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Evaluation and control of the nutritional status of lettuce (*Lactuca sativa var. capitata* L. 'Ostinata') grown in water culture II. Nutrient therapy controlling quantity of final yield

Vurdering og regulering af ernæringstilstanden hos salat (Lactuca sativa var. capitata *L. 'Ostinata') dyrket i vandkultur*
II. Næringsstofterapi til regulering af udbyttets størrelse

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Summary

A series of 4 fertilizer experiments was conducted in 1978 and 1979 with lettuce grown in a number of water culture systems under glasshouse conditions. The aim was to develop models of diagnosis, yield prognosis, and therapy.

The recirculating water culture solutions differed as to the initial concentrations of NO_3^-, NH_4^+, $H_2PO_4^-$, and K^+. In each of the 4 experiments the concentrations of 1 or 2 of these nutrients were increased later during the growing period, the so-called top-dressing with the nutrient in question.

In this paper a preliminary model is developed for conditions of N, P, and K deficiency. The model is based on changes in the concentration of N, P, and K in dry matter at a fixed dry matter weight level of 0.5 g per plant as a result of both imaginary and actual top-dressing. The therapy model is valid for the lettuce variety 'Ostinata' grown in water culture with recirculating solution under glasshouse conditions.

The model shows characteristic relationships between the concentrations of N, P, and K in dry matter similar to models developed for other crops (barley, oats, wheat, rice, soybean, and *Hedera*). It has been found that the relationships between initial concentrations of N, P, and K in dry matter and the maximum increment of these concentrations as a result of top-dressing were affected by seasonal factors. It is uncertain to what extent changes of various other growth factors will affect the therapy model.

Key words: Nutritional status, therapy, lettuce, water culture.

Resumé

Der er i 1978 og 1979 gennemført en serie på 4 gødningsforsøg med hovedsalat dyrket i en række vandkultursystemer under væksthusforhold. Formålet var at udvikle modeller for diagnose, udbytteprognose og terapi.

De recirkulerende vandkulturopløsninger omfattede fra forsøgenes begyndelse forskellige koncentrationer af NO_3^-, NH_4^+, $H_2PO_4^-$ og K^+. I hvert af de 4 forsøg blev koncentrationerne af 1 eller 2 af disse næringsstoffer forøget senere i vækstperioden (eftergødskning).

Der er i denne beretning udformet en foreløbig terapimodel for N-, P- og K-mangel. Modellen er baseret på koncentrationsændringer af N, P og K i tørstoffet ved et valgt tørstofvægttrin på 0,5 g pr. plante, som resultat af både imaginær og virkelig udført eftergødskning. Modellen gælder for salatsorten 'Ostinata', når den dyrkes i en recirkuleret vandkulturopløsning under væksthusforhold.

Modellen viser karakteristiske sammenhænge mellem koncentrationerne af N, P og K i tørstoffet svarende til de modeller, som er udformet for andre afgrøder (byg, havre, hvede, ris, sojabønne og *Hedera*). Det påvises, at sammenhængene mellem koncentrationerne af N, P og K i tørstoffet på den ene side og den maksimale forøgelse af disse koncentrationer som resultat af eftergødskning på den anden side påvirkes af årstidsbestemte faktorer. Det er uvist, i hvor høj grad ændringer af andre vækstfaktorer har indflydelse på terapimodellen.

Nøgleord: Ernæringstilstand, terapi, salat, vandkultur.

Introduction

The goal of research in crop production is to increase quantity and improve quality of final yield. In order to achieve this, reliable methods of evaluating and controlling the fertility status of the growth medium and/or the nutritional status of the plant must be worked out. The chemical composition of the young plant may be used as a basis for interpretation and control of the nutritional status of the plant during early growth.

Møller Nielsen (1973) suggested a fixed level of the dry matter weight (DMw) of the young plant as an expression of the developmental stage. He further suggested the pure-effect of a nutrient as an indication of the highest attainable final yield, due solely to the concentration of that nutrient in the aerial parts of the plant at the fixed DMw-level. Based on the boundary line concept, the nutritional status of the young plant was expressed quantitatively in terms of absolute and relative deficiency and excess of various nutrients (*Møller Nielsen,* 1973; *Møller Nielsen & Friis-Nielsen,* 1976a, b, and c).

