Preparation of solid fertilizer based solution fertilizers under “grass roots” field conditions

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Paper published at Fertilizer News, The Fertilizer Association of India (FAI), December 1996, New Delhi, India

Summary

The aim of this work was to examine the preparation of mixed fertilizer solutions based on cheap solid fertilizers available in the market, where the solutions would be prepared on the farm site with limited facilities under “grass roots” field conditions, with minimal mixing. Urea, ammonium sulphate, phosphoric acid and potassium chloride (white, suitable for fertigation) as N, P, and K sources, respectively, were examined for the preparation of clear liquid solutions.

Clear NK, PK and NPK fertilizer solutions with at least 9-10% nutrients (N, P$_2$O$_5$, K$_2$O) were prepared with initial water temperature of 10°C, based on urea, phosphoric acid and KCl, with minimal mixing. High concentrations of solution fertilizers could not be obtained using ammonium sulphate and KCl because of the formation of potassium sulphate.

When phosphoric acid is used in the formulation, this should be added to the water first to utilize the positive heat of solution.

Clear solutions with the compositions 0-0-8, 4.9-0-4.9, 3.1-0-6.3, 2.7-0-8.1, 6.1-0-3.1 and 7.8-0-2.6 have been prepared from urea and potassium chloride with minimal mixing and the pH of these solutions, after dilution, is in the range 5-7.

Clear solutions with the compositions 0-6.3-6.3, 0-3.7-7.4, 0-3.2-9.6, 0-7.4-3.7, 3.6-3.6-3.6, 2.7-2.7-8.1, 2.7-5.4-2.7, 2.5-5.1-10.1, 7.4-2.5-2.5 and 5.1-1.7-5.1 have been prepared from urea, white phosphoric acid and potassium chloride with minimal mixing and the pH of these solutions, after dilution, is in the range of 3-4. The pH of the water used to prepare the solutions has little effect on the final pH.
Introduction

Fertigation is the application of solid or liquid mineral fertilizers via pressurized irrigation systems, creating nutrient-containing irrigation water. Solid fertilizers can be applied as a single nutrient (e.g. urea), or as multi-nutrient composite of a fertilizer mixture (e.g. ‘Haisol’ series). Liquid fertilizers are of single or multi-nutrient, but due to solubility, the total nutrient concentration is much lower.

In Israel, application of fertilizers is executed by various methods (1,2), including the technique of stock solution preparation. In this technique, farmers are using solid fertilizers as ammonium sulphate, urea, potassium chloride and nitrate, and liquid phosphoric acid to prepare a “tailor made” stock solution. The stock solution is then injected into the irrigation system, at rates of 2-10 litres per 1 M$^3$ of water, depending on the desired concentrations of N, P and K.

Nitrogenous fertilizers are highly soluble (3) and contain low percentage of insoluble residues. White phosphoric acid (liquid) is also suitable for direct application, with appropriate safety measures. The use of potassium chloride in fertigation is common in many crops: most of the citrus, banana, cotton, maize, deciduous trees, tomatoes (in open field) and many others. In general, KCl is used in all crops except in greenhouse production and avocado orchards. A detailed review on KCl in fertigation describes it’s advantages and limitations (4).

Fertigation guidelines are usually given as N, P$_2$O$_5$ and K$_2$O dosage and water requirement on a daily basis per area unit. This data is then utilized to the different fertilizers and application methods (5). Since no commercial body is involved in the use of solid fertilizer based solution fertilizers under “grass roots” field conditions, there are no clear guidelines available, thus precipitation due to too high concentrations often occurs.

The cost of fertilizers for fertigation varies greatly. The most expensive formulas are those containing multi-nutrient solutions, whereas the cheapest are those single-nutrient fertilizers available in the market, such as urea and potassium chloride. There is no scientific evidence for preferring solid or liquid fertilizer, thus, the only factors to be taken in account by the farmer are the quality, cost, ease of application and availability of fertilizers.

The aim of this work was to create stock multi-nutrient solution formulas containing soluble single-nutrient fertilizers and prepared at farm level, with minimal mixing.

Experimental

A system was set up for dissolution of the fertilizers at a fixed temperature and minimal stirring and has been used to determine the maximum solution concentrations that could be obtained in such conditions. The effect of order of addition of the various components was examined and the time to reach complete dissolution was measured, as well as temperature changes during the dissolution of the fertilizers. The compositions of the various K, NK, PK and NPK solutions were decided according to common formulas in use.

