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# Interactive Effects of NPK Nutrients, Water Potential and Irradiance on Contents of Potassium and Phosphate in Cotton Seedlings

By

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With 3 Figures

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## Summary

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Cotton seedlings receiving NPK treatments at different matric water potentials in the root medium under dark or light conditions (irradiance) responded differently to such treatment combinations. Single factors (nutrients, matric water potential and irradiance) have adverse effects on allocation (content) of soluble $K^+$ and $PO_4^3$ in aerial and ground parts of the seedlings. Certain interactions among single factors have significant effects on such contents, whether in aerial- or ground parts or in whole seedlings. Likewise, the relative role of each factor or interaction in affecting the content of both ions differed according to plant part. The baring of the data obtained on the optimization of nutrient use in dry farming practices of cotton cultivations under semi-arid conditions is discussed.

## Zusammenfassung

Farghali K. A. & El-Sharkawi H. M. 1988. Wechselbeziehungen von NPK-Nährelementen, Wasserpotential und Beleuchtung auf den Kalium- und Phosphatgehalt von Baumwollsämlingen. – Phyton (Austria) 28 (2): 171–181, with 3 figures. – Englisch mit deutscher Zusammenfassung.

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Sämlinge von Baumwollpflanzen, die NPK-Nährelemente bei verschiedenem Wasserpotential im Wurzelraum im Licht und im Dunkeln dargeboten bekamen, reagierten unterschiedlich auf die verschiedenen Kombinationen. Als Einzelfaktoren (Nährelemente, Wasserpotential, Beleuchtung) wirken sie ungünstig auf die Verteilung (den Gehalt) von löslichem $K^+$ and $PO_4^{3}$ in den ober- wie unterirdischen Teilen der Sämlinge. In einigen Kombinationen beeinflussen die Faktoren den Gehalt an den genannten Ionen signifikant. Desgleichen ist der relative Einfluß der Faktoren oder ihrer Kombinationen auch den Gehalt an den beiden Ionen in den einzelnen Pflanzenteilen verschieden. Inwieweit die gewonnenen Daten zur Verbesserung der Ausnützung der Nährstoffe in Baumwollkulturen unter semiariden Bedingungen beitragen können, wird diskutiert.

## Introduction

The seedling establishment and development, particularly after depletion of reserve materials during seed germination, is a sensitive stage in successful adaptation of plants in their new habitats. Different environmental factors influncing this success are majorly: mineral nutrition, water potential of the medium and irradiance as soon as plumule emerges (NATR & APEL 1983). The most essential nutrient elements must be made available at an early stage of plant development; and the total uptake and incorporation of minerals should be completed before the increase in mass begins (LARCHER 1980). The variation in irradiance of tobacco seedlings, for example, was found responsible for variation in the effects of nitrogen, phosphorus and potassium in nutrient solution on the amount and distribution of utilized ions (GUBAR 1977). Likewise, irradiance changes affect the efficiency of individual mineral nutrients utilization and improves drought tolerance in plants (NATR & APEL 1983). Also, accumulation of solutes facilitates osmotic adjustment (ROBERT 1981).

The aim of the present work was to study the effects of: irradiance (Ir), matric water potential ($\Psi_m$) and mineral nutrients (nitrogen, phosphorus and potassium, NPK) in the incubation medium, and their mutual interactions, on soluble $K^+$ and $PO^{-2}_4$ content of roots and aerial parts (shoots plus cotyledonary leaves) of germinated young seedlings of cotton.

## Materials and Methods

1. Plant material:

Mature seeds of cotton (*Gossypium barbadense* L., cv. Dandara) were treated with $10^{-3}$ mercuric chloride solution and thoroughly washed with distilled water. Seeds germinated in sterilized petri-dishes in distilled water (matric water potential, $\Psi_m$ = 0 bar) at 29°C, yielded 100% germination. Eight-days-old cotton seedlings were then treated with test solutions (after near complete depletion of storage material from the seeds).

