SOIL POTASSIUM AND SODIUM, PHYSIOLOGICAL RESPONSES AND YIELDS OF TOMATO AS AFFECTED BY POTASSIUM FELDSPAR IN SOIL CULTURE

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ABSTRACT

To assess an alternative to muriate of potash, the effects of ground K-feldspar on the growth and productivity of tomato were investigated under greenhouse conditions at the University of Newcastle, U. K between October 2008 and March 2009. Potassium feldspar was applied at 0, 64, 128, 192 and 256 mg kg-1 soil, arranged in a completely randomized design and replicated five times. Soil properties were determined before and after harvest of fruits. Plant physiological parameters, namely, leaf instantaneous water use efficiency (WUEi), photosynthetic rate, transpiration and stomatal conductance were also determined using non-destructive methods. Total and marketable tomato fresh fruit yields were evaluated along with average fruit weight. The results showed that WUEi, photosynthetic rate and transpiration decreased during vegetative growth and at the on-set of fruit formation but increased significantly ($p < 0.05$) at the peak of fruit setting. Overall, the application of K-feldspar increased the physiological factors but the means were not significantly different ($p < 0.05$). The exception was leaf stomatal conductance that decreased significantly at 256 mg kg-1 soil, compared with the control treatment. Average fruit weight was significantly($p < 0.05$) increased at the application of 64 mg kg-1 soil compared with the control and the higher rates of K. Instantaneous water use efficiency was highly positively correlated with soil exchangeable-K ($r = 0.90^{**}$) but negatively correlated with soil exchangeable-Na ($r = -0.62^{*}$). Photosynthetic rate was positively correlated with transpiration ($r = 0.49^{*}$), stomatal conductance ($r = 0.48^{*}$) and average fruit weight ($r = 0.68^{*}$). It was concluded that ground potassium feldspar is a potential fertilizer for tomato but there is the need for further studies under field conditions.

Keywords: K-feldspar, tomato, physiological factors, shoot and fruit yields.

INTRODUCTION

Tomato is probably one of the most extensively grown vegetable crops, grown on approximately 2.8 million ha worldwide, and on 127,000 ha in Nigeria according to the FAO as reported by Jones (2008). The yields and quality of tomato fruits in Nigeria, in particular have been undermined by low K application and high disease infestation (Idowu and Aduayi, 2007). More than 50% of tomato fruit yield in the country is lost during handling, transportation and transit in stores (Fajoba, 2006). The price of muriate of potash has rose sharply to almost \$1000/tonne in 2008 and fell back to approximately \$600/tonne in 2009. These high prices mean that alternative K-rich silicate rocks and minerals may have lower unit cost for K, and so may become viable in circumstances where farmers cannot afford conventional fertilizers (Manning, 2009). Potassium (K) is the most abundant cation in the cytoplasm of plants and its accompanying anions make a major contribution to the osmotic potential of cells and tissues of glycophytic species (Hsiao and Lauchli, 1986; Marschner, 1998). It also plays a central role in the opening and closing of stomata and thus has key implications for plant water use efficiency. Efficient use of water confers drought tolerance to plants by extending the period over which soil moisture is available. Thus, plants avoid drought stress and the growing season is extended. This is an ecologically important factor influencing adaptation of plants to dry habitats. In agriculture, drought is responsible for more yield losses than any other biotic or abiotic factors.

