

Nitrogen supply affects cannabinoid and terpenoid profile in medical cannabis (<i>Cannabis sativa</i> L.)			
Medium:		Stage:	Flowering

Abstract / Highlights:

- 30, 80, 160, 240, and 320 mg/L N
- N supply affects cannabinoid and terpenoid metabolism
- Concentrations of most cannabinoids and terpenoids tested were highest under the deficient concentration of 30 mg/L and declined with the elevation of N supply.
- THCA and CBDA decreased by 69% and 63%, respectively, from 30 to 320 mg/L
- Plant development and function restricted under 160 mg/L, demonstrating N deficiency.
- Morpho-physiological state optimal at 160–320 mg/L
- Inflorescence yield reflected the plant physiological state, increasing up to 160 mg/L N, and was unaffected by further increase in N.
- High N supply has adverse effects on the production of secondary compounds in cannabis, while it promotes growth and biomass production.
- Optimal N level for yield quantity, that allows also a relatively high secondary metabolites content, is 160 mg L⁻¹ N.

Summary:

- Abstract only / paywall.
- Low N = more potent but less buds; High N = less potent but more buds
- Supposedly, 160 mg/L N is optimal combination of yield and potency, but full article / detailed results not reviewed.

Response of Medical Cannabis (<i>Cannabis sativa</i> L.) Genotypes to K Supply Under Long Photoperiod			
Medium:	Perlite 2-1-2	Stage:	Vegetative

Abstract / Highlights:

- 15, 60, 100, 175, and 240 ppm K
- Growth response to K inputs varied between genotypes
- 15 ppm K insufficient in both with visual deficiency symptoms.
- 245 ppm K excessive and damaging to one genotype, but stimulated shoot and root development in the other.
- Competition for uptake between K and Ca and Mg, and no effect on N and P uptake except in the K-deficiency range.
- Accumulation leaves > roots > stem for N, and roots > leaves > stem for P.
- Most micronutrients (Zn, Mn, Fe, Cu, Cl) tended to accumulate in the root, suggesting a compartmentation strategy for temporary storage, or for prevention of excess concentrations at the shoot tissues.

- Growth reduction (< 15 ppm K) due to water relations of the tissue, transpiration, and carbon fixation.

Other Notes:

- Base Feed: 14.82 mM N-NO₃⁻, 1.62 mM N-NH₄⁺, 1.9 mM P-PO₄⁻², 2.99 mM Ca⁺², 1.45 mM Mg⁺², 1.04 mM Na⁺, 0.37 mM Cl⁻, 0.03 mM Fe⁺², 0.02 mM Mn⁺², 0.005 mM Zn⁺²
- Converted (Check Math): 230 ppm Total N, 59 ppm P, 120 ppm Ca, 35 ppm Mg, 24 ppm Na, 13 ppm Cl, 1.68 ppm Fe, 1.10 ppm Mn, 0.33 ppm Zn
- K₂SO₄ used vs. KCl or KNO₃
- Two cultivars evaluated – “Low THC” (5% CBD/THC) cultivar and “High-THC” cultivar
- Both cultivars = K < 15 ppm = deficiency and developmental delay
- Low THC cultivar = Shoot and root growth increase with K supply up to 175 ppm K, decrease at 240 ppm K
- High THC cultivar = Unchanged 60 – 175 ppm K, significant increase at 240 ppm K

Summary:

- Constant Ca feed of 120 ppm; only up to 240 ppm K; Did not evaluate K:Ca:Mg ratios
- Effects at 240 ppm mainly impact side branch development, not overall main stem or new internodes; Main yield-affecting parameters (e.g., height and stem diameter) may not have been impacted, but not carried through to final yield.
- Results seem to exhibit some effects of K:Ca/Mg antagonism

Impact of N, P, K, and Humic Acid Supplementation on the Chemical Profile of Medical Cannabis (Cannabis sativa L)			
Medium:	Potting Soil	Stage:	Flowering

Abstract / Highlights:

- P enhancement treatment did not affect THC, CBD, CBN, and CBG concentrations in the flowers from the top of the plants, a 16% reduction of THC concentration was observed in the inflorescence leaves.
- NPK supplementation increased CBG levels in flowers by 71%, and lowered CBN levels in both flowers and inflorescence leaves by 38 and 36%, respectively.
- HA was found to reduce the natural spatial variability of all of the cannabinoids studied. However, the increased uniformity came at the expense of the higher levels of cannabinoids at the top of the plants, THC and CBD were reduced by 37 and 39%, respectively.
- The results demonstrate that nutritional supplements influence cannabinoid content in cannabis in an organ- and spatial-dependent manner.

