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Full Length Research Paper

A low cost nutrient formulation with a buffer for simplified hydroponics systems

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The pH of the nutrient solution is a major determinant of nutrient uptake by the plants. The most suitable pH range for the plants is recognized as 5.8 - 6.5. Therefore, the pH of the nutrient solution has been adjusted to this range before application, using a pH meter. Further more, the pH of the root solution might change with time after application due to many factors and it is not practical to adjust the pH of the root solution homogeneously in a aggregate type hydroponics plant bed. These problems can be overcome by incorporating a buffer system into the nutrient formulation. A new nutrient formulation with a buffer (NF) was designed and prepared using commercial grade compounds. The buffer system HPO_4^{2-}/ $H_2PO_4^-$ was prepared using KOH and H_3PO_4 which are also used as sources of K and P in the nutrient formulation. Therefore, no additional cost was incurred due to the buffer system. The buffer capacity was determined as 4 mmol / dm^3. The success of the buffer was evaluated by measuring its ability to withstand pH changes in the plant bed. A field trial was carried out with the formulation NF and commercially available nutrient pack (AI) which does not incorporate a buffer, for tomato and bean plants in a simplified hydroponics system under external environmental conditions. The pH of the solutions in plant beds was measured daily during the first two weeks after transplanting/sowing. The overall pH change in the root solution, two weeks after transplanting (compared to the pH of the solution applied), was less when the tomato and bean plant beds were treated with NF than with AI. This can be attributed to the buffering action of the HPO_4^{2-}/ $H_2PO_4^-$ buffer system in the NF formulation. Since commercial grade chemicals are used to prepare the pack, the cost of the pack is very much less than similar packs available in the market.

Key words: hydroponics buffers, hydroponics nutrients, pH and plants, buffer system KOH, KH_2PO_4, nutrient solutions.

INTRODUCTION

The pH of the nutrient solution is a major determinant of nutrient uptake by the plants. The most suitable pH range for plants is recognized as 5.8 - 6.5 (Harris, 1988) (different crops will favor a different optimum pH). At low pH, cation absorption decreases and anion absorption increases and *vice versa*. The pH of the nutrient solution affects the solubility of nutrients, thus controlling the availability of nutrients to the plant (Smith, 2000). The type of nutrient and the amount of nutrients dissolved and the pH of the water source in which the nutrients are dissolved affect the pH of the nutrient solution (Bradley and Marulanda, 2000). If the pH of the nutrient solution is not in the favorable range, it has to be adjusted using a mild acid or a base as required before application. However, this is less feasible under low-input farming and home gardening scenarios. The pH of the root solution in the plant bed may also change with time due to relative changes in the uptake rates of individual ions by plants, mainly as a response to changes in plant metabolism. Adjusting the pH of the root solution is not practical and effective particularly in an aggregate type hydroponics system. Therefore, incorporation of a buffer system into the nutrient formulation that maintains the pH at the optimum range in the growing bed would be the best resolution. It would be an added advantage if the buffer

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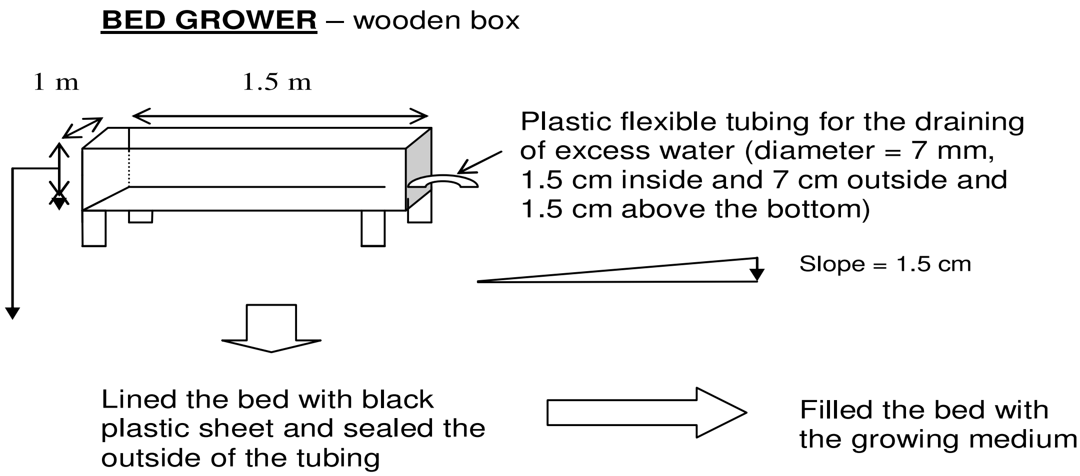