In general, the fertilization with ground rock phosphate for crop production is still being debated and is yet to receive wider acceptance amongst farmers even in developed countries where emphasis is placed on the quality of crop products (Manning, 2009). Potassium is present in four forms in the soil: the unavailable mineral form; the non-exchangeable form in fine-grained micas; the exchangeable form on clay and organic matter surfaces; and K^+ in soil solution. Research on the use of K-feldspar as a source of K for plant nutrition has produced inconsistent results. Approximately 90 to 98% of K in soils is in relatively unavailable primary mineral forms. Although K occurs mainly in the framework of silicate K-feldspars and in micas, the K^+ ion is tied by strong, covalent bonds requiring large amount of energy for its release and thereby reducing its solubility. Sparks (1987) was of the opinion that despite the very low solubility of K-feldspar in the sand fractions of soils, it may provide a more continuous supply of K to soil solution than previously thought. Since K-feldspar is one of the commonest K sources available in Africa, it is therefore imperative to investigate the impact of K-feldspar on crop production. There is little specific information on the effect of K-feldspar on tomato production. In this study, the effects of ground K-feldspar on leaf net CO_2 assimilation, stomatal conductance, transpiration and instantaneous water use efficiency were examined. The study also assessed its impact on soil exchangeable K and Na, fruit yields and moisture content of the tomato plant.

MATERIALS AND METHODS

Soil and K-feldspar sampling, preparation and analysis

Soil samples were collected from Newcastle University's Nafferton Farm, United Kingdom. Soil particle size distribution was determined using wet-sieving technique according to the British Standard (BS 1377-2: 1990). Soil K, calcium, magnesium and sodium were extracted with 1 M ammonium nitrate solution (British Standard Method 63). The potential cation exchangeable capacity of soil was determined using barium chloride solution (Bascomb, 1964). Potassium and Na were determined using transmittance while Ca and Mg were determined using the absorbance mode of atomic absorption spectrophotometry (SpectroAA. 400 Varian UK). Soil pH was determined according to Thomas (1996) modified by the British Standard (1995) (pH meter Model Jenway 3020). Specific electrical conductivity of soil was determined as described by British Standard (1995), using EC meter Model HANNA HI 9835. Total Nitrogen was determined using CNS Analyser (Elementar Analysensysteme GmbH

VarioMAX V7.0.5). Soil organic carbon was determined using LECO Carbon / Sulphur Analyser, according to British Standard (1995) (Carbon / Sulphur Determinator LECO CS-244 HF-100 Induction Furnace LECO Corporation, St. Joseph Michigan, USA). Available P was determined using the method of Olsen et al. (1954) modified by the British Standard (1995), with the ATI Unicam 8625UV/ Visible Spectrometer. All samples were run in duplicate and blanks were run with each batch. Potassium feldspar (orthoclase) of 50 µm approximate grain size was obtained from IMERYS, Cornwall, United Kingdom. The composition of the K-feldspar was confirmed using XRF. Soil exchangeable K and Na were determined again after the experimentation.

Seedling preparation and planting in the greenhouse

Tomato seeds (Lycopersicon lycopersicum (L.) Karst) variety Glacier, were purchased from Thompson and Morgan (UK) Ltd. Glacier tomato is a semi-determinate / semi bush variety, and is very cold tolerant, almost down to 0oC. The tomato seeds were planted in a heated glass house on October 24, 2008 in trays containing peat compost. Nitrogen (N), Potassium (P), Calcium (Ca) and Magnesium (Mg) were applied as basal nutrients using Analar grade reagents. Potassium-feldspar was applied at 0, 64, 128, 192 and 256 mg kg-1 soil, replicated five times. Seedlings were transplanted on November 28, 2008 at three weeks old, at 20-cm tall with 8 leaves average, into 20 cm diameter plastic pots. One seedling was planted per pot. Pots were supplied with deionized water at a consistent volume to maintain 70% of soil field moisture capacity (FMC). Plants were grown under a 16 h photoperiod with supplemental light that maintained a minimum photosynthetic photon flux density (PPFD) of 200 µmol m-2 s-1 at plant height. Minimum temperature during the photoperiod was 22 °C.