The method of evaluating the nutritional status includes diagnosis and yield prognosis as presented in the previous paper (*Yoganathan et al.,* 1982). Therapy based on diagnosis and yield prognosis, as dealt with in this paper, is a method to adjust the nutritional status of plants with the aim of getting quantitatively higher and/or qualitatively better final yield (*Møller Nielsen,* 1979 a and b). The main objective in developing therapy models is to attain absolute optimal concentration of every nutrient i.e. absolute optimal chemical composition of the young plant in order to ensure maximum yield.

Experiments have been carried out to develop therapy models for spring sown cereals (*Møller Nielsen,* 1973, 1979 a) in a temperate climate and for rice (*Sumitra,* 1977; *Sumitra & Møller Nielsen,* 1979; *Møller Nielsen,* 1979 c; *Møller Nielsen et al.,* 1979), maize (*Ahmed,* 1978; *Khan,* 1978; *Kumar & Møller Nielsen*) and soybean (*Selvaratnam,* 1977) in a tropical climate, all under field conditions, and for *Hedera helix ssp. canariensis* (*Møller Nielsen & Willumsen,* 1981) under glasshouse conditions.

The aim of the present study is to develop a therapy model for obtaining high yields of lettuce in water culture under glasshouse conditions. The model is developed by determining the effect of various concentrations of one or more nutrients on the chemical composition of the young plant and on final yield.

Materials and methods

A series of 4 fertilizer experiments was conducted with lettuce (*Lactuca sativa var. capitata* L. 'Ostinata') grown in water culture under glasshouse conditions in 1978 and 1979 at the Research Centre for Horticulture, Årslev:

Experiment 1 (sown 14th June – harvested 3rd Aug.):

The experiment was factorial without replications.

The nutrient concentrations of the water culture solutions at the start of the experiment and top-dressing varied as follows:

1. N: 2, 6, and 18 meq NO_3^-/l (no NH_4^+).
2. P: 0.15, 0.45, and 1.35 meq $H_2PO_4^-$/l.
3. K: 0.3, 1.2, and 4.8 meq K^+/l.
4. Top-dressing with N (increase in N conc.) 22 days after sowing:
   0 (control) and 4 meq NO_3^-/l added as calcium nitrate.

Experiment 2 (sown 8th Sept. – harvested 22nd Nov.):

The experiment was factorial without replications.

The water culture solutions at the start of the experiment and the top-dressing varied as follows:

1. Conc. of total N: 2 and 14 meq NH_4^+ + NO_3^-/l.
2. NH_4-N in per cent of total N: 0, 10, 20, 30 and 40%.
3. Top-dressing with N 28 days after sowing:
   0 (control) and 8 meq NH_4^+ + NO_3^-/l.

The $H_2PO_4^-$ and K^+ concentrations were maintained at 0.45 and 3.0 meq/l respectively for all treatments.

Ammonium nitrate and calcium nitrate were used for top-dressing, with the same ratios of NH_4-N to NO_3-N as in the respective initial solutions.

Experiment 3 (sown 8th Sept. – harvested 22nd Nov.):

The initial concentration level of NO_3^- = 2, NH_4^+ = 0, $H_2PO_4^-$ = 0.45, and K^+ = 4 meq/l, common to all the water culture solutions of this experiment, was increased by top-dressing with N, P, or K or with combinations of N and P, N and K, or P and K. The top-dressing took place 26 days after sowing. The variables of top-dresssing, i.e. the increases of the concentration level, were:

N: 4 and 8 meq NO_3^-/l.
P: 0.45 and 0.9 meq $H_2PO_4^-$/l.
K: 4 and 8 meq K^+/l.
N, P: 4 meq NO_3^-/l, 0.45 meq $H_2PO_4^-$/l.
N, K: 4 meq NO_3^-/l, 4 meq K^+/l.
P, K: 0.45 meq $H_2PO_4^-$/l, 4 meq K^+/l.

One water culture solution was not top-dressed (control). All treatments were replicated twice.

The sources of N, P, and K used for top-dressing were calcium nitrate, potassium nitrate, sodium dihydrogen phosphate, potassium dihydrogen phosphate, and potassium sulphate.

