Nitrogen, phosphorus, and potassium fertilization of almonds

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INTRODUCTION

Almond cultivation is a key horticultural product worldwide with promising prospects in the growing Israeli market. Yet intensive fertilization knowhow is missing and current nutrient application lacks scientific foundations that would enable educated modifications of various varieties to new locations and climates.

We study the effects of macro-nutrients (N, P, and K) on almond trees in a controlled experimental setup with a working hypothesis that improved nutrient application during the growing season (summer) would maximize carbohydrate recharge and secure almond vegetative and reproductive growth in spring.

Our objectives are:

- To characterize almond response to levels of nitrogen, phosphorus, and potassium.
- To define new quantitative parameters to tree nutritional status.
- To model the effects of nutrients on carbohydrate balance in tree crops.

EXPERIMENTS

We have 80 Umelfahem (grafted on GN) saplings in 920 L containers. By April 2017 we began treatments with different levels of nitrogen (N; 0, 10, 30, 60, 100, 150, and 200 mg L^{-1}), phosphorus (P; 0, 1, 3, 6, 15, and 20 mg L^{-1}), and potassium (K; 0, 10, 30, 60, 100, 150, and 200 mg L^{-1}), i.e. 20 treatments, 4 replicates, randomized allocation in 4 blocks. Between July 2017 and October 2017 we monitored the physiology (gas exchange and water potential) of potted almond saplings and tracked their biomass accumulation (leaf area and stem diameter). We also periodically sampled irrigation and drainage water, along with young, yet fully developed, leaves for mineral analyses to validate the treatments.

RESULTS

Biomass accumulation: Severely nitrogen deficient (0 mg N L^{-1}) almond trees had very small canopy cover (~0.5 LAI). LAI increased linearly in higher N levels until reaching a constant value of 1.65 for Irrigation N between 60 and 200 mg N L^{-1}. Hardwood biomass accumulation (represented by stem diameter, SD) followed a similar trend and 0 mg N L^{-1} stopped annual stem growth at a diameter of 8.7 mm. 10 mg N L^{-1} was sufficient to support 50% greater growth before stems reached annual limit at 14.5 mm. Phosphorus was less limiting to begin with, i.e. 0 mg P L^{-1} resulted in LAI of 0.85, but it actually exhibited the highest potential to induce LAI, supporting a canopy cover index of 3 at 15 mg P L^{-1} fertigation. Phosphorus deficiency did not constrain stem growth much either (0 mg P L^{-1} supported stems of 12 mm) yet the negative effects of excessive P (suboptimal LAI) were clear, as SD decreased when P levels increased above 6 mg P L^{-1}. Finally, potassium did not limit or induce LAI at any treatment and it averaged at 1.95 in all K levels, which corresponded to the high N levels and the runner-up P levels of 6 and 20 mg P L^{-1}. Neither did potassium affect stem growth.