Measurement of leaf gas exchange

Leaf photosynthetic rate, transpiration and stomatal conductance were measured in situ on the leaves using a portable infrared gas analyser (Model CIRAS 1 Infra Red Gas Analyzer, PP Systems, Herts, UK). Measurements were taken during the vegetative stage at 3 weeks after transplanting (WAT) on leaves 7 (3 WAT1) and 8 (3 WAT2) counting from the base. Measurements were repeated at the reproductive stage on the leaf just below the first fruit cluster at 4 WAT (at the on-set of fruits formation) and on the youngest expanded leaf at 10 WAT (at the peak fruits setting). The photosynthetic photon flux density (PPFD) provided for gas exchange measurements was 600 µmol m-2 s-1 and measurements were made from 1000 to 1400 h solar time (Kanai et al., 2007). Instantaneous water use efficiency of the plant leaf was estimated using the ratio of net CO2 assimilation to leaf transpiration (CO2 assimilation : leaf transpiration).

Fresh fruit yields

Ripe tomato fruits were harvested on 16th February, 2009 ten weeks after transplanting and 27th February, 2009 all ripe and unripe fruits were harvested at twelve weeks after transplanting and the weight determined. Unripe fruits were kept in labelled plastic containers at room temperature for a week. Thereafter, the weight of unripe fruit was determined again. The weight of unripe fruits and fruits with Blossom-end rot were subtracted from the total weight previously obtained for each treatment and called the marketable fresh weight. The number of tomato fruits was also determined according to Jones (2008).

The average fruit weight was estimated using the expression according to Garg et al. (2008):

$$\text{Average fruit weight (g/ plant)} = \frac{\text{Total weight of fruit}}{\text{Total number of fruit}}$$

The plant shoot fresh weight consisting of stem, leaf, flower and fruits was recorded immediately as plants were harvested. Water content of the plants was determined by first obtaining fresh weight and later drying the plant in an oven at 65°C until a constant weight was obtained. The difference in weight was considered as the water retained by the plant using the following expression (AOAC, 1980):

$$\% \text{ water content} = \frac{\text{Weight of fresh sample} - \text{Weight of dry sample}}{\text{Weight of fresh sample}} \times \frac{100}{1}$$

Data analysis

Data collected were subjected to analysis of variance (ANOVA) to assess treatment effects. The main effects and interactions among effects were tested using the F-test. When significant differences were found in the variance analysis, means were separated using Least Significant Difference (LSD). The degree of correlation (Pearson correlation coefficient) between variables was established using SAS Institute (2000).

RESULTS AND DISCUSSION

Soil properties

Table 1 indicates the physical and chemical properties of the soil used in the experiment. The soil was sandy loam with contents of 69% sand, 20% silt and 11% clay. The soil pH, EC, organic matter, total N and available P fell within the adequate for tomato production (Idowu, 2005). The soil exchangeable K was 74.60 mg kg-1 whilst exchangeable Na was 26.76 mg kg-1, indicating that the K and Na levels were low for good quality tomato (Idowu and Aduayi, 2007). The ratio of soil exchangeable Ca:Mg:K:Na was 74:10:3:1. Potassium-feldspar conventionally contains 8 to 15 % K_2O (Straaten, 2007). However, the ground K-feldspar used for the current study had K:Na ratio of 4:1, indicating that the concentration of Na in the soil and K-feldspar was substantial. The effect of K-feldspar application on exchangeable K and Na contents after the experimentation are shown in Table 2. The exchangeable K contents were not significantly ($p < 0.05$) different with the applications of K from 64 to 192 mg kg-1 soil. The highest rate of K application (256 mg kg-1 soil) significantly ($p < 0.05$) increased the exchangeable K content. On the other hand, the concentration of exchangeable Na was highest in the control while the increasing rates of K application significantly ($p < 0.01$) reduced the exchangeable Na concentration.