Experiment 4 (sown 8th Aug. – harvested 4th Oct.):

The experiment was factorial without replications.

The nutrient concentrations of the water culture solutions at the start of the experiment and the top-dressing varied as follows:

1. N: 0.5, 2, 6, 18, and 54 meq NO_3^-/l.
2. P: 0.15 and 1.35 meq $H_2PO_4^-$/l.
3. Top-dressing with N 33 days after sowing:
   0 (control) and 20 meq NO_3^-/l added as calcium nitrate.

Concentrations of NH_4^+ and K^+ were maintained at 0 and 1.2 meq/l respectively for all treatments.

A description of the experimental conditions and procedures of the four experiments is given by *Yoganathan et al.* (1982).

Results

Final yield of fresh weight

Plants were harvested 50, 75, 75, and 57 days after sowing in the 4 experiments, respectively. Final yield per plant of fresh weight is shown in Tables 1, 2, 3, and 4 for the various treatments of experiments 1, 2, 3, and 4. Generally, the differences in concentrations of N and P in the water culture solutions clearly affected yield while the effect of K was more uncertain (*Yoganathan et al.*, 1982).

In experiments 1, 2, and 4 the effect of top-dressing with different amounts of N (4, 8, or 20 meq/l) on the final yield varied much, but without a clear trend. Also in experiment 3, the effect of top-dressing with N, P, and K or combinations of these nutrients on final yield varied much; the differences were not statistically significant.

Concentrations of nutrients in dry matter

Dry matter weight per plant and concentrations of N, P, and K in dry matter at 5 stages during the growing period are shown in Table 3 for top-dressed and non top-dressed plants of experiment 3. The similar results for top-dressed and non top-dressed plants of the experiments 1, 2, and 4 are not presented in this paper, but may be ordered as 6 separate tables from the secretariat of the Danish Research Service for Plant and Soil Science (Address: Statens Planteavlskontor, Kongevejen 83, DK-2800 Lyngby).

Generally for all four experiments, the concentrations of N, P, and K in dry matter decreased with age. This trend, the so-called dilution effect (*Møller Nielsen & Friis-Nielsen,* 1976 a), was more pronounced in experiments 1 and 4 than in 2 and 3, possibly owing to seasonal factors. The maximum concentrations of N, P, and K in dry matter were higher during the growing periods of the two autumn experiments (2 and 3) than during the summer experiments (1 and 4).

Increased application of N, P, and K at the beginning of the experiments increased the concentration of the applied nutrient in dry matter already in the beginning of the growing period in most cases. Top-dressing with N, P, and K had the same effect, at a later stage of plant growth. These trends are most important for the possibility of making a therapy model.

A fixed dry matter weight of 0.5 g per plant was selected as model level for diganosis as well as therapy. The concentrations of N, P, and K in dry matter at this fixed dry matter weight level are shown in tables 1, 2, 3, and 4 for both non top-dressed and top-dressed treatments. Each of these concentrations is determined from the relationship between dry matter and the concentration of the nutrient in dry matter through a typical part of the growing period, i.e. a time period with characteristic and gradual changes, if any, in the concentration of the nutrient. That is done for every single treatment in the same way as done for each line of the correction model presented in the previous paper (*Yoganathan et al.,* 1982). In most cases in all 4 experiments, 0.5 g dry matter per plant was obtained between 25 and 40 days after sowing.

Therapy model

A therapy model is developed from the results presented in Tables 1, 2, 3, and 4 and based on both early and late top-dressings.

The difference already from the start of an experiment between two initial concentration levels of N, P, or K of two water culture solutions (N, P, and K in experiment 1; N in experiment 2; N and P in experiment 4) constituted a kind of very early top-dressing. This top-dressing, only 6–7 days after sowing, will in the following be referred to as *imaginary top-dressing* of N, P or K.

The later and so-called *actual top-dressings* included N in experiments 1, 2, 3, and 4 and P and K in experiment 3.

Figs 1 and 2 show the basis of the N, P, and K therapy model, in figure 1 derived from imaginary top-dressings, in figure 2 from actual top-dressings.