Other Notes:

- While the process by which they influence cannabinoid content is unclear, the nutritional supplementation treatments clearly affected the concentrations of micro and macronutrients in the plant (Figure 5).

Summary:

- Evaluated supplementation, not base nutrient levels.
- Base feed: 65 ppm N / 17 ppm P / 90 ppm K

Optimal Rate of Organic Fertilizer during the Flowering Stage for Cannabis Grown in Two Coir-based Substrates			
Optimal Rate of Organic Fertilizer during the Vegetative-stage for Cannabis Grown in Two Coir-based Substrates			
Medium:	Coco	Stage:	Flowering

Abstract / Highlights:

- N: 57, 113, 170, 226, and 283 mg N/L of a liquid organic fertilizer (2.00N–0.87P–3.32K)
- Higher yield, growth, potency with larger container capacity (i.e., water-holding capacity)
- Increasing N led to increased growth and yield, but also to a dilution of THC, THCA, and CBGA.
- For higher container capacity, 212–261 mg N/L maximized both yield and cannabinoid yield
- For lower container capacity, max N (283 mg N/L) maximized yield;
- Results may differ with cannabis variety.

Other Notes:

- Veg prep: CO₂ = 545 - 613 ppm; PPFD = 100 – 337; 1 mL/L of 3.0%Ca–1.6%Mg; N = 389 mg N/L (Optimal rate from previous study); Ratio 4.0N–1.3P–1.7K (elemental values → 4-3-2 NPK label)
- Flower overall N = 57, 113, 170, 226, and 283 mg N/L using:
 - o Nutri Plus Organic Bloom = 2.00N–0.87P–3.32K (2-2-4 NPK label) with 100 Mg, 10.0 Zn, 12.8 B, 0.1 Mo 2.3 Cu, and 6.8 Fe (all mg/L)
 - o RO water amended with 1 mL/L of 3.0%Ca–1.6%Mg
 - o Plus 22.9 N mg/L from Organa ADD supplement (2.0N–0.0P–0.0K) with 100.0 Ca, 29,851 Zn, 4892 Mn, 1239 B, 12.7 Mo, 2419 Cu, and 2917 Fe (all mg/L).
- 581 PPFD; CO₂ = 594 – 838 ppm; RO only last week of flower; 6-day dry @ 18°C 50% RH; 11-day cure 18°C 58% RH
- Lower CC (container-capacity) coco may lead to slightly higher yields since they require more frequent fertigation and can provide higher root-zone O₂

Summary:

- Elevated CO₂ may explain why optimal N is higher than in other studies.
- Study used organic fertilizers (less soluble and slower releasing than synthetics) which may explain higher optimal rates. No toxicity symptoms observed except “normal senescence-related chlorosis”...which may have been toxicity from slower release by organic fertilizers.
- Sounds like they increased pre-mixed fertilizer concentration to reach target N values, thereby also increasing other nutrients (vs. just adding additional N)
- Overall, N strategy during flowering can be used as a strategy for “less grams, but higher THC buds” vs. “more grams, but lower THC buds”); combined yield (total grams THC / plant) peaked around 160 – 240 mg/L N.

Response of Medical Cannabis (<i>Cannabis sativa</i> L.) to Nitrogen Supply Under Long Photoperiod			
Medium:	Soilless	Stage:	Vegetative

Abstract / Highlights:

- N = 30, 80, 160, 240, and 320 mg/L
- Optimal 160 mg/L
- Deficiency 30 mg/L
- K, P, Ca, Mg, and Fe highest at N = 160 mg/L
- P, Zn, Mn, Fe, and Cu roots > leaves > stem
- K and Na stem > leaves > roots
- N, Ca, and Mg leaves > roots > stem
- Growth retardation low N (30–80 mg/L) from restricted photosynthetic pigments, carbon fixation, and impaired water relations.
- N > 160 mg/L ion-specific toxicity or indirect induced restrictions of carbon fixation and energy availability.