Leaf physiology at four tomato growth stages

Figures 1a to 1d show the effect of K-feldspar on leaf physiological parameters at the four different growth stages, namely, 3, 4, 8 and 10 WAT. The application of K-feldspar had a significant ($p < 0.05$) effect on leaf instantaneous water use efficiency (WUEI), photosynthetic rate and transpiration at both vegetative and reproductive stages. However, highly significant ($p < 0.01$) values were obtained for only WUEI and stomatal conductance measured at the reproductive stage while higher values were obtained for photosynthetic rate and transpiration at 4 WAT. The WUEI photosynthetic rate and transpiration decreased consistently in the order of 3 WAT1 > 3 WAT2 > 4 WAT > 10 WAT. At the peak of fruit setting, 10 WAT, a significant increase in WUEi was observed with 64 mg K kg-1 soil rate when compared with the control. Further increase in K treatment levels did not produce any significant ($p < 0.05$) increase in water use efficiency. The trends obtained for WUEi and stomatal conductance were similar with the leaf photosynthetic rate and transpiration. The patterns of photosynthetic rate and transpiration observed in this study was similar to those earlier reported by Liu and Stutzel (2002) for tomato plants.

Leaf physiology at two tomato growth stages

The effects of K on the leaf physiological factors at vegetative and reproductive stages are shown in Table 3. At the vegetative stage, the K application had a significant ($p < 0.05$) positive effect on WUEi and photosynthetic rate whilst transpiration rate was reduced by K application. At the reproductive stage, K application produced a highly significant ($p < 0.01$) effect on all the leaf physiological parameters. In addition, at the reproductive stage, the values for all physiological factors were significantly ($p < 0.05$) different at K rates from 0 to 256 mg kg-1 soil, with the exception of WUEI, the value of which was highest at 64 mg K kg-1 soil and decreased to the value for the control at the application of higher K rates.

Average Leaf physiology

The effects of K-feldspar on leaf physiological factors averaged over the different plant growth stages are shown in Table 4. The WUEi, photosynthetic rate, transpiration, stomatal conductance, were highly significantly ($p < 0.01$) affected by K application. However, there was no clear trend with K application rate and either the rates of photosynthesis or transpiration. For example, the highest photosynthetic rates were in plants grown with K application rate of 64 mg kg-1 while the highest leaf transpiration rates were found in plants that had 128 mg kg-1. Only the stomatal conductance showed a clear trend with K application rate with significant decreases with increasing K rates compared with the control. Stomatal conductance plays an important role in the plant-atmosphere water exchange and hence it is a key parameter in many ecological models (Chen et al., 1999). It has been recognized that the opening and closing of stomata are mediated by fluxes of K and accompanying anions such as malates and chloride. The ability of a plant to either close the stomata more rapidly or exhibit a substantial delay in stomatal opening under a limited water supply is a desirable attribute for efficient water use. The findings in this work suggest that the application of high rates of K to tomato could enhance its drought tolerance. Further, K-feldspar applied at the rate of 256 mg kg-1 soil, resulted in a significantly ($p < 0.05$) higher exchangeable K in the soil. This resulted in increased bio-availability of K to the tomato plants (data not shown). Overall, these results showed that the highest rate of K application (256 mg kg-1) gave the highest WUEi and lowest leaf stomatal conductance, which could be attributed to increased leaf K content.

Fruit yields and plant moisture content

The fresh tomato fruit yields, shoot fresh weight (stems, leaves and fruits) and stem and leaf moisture content are shown in Figure 2a to 2c. Total and marketable fruit weight, and shoot moisture content were not significantly ($p < 0.05$) affected by K-feldspar application rates. However, the average fruit weight was significantly affected ($p < 0.05$) with the lowest value obtained at 192 mg K kg-1 soil, the treatment that produced a blossom-end rot fruit. Blossom-end rot of tomato fruits has been associated with ion disorders such as lower content of calcium and phosphorus, and high content of Mg (Ho et al., 2005; Terraza et al., 2008; Magan et al., 2008).