In Figs 1 and 2, the co-ordinate systems *a, d,* and *g* show the relationship between the initial concentration in dry matter of the nutrient in question at 0.5 g dry matter per plant and the increment of this concentration due to top-dressing with the same nutrient. In each of these co-ordinate systems, the curves show the maximum increments obtained for various concentrations in dry matter as a result of the top-dressing in question. These maximum curves were selected because the largest increment in concentration of the nutrient in the young plant, due to a given application of the nutrient, is associated with the largest increment of the final yield according to Fig. 4 in the previous paper (*Yoganathan et al.,* 1982), provided concentrations of other nutrients are optimal (*Møller Nielsen,* 1973).

Each curve of the co-ordinate systems *b, c, e, f, h,* and *i* in Fig. 1 shows the relationship between concentrations of two nutrients in dry matter at 0.5 g dry matter per plant, starting from one and terminating at another solution concentration of the nutrient of the abscissa axis, taking two of the

Table 1. Concentrations of N, P, and K in % of dry matter (DM) at the fixed ry matter weight of 0.5 g per plant and actual yield of fresh weight per plant. Experiment 1.

Koncentrationer af N, P og K i % af tørstof (TS) på det valgte tørstofvægttrin 0,5 g pr. plante og udbytte i friskvægt pr. plante. Forsøg 1.

Treatment *Behandling*	No top-dressing *Ingen eftergødskning* % of DM at 0.5 g DM/pl. *% af TS ved 0,5 g TS/pl.* N	P	K	Actual yield *udbytte* g/pl.	Top-dressing of 4 meq NO_3^-/l *Eftergødskning med 4 mækv. NO_3^-/l* % of DM at 0.5 g DM/pl. *% af TS ved 0,5 g TS/pl.* N	P	K	Actual yield *udbytte* g/pl.
$N_1P_1K_1$	2.6	0.20	3.0	10	3.8	0.26	4.2	8
K_2	2.1	0.10	2.8	1	3.9	0.20	6.1	8
K_3	2.4	0.08	3.2	1	5.3	0.44	8.8	150
P_2K_1	3.8	0.36	3.6	35	4.9	0.53	5.5	139
K_2	4.9	0.50	5.8	187	5.3	0.67	7.8	209
K_3	5.1	0.50	8.6	194	5.6	0.77	9.6	191
P_3K_1	5.1	0.64	4.2	193	5.3	0.74	6.0	234
K_2	4.6	0.61	7.2	130	5.1	0.68	8.6	180
K_3	4.9	0.70	8.2	212	5.3	0.76	9.2	142
$N_2P_1K_1$	3.1	0.24	4.5	16	3.1	0.16	2.4	4
K_2	3.4	0.36	5.4	35	4.2	0.30	6.2	11
K_3	3.6	0.16	6.4	8	5.5	0.40	9.6	69
P_2K_1	4.0	0.30	1.9	23	4.3	0.44	5.8	32
K_2	5.6	0.54	7.5	255	5.8	0.60	7.0	172
K_3	5.8	0.43	7.5	240	5.9	0.57	9.1	217
P_3K_1	5.3	0.62	5.6	228	5.6	0.76	6.6	239
K_2	5.6	0.54	7.0	91	5.5	0.76	8.2	254
K_3	5.8	0.80	8.6	223	6.0	0.82	9.4	267
$N_3P_1K_1$	5.1	0.38	8.2	139	5.3	0.46	5.8	155
K_2	4.6	0.41	7.8	231	5.4	0.53	7.0	95
K_3	5.2	0.64	7.8	182	5.5	0.50	8.8	49
P_2K_1	5.3	0.58	7.2	218	6.0	0.74	9.0	267
K_2	5.6	0.73	8.4	267	6.0	0.77	7.9	209
K_3	5.8	0.70	9.4	176	5.9	0.72	9.1	259
P_3K_1	5.5	0.58	7.8	266	6.1	0.65	8.0	254
K_2	5.6	0.73	7.8	255	6.1	0.80	8.4	238
K_3	5.8	0.70	7.8	258	6.2	0.75	9.6	228

N_1, N_2, and N_3 = 2, 6, and 18 meq NO_3^-/l.
P_1, P_2, and P_3 = 0.15, 0.45, and 1.35 meq $H_2PO_4^-/l$.
K_1, K_2, and K_3 = 0.3, 1.2, and 4.8 meq K^+/l.

water culture solutions into account (imaginary top-dressing).