2. Culture conditions:

A set of culture media consisting of solutions of polyethylene glycol (PEG-6000, Union Carbide Corp., USA) in concentrations that give particular water potentials ($\Psi_m$) of −2, −6 and −10 bar were prepared (c.f. EL-SHARKAWI & SPRINGUEL 1977). Another set of cultures having the same levels of water potential were amended with nutrient solutions (Nr) containing nitrogen (N), phosphorus (P), and potassium (K), supplied as $KNO_3$ and $KH_2PO_4$ in different ratios: N/K = 500/1400 ppm (molar ratio 1:1, from $KNO_3$), N/P/K = 500/500/2050 ppm (molar ratio 1:1:2, from $KNO_3$ + $KH_2PO_4$) and P/K = 500/650 ppm (molar ratio 1:1, from $KH_2PO_4$). Healthy young seedlings were transferred to sterilized petri dishes containing 20 ml. of treatment solutions. Seedlings under different treatments were incubated at 29°C in incubators with air circulation under light conditions (supplied by 60 watt incandescent bulbs, yielding 1500 Lux at culture level, just about the compensation point). Another set of plants receiving the same treatments were incubated in darkness at the same temperature. Three petri dishes were assigned at random to each of 16 treatment combinations (four nutrient treatments at four stress levels) under both light and dark conditions (Ir) amounting to 32 treatment combinations and 96 experimental units.

Nutrient treatments as such express the deficiency of either nitrogen (PK) or phosphorus (NK) or its presence in equal (the same) amounts in the cultures. Only potassium concentration differed according to treatment (either deficient in control, low in PK, medium in NK or high in NPK).

3. Assays of $K^+$ and $PO_4^3$ in plants:

Nine days after receiving treatment, different organs (roots, hypocotyls and cotyledonary leaves) were excised, thoroughly washed with distilled water, blotted dry between filter paper, weighed, homogenized in ice-cold distilled water and the supernatents were kept in deep freeze until the time of assay. Soluble $K^+$ and $PO^{-3}_4$ were measured in extracts according to WILLIAMS & TWINE 1960 and WOODS & MELLON 1941, respectively. The aerial to ground organ ion distribution (aerial/root ratio) in the seedling was estimated from the ratio of content in aerial parts and in the root for both $K^+$ and $PO^{-3}_4$.

The relative role of single factors and their interactions has been evaluated by suitable statistical inferences including analysis of variance (F values), coefficient of determination, $\eta^2$, and simple linear correlation coefficient, r. (OSTLE 1963).

## Results

Total contents of water-soluble $K^+$ and $PO^{-3}_4$ in the seedlings (root + aerial parts), ground (root) and aerial parts (hypocotyl + cotyledonary leaves) showed variable responses to irradiance (Ir), matric water potential ($\Psi_m$) and nutrient elements (Nr) as shown in Figures 1 and 2.

1. Effect of irradiance:

$K^+$ content in the seedlings (whether total, root or aerial part content) are higher under light conditions than in darkness (Fig. 1). Maximum accumulation of $K^+$ in whole seedlings and in aerial parts took place in NPK treatment at $\Psi_m = -2$bar, and in roots at $\Psi_m = -10$ bar. The lowest contents in the whole seedling under light and dark conditions was in the control and at high water potentials including the control ($\Psi_m = 0$ level).

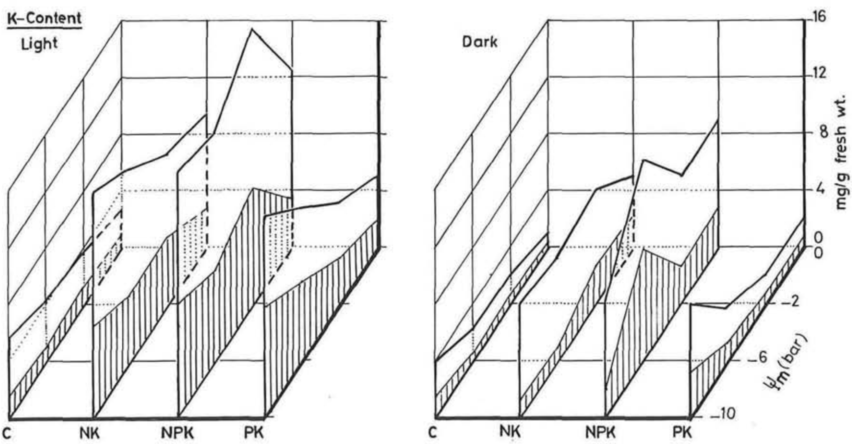


Fig 1: Potassium ($K^+$) content (in mg/g F.wt) in roots, aerial parts and whole seedlings of cotton at different matric water potentials ($\Psi_m$) and nutrient treatments in light and dark conditions. (Blanc areas = aerial part, hatched areas = root.)

The total content of $PO_4^{-3}$ responded to treatments in a manner opposītely to that of $K^+$. The highest total content took place in darkness at $\Psi_m = -10$ bar in nitrogen deficient plants (PK treatment, Figure 2). Relatively higher $PO_4^{-3}$ content in roots and aerial parts was reached under the same conditions. Under light conditions, the highest root content was at low water potentials and also in abscence of nitrogen (PK treatment).