Relationships between soil K and Na, leaf physiological properties, shoot moisture content and fruit yields

Photosynthetic rate was positively correlated with transpiration, and stomatal conductance as has been reported previously (Field et al., 1983). Instantaneous leaf water use efficiency was highly positively correlated ($r = 0.90^{**}$) with soil exchangeable-K but negatively correlated with soil exchangeable-Na and yield components. Average fruit weight was positively correlated with all physiological factors with the exception of WUEi and plant moisture content. Shoot moisture content was positively correlated with all fruit yield parameters, with the exception of average fruit weight, which was not significant. These results implied that the significant increase in average fruit weight with increase in K application rate was not as a result of improved water use. This confirmed the previous report by Jones (2008) that tomato requires less water during fruiting.

CONCLUSION

This study investigated the effects of K-feldspar on soil exchangeable K and Na, plant physiological factors, plant moisture content and yields of tomato fruit in soil culture. The results showed that the application of K-feldspar had a significant ($p < 0.05$) positive effect on leaf instantaneous water use efficiency at reproductive stage when 64 mg K kg-1 soil was applied. The application of higher levels as from 128 to 256 mg K kg-1 soil was not significantly difference from the control. Other physiological parameters were not significantly affected at all application rates. The overall results of the physiological factors indicated that the highest level of K at 256 mg kg-1 soil significantly increased soil exchangeable K and decreased the stomatal conductance when compared with the control. Stomatal conductance is the speed at which water evaporates from pores in a plant, and is directly related to relative size of the stomatal aperture. Basically the higher the evaporation rate, the higher the conductance of the leaf (Lambers, 2008). Average fruit weight was significantly decreased as K application was increased from 128 to 256 mg kg-1 soil. The application of 129 mg K kg-1 soil resulted in blossom-end-rot disease which was attributed to nutrient imbalance in the tomato fruits (Jones, 2008). The application of 64 to 128 mg kg-1 soil appeared to be adequate for improved leaf physiological properties and fruit yield. Potassium has been previously reported related to improve good quality tomato fruit. This study confirmed further that potassium from K-feldspar applied to the soil was available to the tomato plants and could reduce the cost of K-fertilizer for tomato production especially under water-limiting conditions. There is the need for research on the effect of K-feldspar on fruit quality and interactions between the applied K-feldspar and field conditions.

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TABLE 1: Properties of the soil used for the experiment

Texture	Sandy loam
Sand %	69
Silt %	20
Clay %	11
pH	6.28
EC µS/cm	48.11
Organic C %	2.20
Total N %	0.25
Total C %	2.11
Total S %	0.06
Available P mg kg^{-1}	15.66
Exchangeable mg kg^{-1}	
K	74.60
Ca	1989.92
Mg	275.90
Na	26.76
CEC kg ha^{-1}	17.67
K_2O % w/w (K-feldspar)	11.35

TABLE 2: The effect of K-feldspar applications on soil exchangeable K and Na content after 12 weeks of growth of tomato (*Lycopersicon lycopersicum*) in the greenhouse

Treatment	**Exchangeable cations**	
K	**K**	**Na**
mgkg^{-1}	<---------------**mgkg^{-1}**--------------->	
0	22.70bc	108.40a
64	23.10b	95.10c
128	22.00c	99.50b
192	22.90b	87.70d
256	*24.10a*	96.80bc
Mean	22.95	97.49
CV%	1.38	1.63
LSD	0.81	4.08
P	*	***