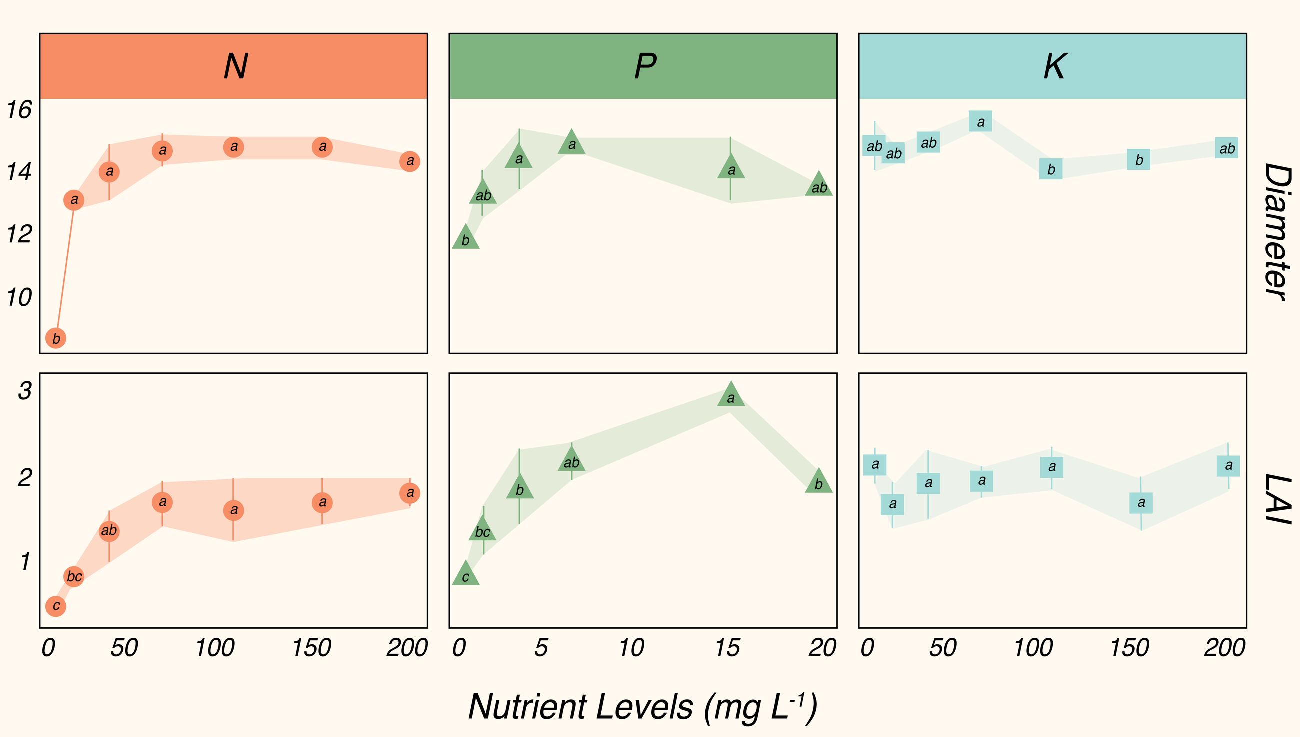
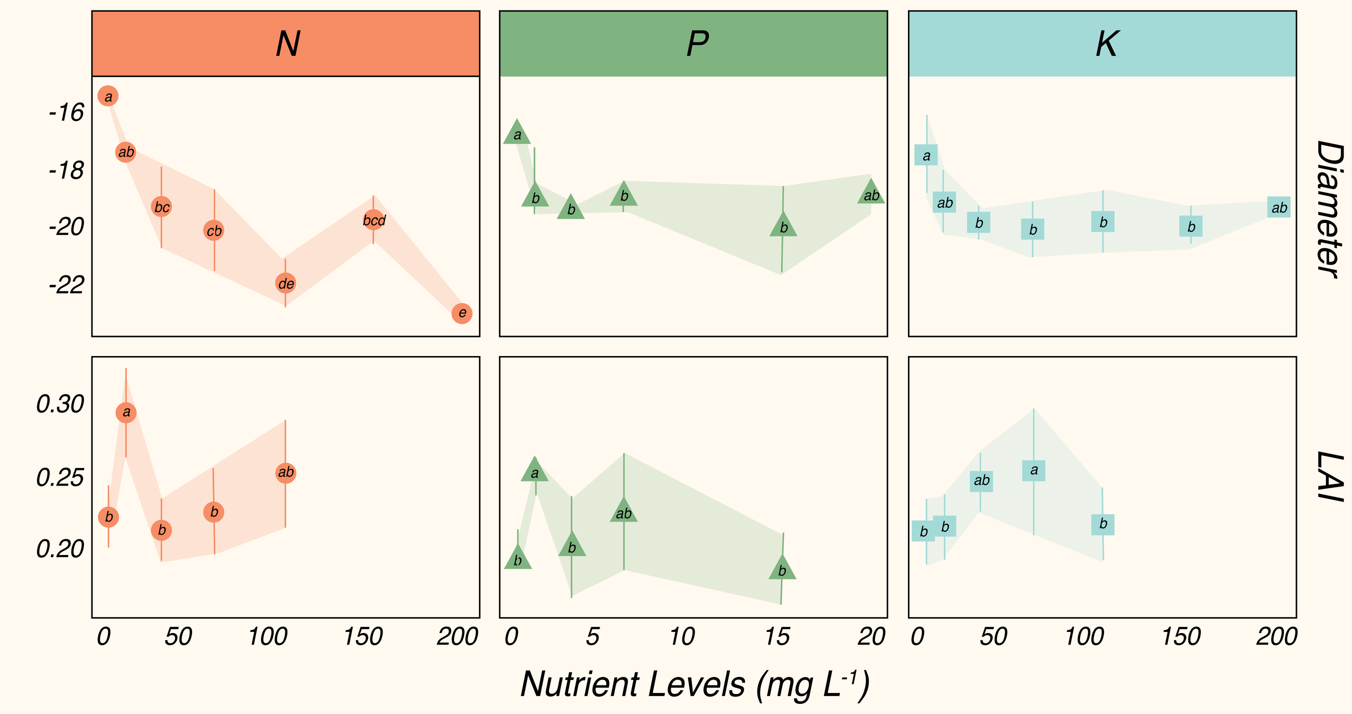