Figure 1. Simplified hydroponics system (Source: Bradley and Marulanda, 2000).

system could be prepared using one or more of the chemicals used to prepare the nutrient formulation, since additional nutrients would then not be required to carry out the buffering action.

MATERIALS AND METHODS

Nutrient formulation with the buffer (NF)

A new formulation (NF) was designed based on the compositions of the nutrient formulations used in countries with similar tropical climatic conditions and a buffer were incorporated into it. The average composition of NF was (in ppm): Ca = 130, N = 170, P = 75, K = 270, Mg = 55, S = 390, Cu = 0.07, Fe = 0.3, Zn = 0.14, Mn = 1.2, Mo = 0.13. The commercial grade chemicals (SOM, EUROPE N.V.) selected to prepare NF were separated into four components which were prepared as follows: (i) Pack A: 61.55 g of $Ca(NO_3)_2.4H_2O$, (ii) Pack B: 1.85 g of KNO_3, 27.35 g of $MgSO_4.2H_2O$, 3.5 g of $CaSO_4.2H_2O$, 1.54 g of $FeSO_4.7H_2O$, (iii) 50 cm^3 of concentrated micro nutrient solution (3.44 g of $MnSO_4.4H_2O$ and 0.66 g of $CuSO_4.5H_2O$ in 1 dm^3 of distilled water), (iv) 250 cm^3 of concentrated buffer solution (prepared as indicated below). Finally, all were dissolved in 50 dm^3 of tap water.

Preparation of the buffer HPO_4^{2-}/ $H_2PO_4^-$ and determination of its buffer capacity

The buffer solution at pH 6.5 was prepared by mixing phosphoric acid solution (1.70 cm^3 of a solution prepared by dissolving 100 g of H_3PO_4 (27% P) in 1/ dm^3) with an appropriate volume of the potassium hydroxide solution (31.76 g / dm^3) to obtain a pH value of 6.5. The buffer capacity was determined by titrating a 10.0 cm^3 portion of this buffer with a standardized KOH solution (0.0147 M).

Nutrient formulation without the buffer (Al - control)

A commercially available nutrient pack (Al) which does not incorporate a buffer system was used as the control. The average composition of the nutrient pack Al was (in ppm): Ca = 106, N = 83, P = 30, K = 124, Mg = 20, S = 226, Cu = 0.02, Fe = 1.0, Zn = 0.10, Mn = 0.27, Mo = 0.05.

Field trials to determine the effectiveness of the buffer

Field trials were carried out for beans and tomato plants using both the nutrient formulations NF and Al. The growing bed was of a simplified hydroponics system made out of wooden containers and is shown in Figure 1.

Each growing bed of beans (*Phaseolus vulgaris* Leguminose) contained 12 plants and a bed of tomato (*Lycopersicon esculentum,* Mill.) contained 6 plants. A mixture of rice hull (fermented for a week and washed) and river sand (washed) in the ratio of 6: 4 was used as the growing medium. The design of the experiment was a randomized completely blocks design (RCBD) with three replicates. The area with beds was covered with a transparent plastic shelter. The pH of the nutrient solutions before application and the pH of the root solution in beds 12 - 24 hours after application of nutrients were measured daily, using a pH meter, during the first two weeks after transplanting/sowing.