The solutions were prepared in a 150 ml reaction vessel jacketed with a circulating cooling liquid at 10°C. The initial volume of tap water was 100 ml and each fertilizer was added rapidly and the solution stirred magnetically for one minute after addition. When the temperature of the solution dropped below the set temperature on dissolution of the
fertilizer (as with ammonium sulphate, potassium chloride or urea) the next addition was only performed after the temperature of the solution had returned to the set temperature. When the temperature rose above the set temperature on addition of the fertilizer (as with phosphoric acid) the next addition continued immediately after the one minute stirring. The turbidity and specific density of the resulting solutions were measured as such, whilst the pH and conductivity were measured after dilution to 1:1000 with dionised water.

The turbidity was measured with a Hach 2100P Turbidimeter (6,7) which was calibrated using a Hach Formazin Turbidity standard of 4000 NTU (Nephelometric turbidity units). A turbidity of 15 NTU relates to about 300 mg/litre of water insoluble material. The tap water used had a turbidity of 2.5 NTU, pH 8.24, total hardness (Ca + Mg) of 80 ppm, total alkalinity, as HCO₃, of 56 ppm and conductivity of 0.9 dS/m (decisiemens/meter). pH and conductivity of the tap water after dilution 1:1000 with dionised water were 7.98 and 0.0087 dS/m respectively. The pH of the dionised water was 6.1.

The fertilizers used were ammonium sulphate, crystalline product from Fertilizers & Chemicals, 21-0-0-24S (N, P₂O₅, K₂O, S); urea, prills from Fertilizers & Chemicals, 46-0-0; KCl, white fertigation grade from Dead Sea Works, 0-0-61; and white phosphoric acid from Rotem Fertilizers, 0-69-0.

Results

The results are presented in table 1 and describe four sets of solutions with various compositions of K, NK, PK and NPK nutrients. The minimum concentration examined for each nutrient was 2.5% (N, P₂O₅, K₂O). The concentrations are given in units of weight/volume, taking into consideration the increase in volume on dissolution of the fertilizers.

K Solutions

The maximum concentration of potassium chloride that could be obtained under the experimental conditions chosen was 0-0-8 (14% KCl), which took about 4 minutes for full dissolution with the temperature dropping initially from 10°C to 4°C. The pH of the solution, after dilution to 1:1000 with dionised water, is 6.7 and the conductivity after dilution is 0.22 dS/m (conductivity of tap water after same dilution is 0.0087 dS/m).

NK Solutions

The compositions examined had the ratios (N-P₂O₅-K₂O) 1-0-1, 1-0-2, 1-0-3, 2-0-1 and 3-0-1 and the results are shown in table 1. The source of nitrogen was either ammonium sulphate or urea and the order of addition of the nitrogen source and the potassium chloride was examined. NK solutions based on ammonium sulphate and potassium chloride are limited to low concentrations because of the formation of potassium sulphate, which has a lower solubility than either of the starting materials. The order of addition of the starting materials can be important and for example 2.7-0-2.7 solution from ammonium sulphate could only be obtained if the KCl was added first (not included in table 1). A concentration of 4.9-0-4.9 could be obtained for the ratio 1-0-1 only with urea as the nitrogen source. The solutions with ratios 1-0-2 and 1-0-3 also could only be obtained with the nitrogen supplied as urea and the preferred order of addition was to add the urea first. Solutions with ratios 2-0-1 and 3-0-1 were obtained only with urea and the preferred order of addition is to add the urea first. The maximum concentrations obtained for these solutions were 4.9-0-4.9, 3.1-0-6.3, 2.7-0-8.1, 6.1-0-3.1 and 7.8-0-2.6 respectively. The pH of these solutions, after dilution to 1:1000 with dionised water.
are in the range of 5-7. The conductivities of the solutions, after dilution with dionised water to 1:1000, are in the range of 0.07-0.24 dS/m. The time to reach full dissolution under the conditions examined varies from 9 to 28 minutes, depending on the composition of the solution.