Figure 1: Stem diameter (SD, mm) and leaf area index (LAI, -) on September 6th 2017 for various nitrogen (N), phosphorus (P), and potassium (K), levels in irrigation solution. Symbols denote averages, vertical lines and ribbon represent standard errors (n=4), and letters denote statistical analysis (One-way ANOVA and LSD by 95% confidence, R 3.2.1).

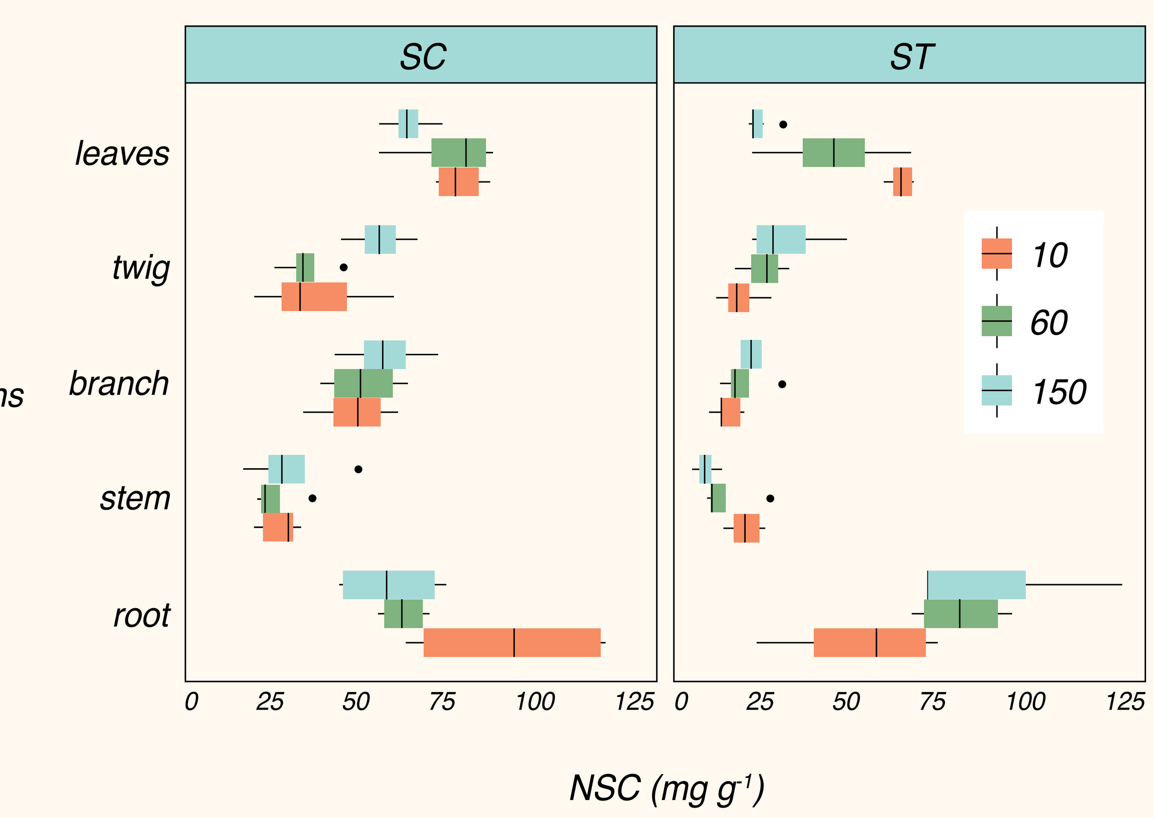
Water loss: Nitrogen deficient almond saplings, with minimal leaf area, transpired very little and maintained a relatively high stem water potential (WP) of -15 kPa, despite their open stomata (g_s of 0.2 mol m^{-2} s^{-1}). As N increased, and trees grew bigger, their WP dropped at midday to alarming levels of -22 kPa at 100 mg N L^{-1} fertigation. Stomata enabled augmented water loss at first (0.3 mol m^{-2} s^{-1} at 10 mg N L^{-1}), then restrained it (0.2 mol m^{-2} s^{-1} at 30 mg N L^{-1}), but finally supported further water loss and reached 0.27 mol m^{-2} s^{-1} at 100 mg N L^{-1}. Phosphorus deficiency also limited canopy size and sustained a high WP (-16.7 kPa) in almond saplings. Yet slightly higher P, 1 mg P L^{-1}, dropped WP to -19 kPa. Nevertheless WP did not decrease further, which resonated with the conservative stomata, that besides a peak of 0.26 mol m^{-2} s^{-1} at 1 mg P L^{-1}, sustained a low conductivity of ~0.23 mol m^{-2} s^{-1} at P levels above 3 mg P L^{-1}. In case of potassium, with similar canopy size in all treatments, stomata actually regulated water loss and the decrease in WP between 0 and 30 mg K L^{-1} (-17.4 to -20 kPa) followed an increase in g_s from 0.22 to 0.26 mol m^{-2} s^{-1}.

