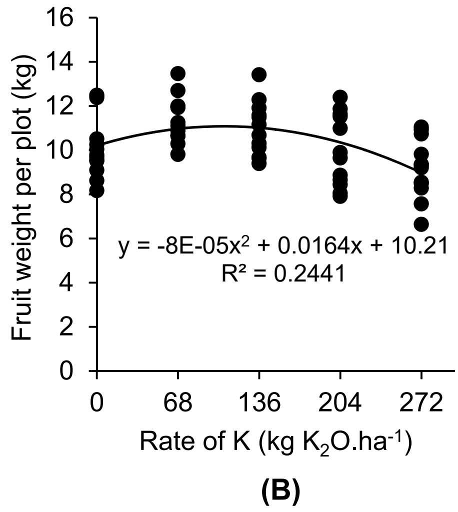
Treatment	Fruit weight per plant (g)	Fruit weight per plot		Fruit weight per hectare (t)
		Marketable (kg)	Unmarketable (kg)	
Source of K				
KCl	454.44 ab	10.71 ab	0.17 a	11.90 ab
ZK	431.53 b	9.22 b	0.16 a	10.24 b
NPK	481.14 a	10.98 a	0.16 a	12.21 a
F	**	**	ns	**
Rates of K (kg $K_2O.ha^{-1}$)				
0	443.57	10.40	0.19	11.56
68	509.65	11.39	0.15	12.66
136	477.01	10.58	0.17	11.76
204	464.63	9.99	0.16	11.10
272	383.67	9.16	0.15	10.18
Response pattern	Q**	Q**	L*	Q**
K sources x rates	ns	ns	ns	ns

Note: The values followed by the same letters within the same column are not significantly different according to Tukey test at 5%; ns: not significant; *P < 0.05; **P < 0.01. Response pattern was determined by orthogonal polynomial test; L: linear; Q: quadratic.

demonstrated that P could increase the number of fruits, weight per fruit, and the total harvest weight of large red chili fruit.

Fruit weight per plant, marketable fruits per plot, and fruit weight per hectare after treatment with different K rates showed quadratic responses (Table 5). The fruit weight per plant reflects the ability of plants to optimally allocate photosynthate to their reproductive organs. Furthermore, the fruit weight per plant will





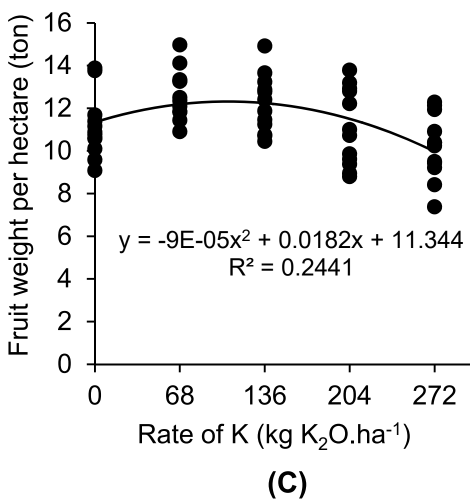


Figure 2. Fruit weight per plant (A), fruit weight per plot (B), and fruit weight per hectare (C) at different K rates

affect fruit weight per plot and fruit weight per hectare. Potassium plays an important role in photosynthate translocation. A study by Golcz et al. (2012) in sweet pepper showed that there was an increase in the total harvest, marketable, and harvestable yield per plant along with an increase in K rates. According to Bhuvaneswari et al. (2013) number of chilli pepper fruit per plant increased with the increment of K. Another study by Amisnaipa (2014) also demonstrated that K could increase the fruit weight of large red pepper.

The increase in K rates reduced the unmarketable fruit weight per plot (Table 5). Unmarketable fruits consisted of deformed fruits and fruits infested by pests (caterpillars) and disease (anthracnose). According to Romheld and Kyrkby (2010), Wang et al. (2013), and Zorb et al. (2014) K can reduce the invasion of pests and diseases in plants. A study by Widyanti and Susila (2015) also showed that K fertilization could increase the marketable fruit weight and reduce the unmarketable fruit weight.

Chilli crops had a quadratic response pattern to rates of K fertilization (Figure 2 A, B, C), and based on fruit weight per plant the optimum rate of K was 108.12 kg $K_2O.ha^{-1}$ with a maximum yield of 498.65 g per plant (Figure 2 A). As for the fruit weight per plot, the optimum K rate was 102.5 kg K_2O per ha with a maximum yield of 11.05 kg per plot (Figure 2 B). The optimum rate of K for a maximum fruit weight per ha (12.26 $t.ha^{-1}$) was 101.11 kg $K_2O.ha^{-1}$ (Figure 2 C).