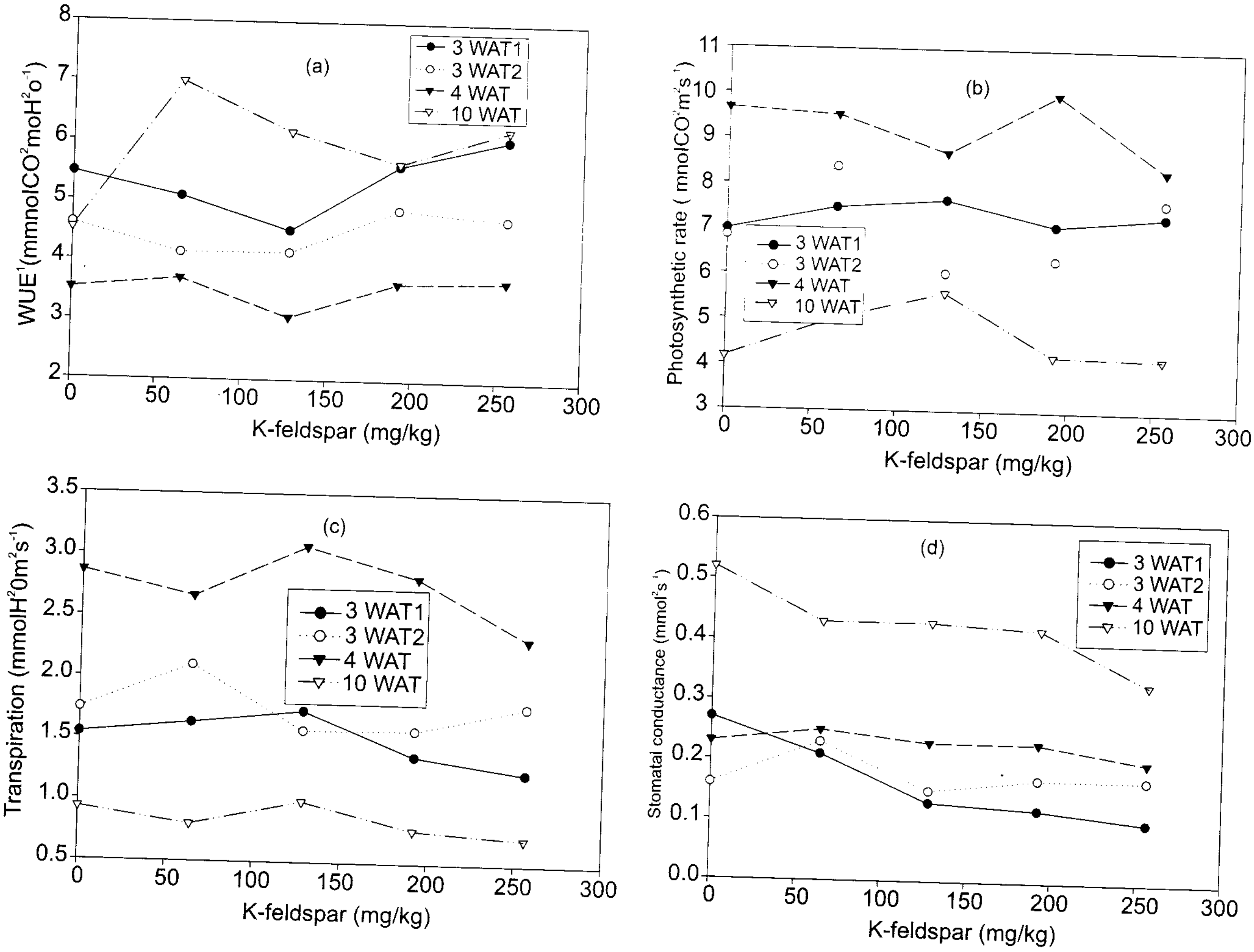

FIGURE 1: Effect of K-feldspar on leaf (a) Instantaneous water use efficiency (WUE_I), (b) Photosynthetic rate ($\mu molCO_2 m^{-2} s^{-1}$) (c) stomata conductance and (d) Transpiration of the tomato. (Bars represent significant LSD at $p < 0.05$. K rate at 0, 64, 128, 192 & 256. WAT = Weeks after transplanting).