RESULTS AND DISCUSSION

In order to maintain the pH in the optimum range of 5.8 - 6.5, a buffer system was incorporated into the nutrient formulation NF. It is possible to use a buffer system composed of either NaOH / NaH_2PO_4 or KOH / KH_2PO_4 as the dissociation constant of $H_2PO_4^-$ is 7.2. Use of the NaOH / NaH_2PO_4 system would be more economical. However, this would result in the toxic level of sodium, which is about 100 ppm (Douglas 1985) for most of the plants, being exceeded. Furthermore, unlike K, Na has not been identified as an essential element. Therefore, the buffer system KOH / KH_2PO_4 was selected for use in the new nutrient formulation.

Calculation of the ratio of $[HPO_4^{2-}]$ / $[H_2PO_4^-]$ in the buffer system

KH_2PO_4 undergoes the following dissociations in an aqueous medium (Vogel 1989). (It is assumed that the dissociation of HPO_4^{2-} does not take place since the

Table 1. Average changes in pH in the root solutions of beds with tomato and bean plants.

No. of days after transplanting	Average changes* in pH in the root solution in beds			
	Tomato plants		Bean plants	
	Treatment Al	Treatment NF	Treatment Al	Treatment NF
2	0.14	0.55	-0.08	0.45
3	0.67	0.45	0.19	0.48
4	0.47	0.30	0.28	0.38
5	0.30	0.14	0.01	-0.06
7	0.28	0.13	0.04	0.04
8	-0.72	-0.62	-1.44	-0.77
10	-0.56	-0.35	-0.64	-0.39
11	-0.32	-0.32	-0.56	-0.26
14	-0.54	-0.30	-0.81	-0.38
15	-0.45	-0.07	-0.67	-0.11

*change in the pH = pH of the nutrient applied - pH of the root solution.

pK_{a_3} value is very high)

$$H_2PO_4^- \rightarrow HPO_4^{2-} + H^+ \qquad pK_{a_2} \equiv 7.2$$
$$HPO_4^{2-} \rightarrow PO_4^{3-} + H^+ \qquad pK_{a_3} \equiv 12.4$$

Considering the dissociation of $H_2PO_4^-$,

$$pH = pK_{a_2} + \log\left(\frac{[HPO_4^{\ 2-}]}{[H_2PO_4^{\ -}]}\right) \tag{1}$$

By applying the Henderson – Hasselbalch equation (1), it can be seen that the pH of the buffering medium will vary depending on the log value of the $[HPO_4^{2-}]$ / $[H_2PO_4^-]$ ratio (since pK_{a_2} is a constant). Due to the buffering action, with addition of H^+ or OH^- the following reactions will take place.

$$HPO_4^{2-} + H^+ \rightarrow H_2PO_4^-$$

$$H_2PO_4^- + OH^= \rightarrow HPO_4^{2-} + H_2O$$

The number of moles of HPO_4^{2-} or $H_2PO_4^-$ generated due to the addition of acid or base will be equal to the number of moles of acid or base added. The change in pH will not be that significant if the concentrations of both the HPO_4^{2-} and $H_2PO_4^-$ are high, that is, if the buffer capacity is high. If the difference between pH and pK_{a_2} is small, the change in the ratio of $[HPO_4^{2-}]$ / $[H_2PO_4^-]$ will be small, thus increasing the capacity of the buffer. For example, considering the maximum optimum pH, that is, pH 6.5, the concentrations for the buffer with the highest capacity can be worked out using equation (2),

$$6.5 = 7.2 + \log\left(\frac{[HPO_4^{\ 2-}]}{[H_2PO_4^{\ -}]}\right) \tag{2}$$

The buffer capacity can be increased by increasing the total amount of phosphorus. The amount of phosphorus can be increased up to 80 ppm (2.58×10^{-3} M), which is the maximum tolerable limit of phosphorus in most plants (Smith 2000). Therefore, the sum of the amounts of HPO_4^{2-} and $H_2PO_4^-$ can be increased up to 2.58×10^{-3} M, since KH_2PO_4 is the only source of phosphorus. Using equation (2), the concentrations of $[H_2PO_4^-]$ and $[HPO_4^{2-}]$ required are calculated as 2.152×10^{-3} M and 0.429×10^{-3} M respectively, at the highest "allowed" buffer capacity, at a pH of 6.5. The buffer capacity was determined as 4 mmol / dm^3.