Content of Ascorbic Acid and Capsaicin

The application of K increased ascorbic acid content compared to those in the control group (Table 6). The content of ascorbic acid in fruits treated with 68 kg $K_2O.ha^{-1}$ in the form of KCl and ZK was 13 and 7% higher than those in the control group, respectively. On the other hand, the application of 204 kg K_2O.

ha^{-1} NPK resulted in higher ascorbic acid content (19%) as opposed to the control. In the synthesis of ascorbic acid, potassium plays a role as an enzyme activator. According to Mazid et al. (2011), the enzymes involved in ascorbic acid synthesis include glucose 6-phosphate isomerase, phosphomannose isomerase, phosphomannose mutase, GDP-mannose pyrophosphorylase, L-galactose dehydrogenase, and GDP-glucose-2-epimerase. Similarly, treatment with K has also been shown to increase the ascorbic acid levels in sweet pepper (El-Bassiony et al., 2010), tomatoes and red chili (Wuzhong, 2002).

The results showed that the capsaicin contents increased after treatment with K (Table 6). The rate of 68 kg $K_2O.ha^{-1}$ K in the form of KCl and ZK resulted in 61 and 35% higher capsaicin content compared to the control group, respectively. On the other hand, NPK at 204 kg $K_2O.ha^{-1}$ resulted in higher ascorbic acid content (24%) than the control group. According to Fageria (2009) potassium can activate more than 60 enzymes involved in plant growth and increase the absorption of other nutrients, which are important for metabolism of N and P. The accumulation of capsaicin in chili fruit is particularly influenced by nitrogen, especially in the form of nitrate (Gonzalez, 2010).

Correlation test results demonstrated that shoot dry weight and shoot K uptake at 18 WAP and the number of fruits correlated positively with fruit weight per plant, fruit weight per plot, and fruit weight per hectare (Table 7). Similar results were demonstrated at 10 WAP (Table 7).

Fertilizer application through drip irrigation for field production of chilli pepper can increase the effectiveness and efficiency of fertilizer uses, and increase chilli pepper yield. More studies need

Table 6. The content of ascorbic acid and capsaicin in chili pepper fruits at various K sources and rates

Rates of K (kg $K_2O.ha^{-1}$)	Content of ascorbic acid and capsaicin on fertilizer sources		
	KCl	ZK	NPK
	ascorbic acid (mg.100 g^{-1})		
0	2256	2333	2060
68	2543 (13)*	2507 (7)	2320 (13)
136	2332 (3)	2346 (1)	2268 (10)
204	2325 (3)	2481 (6)	2451 (19)
272	2340 (4)	2420 (4)	2353 (14)
	capsaicin (ppm)		
0	929	947	906
68	1496 (61)	1278 (35)	977 (8)
136	1028 (11)	1177 (24)	894 (-1)
204	984 (6)	1211 (28)	865 (-4)
272	1453 (56)	947 (0)	1119 (24)

Note: *Values within brackets are percentages of the control treatment

Tabel 7. Correlation analysis of chilli pepper growth and yield components

Variable	Shoot dry weight 18 WAP	Shoot K uptake 18 WAP	Fruit number per plant	Fruit weights per plant	Fruit weights per plot	Fruit weights per hectare
Plant height 10 WAP	0.38**x	0.24	0.18	0.24	0.48**	0.48**
Shoot dry weight		0.71**	0.27**	0.59**	0.61**	0.61**
Shoot K uptake			0.21	0.45**	0.43**	0.43**
Fruit number per plant				0.45**	0.32*	0.32*
Fruit weights per plant					0.68**	0.68**
Fruit weights per plot						1.00**

Note: Values indicate the correlation coefficients at $P < 0.05$ (*), $P< 0.01$ (**). Shoot dry weight and shoot uptake values are correlation coefficients at 18 weeks after planting.

to be conducted at different locations as fertilizer requirements are likely to be site-specific. This research has provided more information for fertilizer requirements of chilli crops, and be a reference for potassium fertilization of field grown chilli pepper in the tropics.

Conclusion

The best K fertilizer source for chilli pepper production through drip irrigation is NPK and KCl with an optimum rate of 101.11 kg $K_2O.ha^{-1}$ to get a maximum yield of 12.26 $t.ha^{-1}$. Chilli crops fertilized with NPK and KCl produced the greatest chilli fruit weight per plant, fruit weight per plot, and fruit weight per hectare.

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