PK Solutions

The compositions examined had the ratios (N-P$_2$O$_5$-K$_2$O) 0-1-1, 0-1-2, 0-1-3 and 0-2-1 and are based on technical grade white phosphoric acid (WA) and potassium chloride. The results are shown in table 1. The dissolution, or dilution, of the phosphoric acid is exothermic and results in an increase in the solution temperature of 2-3°C so that the addition of the acid first reduces the time for dissolution of the potassium chloride added next. In some cases when potassium chloride was added first and did not dissolve completely, dissolution was completed after addition of the phosphoric acid. The maximum concentrations obtained for the PK solutions examined were 0-6.3-6.3, 0-3.7-7.4, 0-3.2-9.6 and 0-7.4-3.7 respectively. The pH of all these solutions, after dilution to 1:1000 with dionised water are in the range of 2.7-3.4. The conductivities of the solutions, after dilution with dionised water to 1:1000, are in the range of 0.35-0.45 dS/m. The time to reach full dissolution under the conditions examined varies from 2 to 16 minutes, depending on the composition of the solution.

NPK Solutions

The compositions examined had the ratios (N-P$_2$O$_5$-K$_2$O) 1-1-1, 1-1-3, 1-2-1, 1-2-4, 3-1-1 and 3-1-3, and are based on technical grade white phosphoric acid (WA), urea and potassium chloride. The results are shown in table 1.

The dissolution, or dilution, of the phosphoric acid is exothermic and results in an increase in the solution temperature of 2-4°C so that the addition of the acid first reduces the time for dissolution of the next component added. Therefore the phosphoric acid was added first in all cases and the order of addition of the nitrogen source and potassium chloride was varied. The maximum concentrations obtained for the NPK solutions examined were 3.6-3.6-3.6, 2.7-2.7-8.1, 2.7-5.4-2.7, 2.5-5.1-10.1, 7.4-2.5-2.5 and 5.1-1.7-5.1 respectively. The pH of all these solutions, after dilution to 1:1000 with dionised water are in the range of 3.1-4.3. The conductivities of the solutions, after dilution with dionised water to 1:1000, are in the range of 0.2-0.49 dS/m. The time to reach full dissolution under the conditions examined varies from 4 to 20 minutes, depending on the composition of the solution.

The maximum concentrations obtained for the various compositions examined and described in Sections 3.1, 3.2, 3.3 and 3.4 are summarized in the following Table.
Table 1. Maximum concentrations and solution characteristics of various fertilizer solutions prepared at 10°C.

<table>
<thead>
<tr>
<th>Ratio (N-P2O5-K2O)</th>
<th>Composition (Weight/volume)</th>
<th>Raw materials (by adding order)</th>
<th>Turbidity (NTU)</th>
<th>Specific gravity</th>
<th>pH (1:1000)</th>
<th>Conductivity (1:1000, dS/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>K 0-0-1</td>
<td>0-0-7.9</td>
<td>KCl</td>
<td>12.2</td>
<td>1.06</td>
<td>6.7</td>
<td>0.22</td>
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<td>NK 1-0-1</td>
<td>4.9-0-4.9</td>
<td>Urea/KCl</td>
<td>16.0</td>
<td>1.07</td>
<td>6.2</td>
<td>0.16</td>
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<tr>
<td></td>
<td>1-0-2</td>
<td>Urea/KCl</td>
<td>7.5</td>
<td>1.07</td>
<td>5.4</td>
<td>0.19</td>
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<td></td>
<td>1-0-3</td>
<td>Urea/KCl</td>
<td>8.8</td>
<td>1.09</td>
<td>5.1</td>
<td>0.24</td>
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<tr>
<td></td>
<td>2-0-1</td>
<td>Urea/KCl</td>
<td>7.5</td>
<td>1.05</td>
<td>4.8</td>
<td>0.09</td>
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<tr>
<td></td>
<td>3-0-1</td>
<td>Urea/KCl</td>
<td>15.3</td>
<td>1.08</td>
<td>5.1</td>
<td>0.07</td>
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<td>PK 0-1-1</td>
<td>0-6.3-6.3</td>
<td>H3PO4/KCl</td>
<td>3.2</td>
<td>1.09</td>
<td>2.7</td>
<td>0.45</td>
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<td>0-1-2</td>
<td>H3PO4/KCl</td>
<td>8.4</td>
<td>1.11</td>
<td>3.3</td>
<td>0.35</td>
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<td>0-1-3</td>
<td>H3PO4/KCl</td>
<td>7.1</td>
<td>1.12</td>
<td>3.4</td>
<td>0.36</td>
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<tr>
<td></td>
<td>0-2-1</td>
<td>H3PO4/KCl</td>
<td>3.0</td>
<td>1.09</td>
<td>2.7</td>
<td>0.41</td>
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<td>NPK 1-1-1</td>
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<td>H3PO4/Urea/KCl</td>
<td>5.4</td>
<td>1.08</td>
<td>3.3</td>
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<td></td>
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<td>H3PO4/Urea/KCl</td>
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<td>0.20</td>
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<tr>
<td></td>
<td>3-1-3</td>
<td>H3PO4/Urea/KCl</td>
<td>8.3</td>
<td>1.08</td>
<td>3.7</td>
<td>0.22</td>
</tr>
</tbody>
</table>