Other Notes:

- Single indica cultivar ~7% THC / ~7% CBD
- 400 PPFD; 18/6 light cycle; 28C/42%RH and 25C/49%RH day/night
- Base Feed: N (per above), plus (in mM): 5.1 K⁺, 1.9 P-PO₄⁻², 1.12 Ca⁺², 1.83 Mg⁺², 3.25 Na⁺, 2.77 S-SO₄⁻², 2.57 Cl⁻, 0.03 Fe⁺², 0.014 Mn⁺², 0.006 Zn⁺², 0.0006 Cu⁺², 0.0003 MoC₂, and 0.009 B⁺³.
- Converted (ppm): 200 ppm K, 59 ppm P, 45 ppm Ca, 45 ppm Mg, 75 ppm Na, 89 ppm S, 91 ppm Cl, 1.68 ppm Fe, 0.77 ppm Mn, 0.39 ppm Zn, 0.04 ppm Cu, 0.03 ppm Mo, 0.10 ppm B

Summary:

- Leaf, root, stem mass peaked at N = 160 mg/L, then decreased at higher levels.
- Restricted growth and chlorosis at 30-80 mg/L N;
- Restricted root growth starting at 240 mg/L N, but no noticeable pigmentation changes until 320 mg/L N (i.e., As N increases, growth becomes sub-optimal before significant visual toxicity symptoms appear).
- Other symptoms of high N include reduced photosynthesis, stomatal closure, and reduced water transpiration (all of which could potentially be detected by increase in leaf temperature offsets)

The Highs and Lows of P Supply in Medical Cannabis: Effects on Cannabinoids, the Ionome, and Morpho-Physiology			
Medium:	Perlite 2-1-2	Stage:	Flowering

Abstract / Highlights:

- P = 5, 15, 30, 60, and 90 mg/L (ppm)

- P = 15 mg/L insufficient
- P = 30–90 mg/L optimal range (30 mg/L sufficient for 80% of the maximum yield)
- 80% of the plant P accumulates in inflorescences;
- P > 5 mg/L reduced THCA and CBDA concentrations by up to 25%.
- Cannabinoid concentrations decreased linearly with increasing yield, consistent with a yield dilution effect, but the total cannabinoid content per plant increased with increasing P supply.
- Cannabinoid concentrations highest under <30 mg/L P, vs. inflorescence biomass highest under 30–90 mg/L
- P regime should be adjusted to reflect production goals.

Other Notes:

- Two cultivars (“high THC / Low CBD” and “Balanced THC/CBD”); Five fertigrations over 63 – 68 days flowering; 980 PPFd; HPS bulbs;
- Cannabinoids measured after drying @ 19.5C/45%RH for 2 weeks; Cannabinoids reported as average of top and bottom inflorescences; Dry weight measured after 65C for 72 h;
- Base feed = P per above, plus (converted to ppm): 175 ppm N, 100 ppm K, 120 ppm Ca, 35 ppm Mg, 47 ppm S, 2.13 ppm Cl, 1.17 ppm Fe, 0.60 ppm Mn, 0.33 ppm Zn, 0.05 ppm Cu, 0.03 ppm Mo, 0.10 ppm B
- High THC/Low CBD cultivar more sensitive to low P
- P accumulates in roots during vegetative, but not during flowering; instead, P during flowering accumulates in inflorescences and excess P accumulates in leaves
- P intake slows after elongation stops and relies more on P re-mobilization;

Summary:

- No toxicity seen at max P (90 mg/L), but shows decreased inflorescence accumulation and increased root accumulation suggesting a possible defense against toxicity.
- Max THCA & CBDA concentrations for both cultivars occurred at P < 30 mg/L, but this also reduced final dry weight and total THCA/CBDA per plant.
- Total THCA & CBDA per plant increased slightly up to 90 mg/L for “Balanced THC/CBD” cultivar; No increase in total THCA & CBDA per plant above 30 mg/L for “High THC / Low CBD” cultivar
- Overall, similar yield dilution effect as N during flowing.

Impact of Phosphorus on Cannabis sativa Reproduction, Cannabinoids, and Terpenes			
Medium:	80/20 Peat / Perlite	Stage:	Both

Abstract / Highlights:

- P = 3.75, 7.50, 11.25, 15.0, 22.50, and 30.0 mg/L
- P >11.25 mg/L P did not increase cannabinoid concentrations, but P = 30 mg/L had greater plant width and may result in more buds per plant.

Other Notes:

- One cultivar – “BaOx”, a high CBD strain

- N & K at 150 mg/L
- Other nutrients based on past research for ornamental flowers. Reference given, but individual ppms not listed. Two container Epsom salt amendments given throughout cycle.

Summary:

- Focused on very low P levels to find minimums. Levels were too low to find maximum level.
- Evaluated max cannabinoid concentration, but not total yield per plant.