2. Effect of matric water potential ($\Psi_m$):

Total $K^+$ content in roots and aerial parts increased progressively with decreasing $\Psi_m$, particularly under light conditions with NPK. $K^+$ content in both aerial and ground organs was low at $\Psi_m = -2$ bar in darkness in the same nutrient treatment (NPK) and much higher under light condition. This indicates the interactive effects among the experimental factors (nutrients, $\Psi_m$ and Ir) on $K^+$ status in cotton seedlings.

Total content of $PO_4^{-3}$ tends to a maximum at low matric water potential (−10 bar) irrespective of irradiance or nutrient treatment. On the other hand, $PO_4^{-3}$ content in the roots gradually increased with decreasing $\Psi_m$ regardless of irradiance except with NPK under light conditions where $PO_4^{-3}$ content reached a maximum at $\Psi_m = -2$ bar. Also, $PO_4^{-3}$ accumulation in aerial parts is higher at relatively low water potentials in darkness than under light conditions, as well as at high water potentials in NPK treatment under darkness, where the aerial parts contained relatively higher amounts at $\Psi_m = -2$ bar.

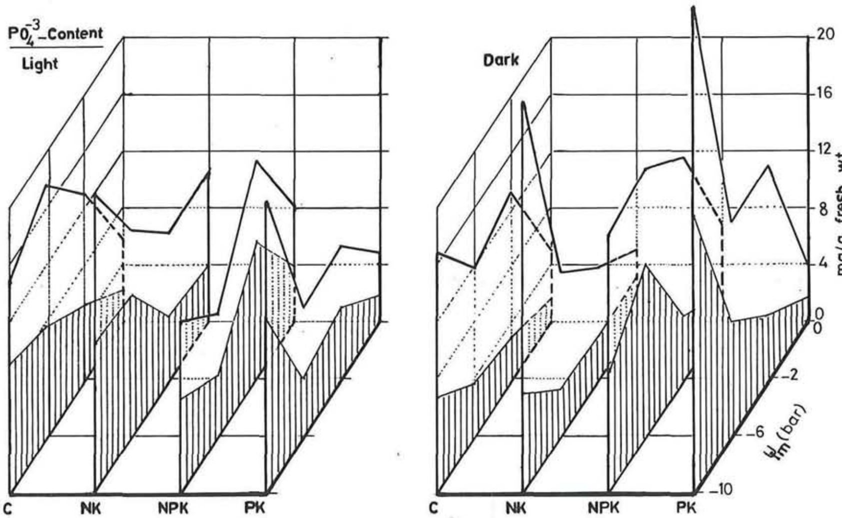


Fig 2: Phosphate ($PO_4^{-3}$) content (in mg/g F.wt) in roots, aerial parts and whole seedlings of cotton at different matric water potentials ($\Psi_m$) and nutrient treatments in light and dark conditions. (Signatures see Fig. 1.)

3. Effect of mineral nutrients (NK, PK, NPK):

Presence or deficiency of either nitrogen or phosphorus, and presence of potassium at different concentrations in the incubation medium influenced both $K^+$ and $PO_4^{-3}$ status in young cotton seedlings. With NPK treatment, total $K^+$ content under light condition is relatively higher over a wide range of water stress ($\Psi_m = -2$ to $-10$ bar). Likewise is $K^+$ content in roots. $K^+$ status in aerial parts increased with NK and NPK treatments (the latter yielding higher $K^+$ content in whole plants) especially at low $\Psi_m$ (more under light conditions). Despite the higher total $K^+$ content under NK treatment than those of PK, the contents in roots was higher in plants of the latter treatment, particularly at relatively low matric potentials.

Total $PO_4^{-3}$ contents in plants grown in darkness were higher in NK and PK than that in either control or NPK treatment, particularly at moderate and low $\Psi_m$ (−6 to −10 bar). The same was the case in roots treated with PK whether under light or dark conditions. $PO_4^{-3}$ content in aerial parts increased with NK and PK in darkness at low $\Psi_m$ (−10 bar). Its content at different $\Psi_m$ levels in the control treatment (in abscence of nuntrient elements) is nearly unchanging regardless of light conditions.