Effect of pH of Water

The effect of pH of the water was examined for solutions of the individual fertilizers. The tap water used had a pH of 8.2 and the pH of the solutions obtained are shown in table 1. To examine the effect of more acidic water, the tap water was acidified to pH 6 by the addition of HCl and solutions of potassium chloride, ammonium sulphate, urea and phosphoric acid prepared and the resulting pH determined. The pH values were similar to those found for the various K, NK, PK and NPK compositions, namely solutions based on potassium chloride, ammonium sulphate and urea had a pH of 6-6.5, whilst a solution of phosphoric acid had a pH of 3.5, measured as for the other solutions after dilution to 1:1000 with dionised water.

Large Scale Tests

In order to confirm the results described above, two large scale tests were performed at our laboratory in Beer-Sheva. Two compositions, NK 3-0-9, and NPK 4-4-4 were prepared as follows. A drum was filled with 100 litres of tap water, temperature 15°C, and the fertilizers added rapidly with minimal stirring with a long pole. For the NK solution urea was added first, stirred for about one minute and then the potassium chloride was added. Total dissolution occurred within a few minutes, although the temperature of the solution dropped by 10°C. For the NPK solution, the phosphoric acid was added first, followed by urea and then potassium chloride, with minimal stirring with the pole with each addition. The temperature of the solution increased initially and after addition of the urea and potassium chloride dropped by 4°C.
Discussion

The results presented in this work show that a variety of K, NK, PK and NPK clear solutions can be prepared from urea or ammonium sulphate and with phosphoric acid and white potassium chloride with total nutrients, as expressed in units of N, P$_2$O$_5$ and K$_2$O, of at least 8-10%. The use of ammonium sulphate in solutions containing KCl is limited to low concentrations because of the formation of the less soluble potassium sulphate and higher concentrations of NK or NPK solutions can only be obtained with urea as the nitrogen source.

The heat of solution of the fertilizers ammonium sulphate, urea and potassium chloride is negative (endothermic), resulting in considerable cooling, whilst the heat of solution when diluting phosphoric acid in water is positive (exothermic), resulting in a rise in the temperature of the solution. This exothermic behavior of phosphoric acid, can be utilized by adding it first, before the addition of urea or potassium chloride.

The overall concentration of mixed fertilizer solutions is not dependent on the order of addition, but the kinetics of dissolution are affected, especially in the case of minimal mixing, because of the different heats of solution.

The pH (1:1000) of K and NK solutions are in the range of 5-6, whilst solutions based on phosphoric acid are in the range of 3-4. The pH of the fertilizer solutions is only affected slightly by the pH of the water and remains in the ranges quoted above for water with pH between 6 to 8.

Application of, for example, 2 litres of 1-1-1 (3.6-3.6-3.6) stock solution to 1M$^3$ irrigation water, will give concentrations of 72 ppm of N, P$_2$O$_5$ and K$_2$O.

Conclusions

- High concentrations of NK and NPK solutions based on KCl can only be prepared using urea as the nitrogen source.
- Total nutrient concentrations of at least 9-10% and up to 17% in certain formulations, at 10°C, can be obtained from mixtures of urea, phosphoric acid and potassium chloride.
- The pH of the water has little effect on the final pH of the solutions.
- The dissolution time with minimal stirring, as in field conditions, for the compositions described in this work is short.

References