Field experiments

pH changes in beds with tomato plants

The pH of the applied nutrient solution in the first and second week after transplanting was 6.6 and 6.1 respectively. During the first week after transplanting, a decrease in average pH was observed in the root solutions of the beds with both treatments NF and Al (compared to the pH of the nutrient solution applied). The change in average pH in the first week after transplanting was greater (0.14 - 0.67) in the root solutions of the plants treated with Al than the plants treated with NF (0.14 - 0.55) (Table 1 and Figure 2). In the second week after transplanting, the average pH of the root solutions of the beds treated with both the nutrient solutions increased (compared to the pH

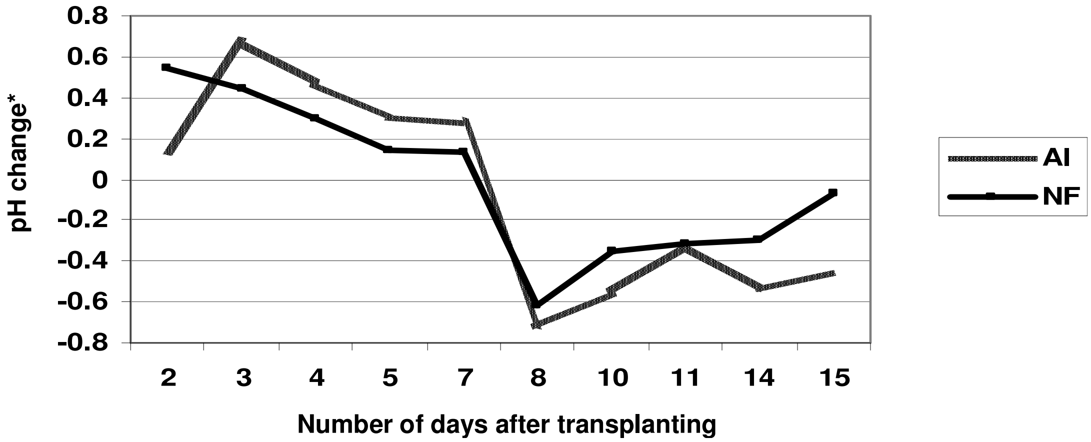

Figure 2. Average changes in pH in the root solution in tomato beds with time.
(*change in pH = pH of the nutrient applied - pH of the root solution).

Figure 3. Average changes in pH of the root solution in bean beds with time.
(*pH change = pH of the nutrient applied - pH of the root solution).

of the nutrient solution applied). During this period, the average change in pH of the root solutions of the beds treated with Al was greater (0.32 - 0.72) than those treated with NF (0.07 - 0.62). When the entire two week period after transplanting is considered, a greater change in pH in the root solution (compared to the pH of the solution applied) was seen in the tomato plant beds treated with Al (range, -0.72 to +0.67) than in those treated with NF (range, -0.07 to +0.55).

pH changes in beds with bean plants

In the first four days after sowing, the change in pH (compared to the pH of the nutrient solution applied) of root solutions of the beds treated with NF was greater (0.04 - 0.48) than those treated with Al (0.01 - 0.28). For both the treatments, the pH change of the root solution was similar, during 5th - 7th day (Table 1 and Figure 3). During the second week after sowing, the average pH of the root solutions of the beds treated with both the nutrient types increased (compared to the pH of the nutrient solution applied). During this period, the change in average pH was greater in beds treated with Al (0.56 - 1.44) than those treated with NF (0.11 - 0.77). When the entire two week period after sowing is considered, the greatest change in average pH was observed in the root solution of the bean plant beds treated with Al (from -1.44 to +0.28).

Conclusion

The change in average pH of the root solution of beds with tomato and beans treated with NF was less than those treated with AI. This can be attributed to the buffering action of the HPO_4^{2-}/ $H_2PO_4^-$ buffer system in the NF formulation. This buffer system which is composed of KOH and KH_2PO_4, has the added advantage of being the nutrient sources of K and P in the nutrient formulation. Therefore, no extra cost is incurred for incorporating the buffer into the nutrient formulation. Since these chemicals used in the preparation of the nutrient pack are of commercial grade, the preparation of the packs is economical.

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