The effects of single factors and their interactions (as given by F and $\eta^2$ values) on the content of water soluble $K^+$ and $PO_4^{-3}$ in seedlings are given in Table 1. Nutrients had a highly significant effect on $K^+$ in different organs,

Table 1

F and $\eta^2$ values for the effects of nutrients (Nr), water potential ($\Psi_m$), irradiance (Ir) and their interactions on $PO_4^{-3}$ and $K^+$ contents in young whole seedlings, roots and aerial parts of cotton.

| Ion | Source of variance | Whole seedlings | | Roots | | Aerial parts | |
|---|---|---|---|---|---|---|---|
| | | F | $\eta^2$ | F | $\eta^2$ | F | $\eta^2$ |
| $K^+$ | Nr | 141.6**) | 0.56 | 27.4**) | 0.36 | 18.0**) | 0.66 |
| | $\Psi_m$ | 26.8**) | 0.11 | 8.1**) | 0.11 | 2.1 | 0.08 |
| | Ir | 164.1**) | 0.22 | 49.6**) | 0.22 | 8.7**) | 0.16 |
| | Nr × $\Psi_m$ | 4.0**) | 0.05 | 2.3*) | 0.09 | 0.8 | 0.06 |
| | Nr × Ir | 6.8**) | 0.02 | 3.8*) | 0.05 | 0.3 | 0.01 |
| | $\Psi_m$ × Ir | 2.9**) | 0.01 | 4.5**) | 0.06 | 0.0 | 0.00 |
| | Nr × $\Psi_m$ × Ir | 2.9**) | 0.03 | 2.8**) | 0.11 | 0.4 | 0.03 |
| $PO_4^{-3}$ | Nr | 1.5 | 0.01 | 4.0*) | 0.05 | 1.7 | 0.02 |
| | $\Psi_m$ | 92.0**) | 0.60 | 42.9**) | 0.49 | 38.6**) | 0.43 |
| | Ir | 8.5**) | 0.02 | 1.4 | 0.01 | 23.4**) | 0.09 |
| | Nr × $\Psi_m$ | 10.5**) | 0.20 | 5.9**) | 0.20 | 6.9**) | 0.23 |
| | Nr × Ir | 8.6**) | 0.05 | 7.7**) | 0.09 | 2.3*) | 0.03 |
| | $\Psi_m$ × Ir | 9.5**) | 0.06 | 2.2 | 0.02 | 9.9**) | 0.11 |
| | Nr × $\Psi_m$ × Ir | 3.1 | 0.06 | 4.2**) | 0.14 | 2.7*) | 0.09 |

*) Significant at $P < 0.05$.
**) Significant at $P < 0.01$.

and only significant effect on $PO_4^{-3}$ content of roots. $\Psi_m$ had a highly significant effect on both $K^+$ and $PO_4^{-3}$ contents of roots and whole seedlings as well as on $PO_4^{-3}$ contents in aerial parts. Irradiance effect on $K^+$ and $PO_4^{-3}$ contents in whole seedlings and aerial or ground organs was highly significant except with $PO_4^{-3}$ in roots. The effect of $\Psi_m$ on $PO_4^{-3}$ contents in whole seedlings ground and aerial organs is predominant ($\eta^2 = 0.60$, 0.49 and 0.43, respectively). Likewise, is the effect of nutrient on $K^+$ ($\eta^2 = 0.56$, 0.36 and 0.66, respectively). A highly significant effect of the interaction Nr × $\Psi_m$ on $PO_4^{-3}$ contents existed but its share in the total effect is subdominant to that of nutrient alone. Also, its effect on total $K^+$ contents is highly significant and is only significant in case of roots. The effect of the interaction (Nr × Ir) and $K^+$ content of roots is similar to the effect of (Nr × $\Psi_m$). Its effect on $PO_4^{-3}$ in roots and in whole seedlings was highly significant, and just significant in aerial parts. The interaction ($\Psi_m$ × Ir) had a highly significant effect on the total and aerial part $PO_4^{-3}$ contents. Its effect on $K^+$ content of roots and whole seedlings is significant. The tri-factorial interaction (Nr × $\Psi_m$ × Ir) had a highly significant effect on both $K^+$ and $PO_4^{-3}$ contents in different seed organs (except on $K^+$ of aerial parts). The role of this interaction, however, is relatively minor.