TABLE 3: The effect of K-feldspar application on plant physiological factors of tomato (*Lycopersicon lycopersicum*) at (a) vegetative and (b) reproductive stages in the greenhouse

Treatments	WUE_i	Photosynthetic rate	Transpiration	Stomatal conductance
K mgkg^{-1}	(mmolCO_2molH_2O^{-1})	(μmol m^{-2} s^{-1})	(mmolH_2O m^{-2} s^{-1})	(mol m^{-2} s^{-1})
		(a)		
0	5.04a	6.91ab	1.64a	0.22a
64	4.60a	7.93a	1.87a	0.22a
128	4.33a	6.85b	1.65a	0.14a
192	5.24a	6.72b	1.48a	0.14a
256	5.39a	7.47ab	1.51a	0.14a
Mean	4.92	4.71	1.63	0.17
LSD	1.66	1.30	0.50	0.11
P	*	*	*	ns
		(b)		
0	4.02b	6.91a	1.89ab	0.38a
64	5.34a	7.27a	1.73ab	0.34a
128	4.61ab	7.15a	2.03a	0.33a
192	4.64ab	7.11a	1.80ab	0.33a
256	4.95ab	6.25a	1.52ab	0.27a
Mean	4.71	6.94	1.80	0.33
LSD	1.30	1.16	0.44	0.15
P	***	***	***	***

(WUE_I) = Instantaneous water use efficiency

TABLE 4: The effect of K-feldspar application on average plant physiological factors of tomato (*Lycopersicon lycopersicum*) at reproductive stages in the greenhouse

Treatments K mgkg^{-1}	WUE$_I$ (mmolCO$_2$molH$_2$O^{-1})	Photosynthetic rate (µmol m^{-2} s^{-1})	Transpiration (mmolH$_2$O m^{-2} s^{-1})	Stomatal conductance (mol m^{-2} s^{-1})
0	4.53a	6.91a	1.77a	0.30a
64	4.97a	7.66a	1.80a	0.28ab
128	4.47a	7.00a	1.84a	0.23ab
192	4.94a	6.92a	1.64a	0.24ab
256	5.17a	6.86a	1.52a	0.20b
Mean	4.82	7.06	1.71	8.11
CV%	34.15	17.49	30.50	3.43
LSD	1.04	0.78	0.33	0.72
P	***	***	***	***