Elevated Phosphorus Fertility Impact on Cannabis sativa 'BaOx' Growth and Nutrient Accumulation			
Medium:	70/30 Peat / Perlite	Stage:	Both

Abstract / Highlights:

- Grower P fertility rate recommendations vary greatly, with suggestions of up to 196 mg/L P
- P = 15, 60, 120, and 180 mg/L
- High CBD-type cultivar 'BaOx'.
- Plant height, diameter, and total biomass were similar across all examined P rates.
- No differences in biomass production were found, indicating that rates above 15 mg/L P are not beneficial for plant growth.

Other Notes:

- One cultivar – "BaOx", a high CBD strain;
- Base feed: 150 ppm N, 150 ppm K, 125 ppm Ca, 45 – 90 ppm Mg, 54 ppm S, 4 ppm Fe, 1 ppm Mn, 0.2 ppm Cu, 0.2 ppm Zn, 0.5 ppm B, 0.01 ppm Mo
- "P toxicity levels have not been established for C. sativa"
- 60 mg/L P produced 20.7% greater total bud weight compared to 120 mg/L (which produced the lowest total bud weight)

Summary:

- No toxicity at max P = 180 mg/L
- Evaluated bud dry weight, but not cannabinoid concentrations or total cannabinoid/plant
- Not enough P levels within Bernstein optimal range (30 – 90 mg/L P)

Augmenting Nutrient Acquisition Ranges of Greenhouse Grown CBD (Cannabidiol) Hemp (Cannabis sativa) Cultivars			
Medium:	Peat	Stage:	Vegetative

Abstract / Highlights:

- Focused on Hemp / CBD (<0.3% THC)

- Foliar tissue analysis for thirteen cultivars
- Significant differences were found among all thirteen cultivars in accumulation of both micro and macro essential nutrients, widening the range of the fertility requirements of Cannabis plants grown in this production model for CBD harvesting.

Other Notes:

- Base Feed: 13–2–13 Calcium-Magnesium (Ultrasol TM SQM, North America Corporation, Atlanta, GA, USA) supplied at 150 mg/L N [Seems to be a N-Ca-Mg only mixture, but current label amounts seem different than those used in the study]
- Grown for 12-weeks
- Does not mention nutrient feed for other macro/micro nutrients; may have relied solely on media (Sunshine Mix #1, Sun Gro Horticulture)

Abstract / Highlights:

- Study provides levels of macro/micro nutrients accumulated in mature leaves for 13 different hemp CBD cultivars. Mainly relevant for commercial operations performing laboratory foliar analysis as part of monitoring programs.
- Not directly applicable to optimal feed levels, except to reinforce that optimal feed levels may vary among cultivars.

Optimization of N, P, K for soilless production of Cannabis sativa in the flowering stage using response surface analysis			
Medium:	Expanded Clay	Stage:	Both / Flowering

Abstract / Highlights:

- Single high THC/low CBD cultivar (Gelato) in DWC
- N = 70, 120, 180, 250, 290 mg/L,
- P = 20, 40, 60, 80, 100 mg/L and
- K = 60, 120, 200, 280, 340 mg/L
- Optimal N = 194 mg/L
- Optimal P = 59 mg/L
- Inflorescence yield did not respond to K in the tested range.

Other Notes:

- “Growers often supply plants with relatively high P concentrations (up to 200 mg/L) during the flowering stage based on a belief that this promotes flower development. However, there is little evidence to support this practice. “
- “Yield of aquaponically-grown cannabis (g/plant) increased linearly with increasing nutrient solution K concentration in the range of 15-150 mg L⁻¹ (Yep and Zheng, 2020).” [Paywall]
- MH lights; 570 PPFD; 25C/65% RH; No CO₂ addition;
- Same feed for 3 weeks of vegetative prior to starting flowering: (mg L⁻¹): 112.8 N-NO₃, 7.2 N-NH₄, 40 P, 180 K, 110 Ca, 45 Mg, and 60 S.
- Flowering and vegetative micronutrients: (mg L⁻¹): 2.1 Fe, 0.6 Mn, 0.12 Zn, 0.03 Cu, 0.39 B, and 0.018 Mo.

- 20 different N-P-K-Ca-Mg-S-Cl formulations during flowering. Max-Min ranges consisted of: 70 – 290 ppm N, 20 – 100 ppm P, 60 – 340 ppm K, 130 – 260 Ca, 45 Mg, 180 S, 5 – 190 Cl
- “Representative samples of fresh inflorescences” were analyzed, but no further details of sample locations were provided. No nutrient treatment effects found on inflorescence cannabinoid content.