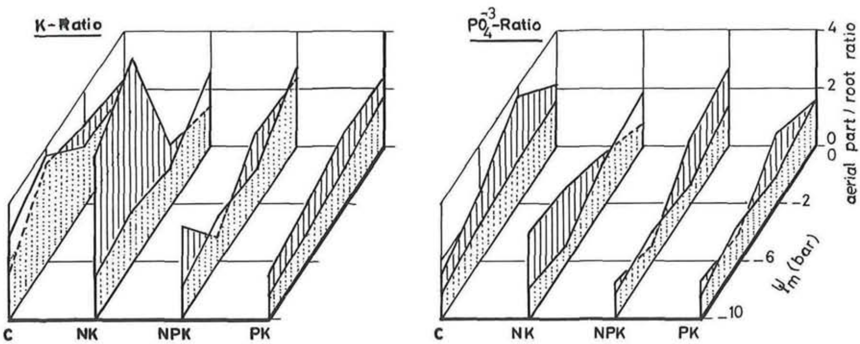


Fig 3: "Aerial part/root" ratio of $K^+$ of $PO_4^{-3}$ contents in young cotton seedlings at different matric water potentials ($\Psi_m$) and nutrient treatments in light (blanc areas) and dark conditions (hatched areas).

4. "Aerial part/root" ratios of $K^+$ and $PO_4^{-3}$:

Allocation of $K^+$ and $PO^{-3}_4$ in seedlings under the effect of nutrients, $\Psi_m$ and irradiance are shown in Figure 3. In case of $K^+$, abscence of light yielded a higher ratio than in irradiated plants especially with NK treatment (P absent) and particularly at low water potentials. At higher $\Psi_m$ (0 to −2 bar), this ratio is higher in irradiated plants with all nutrient combinations (also, in darkness with PK). At moderate and low water potentials (−6 and −10 bar), the aerial part/root content of $K^+$ was higher in etiolated plants with NK and NPK. In the control plants (no nutrients) it was higher under lights conditions (decreased in darkness). Generally the $K^+$ ratio is not changed by nutrient treatment combinations in the light, but differs among such treatments as well as in the control under dark conditions.

"Aerial part/root" ratio of $PO_4^{-3}$ in control plants (ranging between 0.5 and 3.7) generally attained a maximum value at relatively high water potentials under dark conditions. With NK treatment, the ratio decreased with decreasing $\Psi_m$ in irradiated plants and increased in the dark. It was relatively higher with NPK and PK treatments at higher water potentials, regardless of light condition.

A high "aerial part/root" ratio of $PO_4^{-3}$ may be resulting from the accumulation of this ion in the aerial parts and its decrease may be due to utilization of $PO_4^{-3}$ in the metabolism of aerial parts or its increase in the roots due to impaired translocation.

5. The correlation between soluble $PO_4^{-3}$ and $K^+$ in seedlings:

Under the single experimental factors or their interactions the relationships between $PO_4^{-3}$ and $K^+$ contents were different in roots, aerial parts as well as in whole seedlings (Table 2). With changing $\Psi_m$ irradiance and Nr × $\Psi_m$ interaction (under contrasting lighting conditions) there was highly significant positive correlation between the contents of both elements in the roots. Likewise, the amounts in whole seedlings and in aerial parts correlated positively under changing $\Psi_m$. Only, change in irradiance condition yielded a significant negative correlation between the content of $K^+$ and $PO_4^{-3}$ in whole seedlings and in aerial parts. Under other conditions, no significant correlation between both elements was detected. Such significant positive or negative correlations reflects the role of the investigated factors on the utilization of different ions in the metabolic activity of different organs in young seedlings.

Table 2

Correlation coefficient (r) values between $PO_4^{-3}$ and $K^+$ contents in young whole seedlings, aerial parts and roots of cotton under the effect of nutrients (Nr), ($\Psi_m$), irradiance (Ir) and their interactions.

| Source of variance | Whole seedlings | Roots content | Aerial ports content |
|---|---|---|---|
| Nr | 0.294 | 0.610 | −0.223 |
| $\Psi_m$ | 0.955*) | 0.965**) | 0.901*) |
| Ir | −0.999*) | 1.000**) | −1.000**) |
| Nr × $\Psi_m$ | 0.433 | 0.608**) | 0.292 |
| Nr × Ir | −0.122 | 0.270 | −0.468 |
| $\Psi_m$ × Ir | 0.315 | 0.434 | 0.168 |
| Nr × $\Psi_m$ × Ir | 0.185 | 0.246 | 0.058 |

*) Significant at $P < 0.05$.
**) Significant at $P < 0.01$.