(WUE$_I$) = Instantaneous water use efficiency

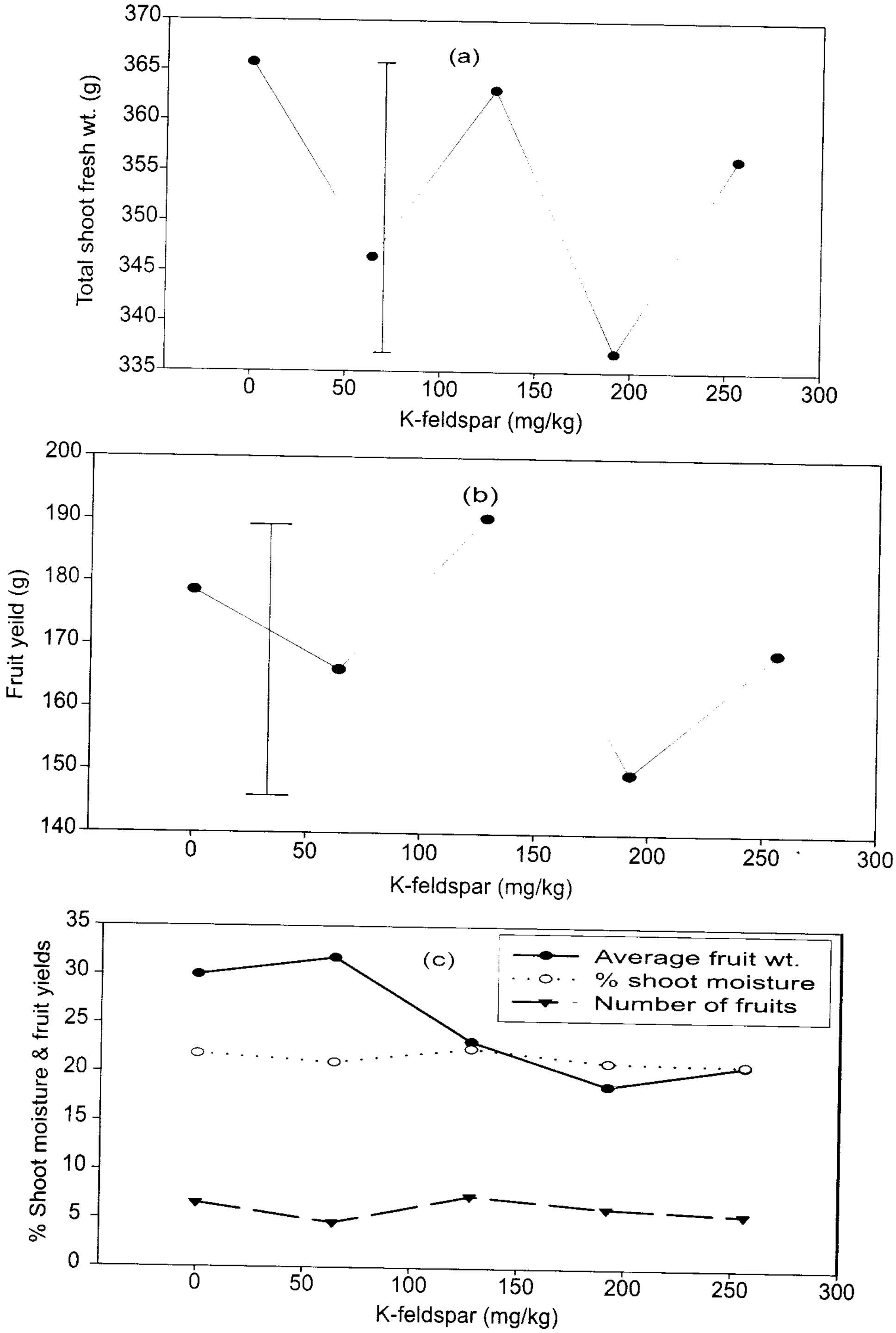

FIGURE 2: Effect of K-feldspar on mean (a) shoot weight (b) total fruit weight and marketable fruit weight, and (b) % shoot moisture content, number and average fruit weight of the tomato. Bars represent significant LSD at $p < 0.05$.

TABLE 5: Correlation relationship between physiological factors and tomato fruit yields as affected by K-feldspar

	WUE_i	Photosynthetic rate	Transpiration	Stomatal conductance	Moisture content %
WUE_i	0.16^{ns}	-0.78^{*}		-0.53^{*}	
Photosynthetic Rate		0.49^{*}		0.48^{*}	
Transpiration				0.69^{*}	
Stomata conductance					
Fresh fruit weight	-0.89^{*}	-0.29^{ns}	0.59^{*}	0.09^{ns}	0.98^{***}
Marketable fruit	-0.71^{ns}	-0.01^{ns}	0.60^{*}	0.23^{ns}	0.80^{*}
Number of fruit	-0.71^{*}	-0.71^{*}	0.20^{ns}	-0.15^{ns}	0.76^{*}
Average fruit weight	-0.29^{ns}	0.68^{*}	0.63^{*}	0.86^{**}	0.01^{ns}
Fresh shoot weight	-0.60^{*}	-0.31^{ns}	0.29^{ns}	0.16^{ns}	0.68^{*}
% Shoot moisture content	-0.94^{**}	-0.25^{ns}	0.68^{*}	0.24^{ns}	
Soil exchangeable K	0.90^{**}	-0.05^{ns}	-0.85^{**}	-0.47^{*}	-0.83^{**}
Soil exchangeable Na	-0.62^{*}	-0.18^{ns}	0.38^{ns}	0.50^{*}	0.56^{*}