Figure 2: Midday stem Water Potential (WP, kPa) and stomatal conductivity (g_s, mol m^{-2} s^{-1}) at September 15th for various nitrogen (N), phosphorus (P), and potassium (K), levels. Symbols denote averages (circles for N, triangles for P, and squares for K), vertical lines and ribbon represent standard errors (n=4), and letters denote statistical analysis (One-way ANOVA and LSD by 95% confidence, R 3.2.1).



Carbohydrate management: Soluble carbohydrates (SC) in leaves average 74 mg g^{-1} for the 10 and 60 mg N L^{-1} yet dropped to 62 at 150 mg N L^{-1}. This trend was amplified in starch that dropped linearly from 62 to 23 mg g^{-1} between 10 and 150 mg N L^{-1} fertigation. Twigs acquired NSCs in high N fertigation as SC increased from 35 to 53 mg g^{-1} and ST increased from 18 to 31 mg g^{-1} between 10 and 150 mg N L^{-1}. Branches followed the same trend, mildly though, as starch increased from 14 to 21 mg g^{-1}, while stems reversed it as starch decreased from 19 to 9 mg g^{-1} between 10 and 150 mg N L^{-1}. Finally, roots, exhibiting the biggest capacity for NSCs, decreased SC from 89 to 56 mg g-1 while increasing starch from 52 to 88 mg g^{-1} between 10 and 150 mg N L^{-1} fertigation.

Figure 3: Non-structural carbohydrate (NSC) of leaves, twigs, branches, stems, and roots of almond saplings fertigated with 10, 60, or 150 mg N L^{-1} (red, green, or blue bars respectively) at October 10th. Carbohydrates are represented by medians (vertical line inside the bar), standard deviation (bars), and outliers (single dots) while they are grouped as soluble carbohydrates (SC, left panel) and starch (ST, right panel).



CONCLUSION

Nitrogen, phosphorus, and potassium are all critical to almond sapling. Nitrogen promotes growth, yet in young trees, its benefits were restricted to lower fertigation N levels and its excesses appeared to drive saplings off their root-to-shoot ratio and result in water stress. Phosphorus is also highly necessary to almond sapling development, and its commercial application could be insufficient. In fact, P benefited trees in concentrations way beyond the field current recommendations. As for potassium, almond saplings developed well, independent of fertigation L levels. Their water status and stomata regulation did respond to K fertigation, implying that there are underlying processes which we expect to unravel soon, probably during flowering and fruit-set (i.e. March 2018). Finally, carbohydrate management, predictably, responded to fertigation and represented nutritional status. N deficiency resulted in high sugar and low starch in roots, denoting amplified root development, whereas N excess forced leaves to low sugar and starch, as photosynthates were depleted due to induced canopy growth.

Figure 4: Selected pictures of almond saplings on September 1st 2017 fertigated according to the common practice (60-10-60 NPK, tree on the left), nitrogen deficient (0-10-60, 2nd tree from the left), potassium deficient (60-0-60, 3rd from left), or phosphorus deficient (60-10-0, tree on the right).

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