## Discussion

Cultivation of cotton is considered in several semi-arid areas of the world (cf. JORDAN 1983). Mineral deficiency, low matric water potential and variable energy budgets are three prominant ecological factors in such areas. Interactions among such factors, if present, would greatly modify the effect of each of such single factors on physiological responses of plants, especially those introduced to such habitats. Knowledge of fundamental interactions of individual components of mineral nutrition and external environment is necessary for increasing the efficiency of fertilizers in plant productivity (NATR & al. 1983). Adaptational changes, which occur in seedlings after changes in irradiance, was found responsible for variation in the effects of N, P and K in nutrient media on the quantity of utilized ions (GUBAR 1977, NATR & APEL 1983).

In the investigation hitherto undertaken on young cotton seedlings, highly sensitive to such single factors, it was found that their interactions (as well as single factors) have significant effects on contents and allocation of two key nutrients (free soluble K and free soluble P). Total content of K in whole seedlings or in ground and aerial parts were much higher under light conditions at relatively low matric water potentials. Its content responded to increasing ambient K concentration in the medium. Also, presence of either N or P in the incubation medium influenced its uptake. It has been explained by TAKAO 1982 that in the dark or dim light, potassium uptake rythm damped out promptly, probably due to lack of energy to drive the uptake system. The same phenomenon has been observed by EL-SHARKAWI 1973, working on uptake of K by soybean from nutrient media under reduced water potential, where K influx to plant roots was higher during daytime and greatly slowed down at night. HANSON 1972 explained the influence of the amount and form of added nitrogen on ion absorption from the nutrient medium as due to either changes in metabolic processes or to changes in concentration or activities of ions. Increased stimulation of P absorption by nitrogen was attributed to specific influence of N on the physiological activity of the roots that control P absorption and transfer into the symplast (LEONCE & MILLER 1966, WHITE 1973).

It is clearly indicated from data presented above that each of $\Psi_m$, Nr, Ir and their mutual interactions significantly affected, in various degrees (indicated by $\eta^2$ values), the free $K^+$ content in both whole seedlings and in roots. However, only Nr and Ir had significant effects on its content in aerial parts. Also, in ground and aerial parts, as well as in whole seedlings, the role of Nr in affecting $K^+$ content was dominant and that of Ir was subdominant.

Data on $PO_4^{-3}$ content indicate that PK and NK treatments induced higher $PO_4^{-3}$ content in whole seedlings, particularly at lower $\Psi_m$ (higher matric stress) regardless of irradiance. Its content in roots, however, was higher in darkness (in contrast to $K^+$ content). CARTWRIGHT 1972 indicated promoted uptake of $PO_4^{-3}$ by excised barley roots after a period of phosphate starvation. Single factors and interactions had adverse affects on $PO_4^{-3}$ content in roots and aerial parts. Thus, both $\Psi_m$ and Ir, as well as their interactions with Nr had significant effects on $PO_4^{-3}$ content of aerial parts (and whole seedlings). In roots, it was Nr, $\Psi_m$, their interactions and the trifactorial interaction (Nr × $\Psi_m$ × Ir) that exerted significant effects on $PO_4^{-3}$ content. Total or partial (in ground and aerial organs) $PO_4^{-3}$ content was predominantly affected by $\Psi_m$.

The allocation (distribution between aerial parts and roots) of $K^+$ and $PO_4^{-3}$, as expressed by the "aerial part/root" ratio of ion content, apparently depends on nutrient treatment and stress level. With both ions, this ratio has higher value with NK treatment especially at lower $\Psi_m$ (higher stress, −6 to −10 bar) and in darkness more than in light (Figure 3). With other nutrient treatments, the ratio is greater at higher $\Psi_m$ (0 to −2 bar). The high ratio is mainly due to higher content in aerial parts of both $K^+$ and $PO_4^{-3}$. Its value, however, is lower for $PO_4^{-3}$. As $K^+$ is related to carbohydrate metabilism (MUNSEN 1970), its higher content in the aerial parts may be serving active sites of intense metabolism.

The entry of an ion may be aided by another of the opposite charge having similar or greater mobility in water and in cell membranes (DOGER & TONG 1979). The significant positive correlations recognized between K and P, particularly at low $\Psi_m$, could be explained according to this hypothesis. Apparently, such correlation is greatly influenced by ambient external factors and particular interactions as demonstrated in the results (Table 2).

Accordingly, it can be safely concluded from data obtained that NPK fertilizers are fruitful when used at limited water supply in cotton farms under semi-arid conditions. This is particularly important in potassium nutrition. The role of interactions among experimental factors is quite evident (significant) in this respect as revealed by statistical inferences. Such interactions are quite expectable in semi-arid habitats as a rule rather than as an exception.

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