Summary:

- Appears to have measured overall inflorescence weight and cannabinoid concentrations, but no attempt to determine total THC/plant.
- The optimal concentrations of nutrient solution N and P was predicted to be approximately 194 mg L⁻¹ N, 59 mg L⁻¹ P, respectively.
- Inflorescence yield decreased markedly outside of the range of 160-240 mg L⁻¹ N, and 40-80 mg L⁻¹ P.
- Inflorescence yield did not respond to nutrient solution K concentration within the tested range (60 – 340 mg/L), indicating the K currently supplied (300-400 mg L⁻¹) by some commercial cultivators are likely too high.

Response of essential oil hemp (<i>Cannabis sativa</i> L.) growth, biomass, and cannabinoid profiles to varying fertigation rates			
Medium:	Peat (Pro-Mix Myco)	Stage:	Both / Flowering

Abstract / Highlights:

- Five CBD hemp cultivars
- Based: 20-20-20 fertilizer at 0, 50, 150, 300, 450, and 600 ppm N equating to 0.33 (control), 0.54, 0.96, 1.59, 2.22, and 2.85 dSm⁻¹, respectively.
- 8-week veg / 8-week flowering period
- Confirmed SPAD-502 chlorophyll meter could identify nutrient deficiency
- Optimal fertilizer rates were observed at 50 ppm N, while increased fertilizer rates significantly reduced plant growth, biomass accumulation, and cannabinoid concentrations.

Other Notes:

- Peters Professional 20-20-20 (N-P-K) with micronutrients (0.050% Mg, 0.0125% B, 0.0125% Cu, 0.050% Fe, 0.025% Mn, 0.005% Mo, and 0.025% Zn) at (0, 50, 150, 300, 450, and 600 ppm nitrogen) and EC (0.33, 0.54, 0.96, 1.59, 2.22, and 2.85 dS m⁻¹)
- Toxicity apparent at 300 ppm N and above

Summary:

- Hemp / CBD only
- Equal parts NPK, no discussion of Ca, but starting EC of water ~170 ppm-500
- Lack of resolution in N concentrations near coires, increasing nutrient concentrations along with N concentrations, and no discussion of Ca reduces applicability and utility of results.

Magnesium's Impact on Cannabis sativa 'BaOx' and 'Suver Haze' Growth and Cannabinoid Production			
Medium:	70/30 Peat / Perlite	Stage:	Both / Flower

Abstract / Highlights:

- Two CBD hemp cultivars
- Mg (0.0, 12.5, 25.0, 50.0, 75.0, and 100.0 mg/L)
- Foliar Mg concentrations increased linearly for all life stages with the greatest foliar Mg concentrations being in the highest rate of 100.0 mg/L Mg.
- 50.0 and 75.0 mg/L Mg optimized plant height, diameter, and plant total dry weight as well as having similar cannabinoid concentrations.

Other Notes:

- Media amended with CaOH at 2.3 kg·m⁻³
- Custom fertilizer mix of individual salts; Concentrations of salts held constant while Mg varied; Individual elemental ppms not reported
- Vegetative:
 - o No apparent Mg deficiencies at any feed rate
 - o A plateau in growth metrics was observed between a fertility rate of 50.0 and 75.0 mg·L⁻¹ Mg.
- Flowering:
 - o Mg deficiency in one cultivar at < 25 mg/L Mg
 - o Symptoms = slight yellowing of the interveinal regions of the lower and older foliage progressing to more pronounced yellowing and ultimately necrotic spotting leading to total leaf necrosis and abscission.
 - o Deficiency symptoms often develop after bud formation has begun due to Mg being translocated from leaves to the developing buds.

Summary:

- Hemp / CBD only
- Recognizes competition between K/Ca/Mg, but no attempts to control or measure ratios, or evaluate impact of Ca amendments and feed.
- Unclear if reported optimums (50 – 75 mg/L Mg) are dependent on K and Ca levels in media and feed.

Balancing the Nutrient Equation in Cannabis Cultivation			
Medium:	N/A	Stage:	N/A

Abstract / Highlights:

- From poinsettia production, provide K, Ca and Mg in a 4:2:1 ratio to avoid antagonisms.

- Recommended levels for poinsettias (200 ppm K / 100 ppm Ca / 50 ppm Mg) should be similar for cannabis.

Other Notes:

- Need to be careful of NCSU articles in Cannabis Business Times. Whipker, Cockson, Veazie are mostly focused on CBD Hemp research and base most of their assumptions on past research with ornamental flowering plants, so their conclusions and recommendations may not be directly transferrable to high THC cannabis.