Each curve of the co-ordinate systems *b, c, e, f, h*, and *i* in Fig. 2 shows the relationship between concentrations of two nutrients in dry matter at 0.5 g dry matter per plant, starting without and terminating with top-dressing of the nutrient of the abscissa axis. The curves shown include different quantities of actual top-dressing.

When comparing Fig. 1 and Fig. 2 a fairly good agreement is found as to the co-ordinate systems *b, c, e, f, h*, and *i*. They all show clear synergism between the nutrients N, P, and K except in the co-ordinate system *i* of figure 1 for the lowest

Table 2. Concentrations of N, P, and K in % of dry matter (DM) at the fixed dry matter weight of 0.5 g per plant and actual yield of fresh weight per plant. Experiment 2.
Koncentrationer af N, P og K i % af tørstof (TS) på det valgte tørstofvægttrin 0,5 g pr. plante og udbytte i friskvægt pr. plante. Forsøg 2.

Treatment *Behandling*	No top-dressing *Ingen ftergødskning* % of DM at 0.5 g DM/pl. *% af TS ved 0,5 g TS/pl.*			Actual yield *udbytte* g/pl.	Top-dressing of 8 meq $NH_4^+ + NO_3^-/l$ *Eftergødskning med 8 mækv. $NH_4^+ + NO_3^-/l$* % of DM at 0.5 g DM/pl. *% af TS ved 0,5 g TS/pl.*			Actual yield *udbytte* g/pl.
	N	P	K		N	P	K	
N_1R_1	5.9	0.90	8.9	90	6.5	0.96	10.2	83
R_2	6.0	0.80	9.3	88	6.2	0.84	8.8	88
R_3	5.9	0.94	8.7	88	6.3	1.01	9.8	106
R_4	5.9	0.97	10.2	117	6.3	0.99	9.2	79
R_5	5.6	0.94	9.2	80	6.3	0.82	8.6	108
N_2R_1	6.0	0.90	9.0	100	6.4	0.94	10.4	108
R_2	6.2	0.96	9.9	94	6.5	1.00	9.0	88
R_3	6.3	0.98	9.0	125	6.5	0.90	8.5	125
R_4	6.4	0.90	9.2	112	6.7	0.95	8.8	120
R_5	6.5	0.96	8.2	101	6.9	1.02	8.8	113

N_1 and N_2 = 2 and 14 mq $NH_4^+ + NO_3^-/l$.
R_1 R_2, R_3, R_4, and R_5 = 0, 10, 20, 30, and 40% NH_4-N out of total N.
0, 10, 20, 30 og 40% NH_4-N ud af total N.

Table 3. Dry matter weight per plant, concentrations of N, P, and K in dry matter at different stages of growth and at the fixed dry matter (DM) weight of 0.5 g per plant, and actual yield of fresh weight per plant. Experiment 3.
Tørstofvægt pr. plante, koncentrationer af N, P og K i tørstoffet (TS) på forskellige udviklingsstadier og på det valgte tørstofvægttrin 0,5 g pr. plante samt udbytte i friskvægt pr. plante. Forsøg 3.

Treatment *Behandling*	g dry matter/plant *g tørstof/plante* Days after sowing: *Dage efter såning:*					% N in dry matter *N i % af tørstof*				
	18	26	34	46	75	18	26	34	46	75
No Top	0.02	0.04	0.37	1.1	3.0	6.2	6.3	5.9	6.0	5.2
N_1	0.02	0.07	0.40	1.1	3.6	6.4	6.5	6.4	6.1	6.0
N_2	0.02	0.06	0.42	1.2	3.6	6.6	6.3	6.4	6.0	5.8
P_1	0.02	0.06	0.36	1.1	3.2	6.4	6.5	6.4	6.2	6.0
P_2	0.02	0.07	0.43	1.2	3.5	6.3	6.3	6.2	6.1	5.6
K_1	0.02	0.07	0.39	1.3	3.7	6.4	6.5	6.3	6.1	5.4
K_2	0.02	0.08	0.39	1.2	3.3	6.4	6.4	6.3	6.1	6.1
N_1P_1	0.02	0.05	0.38	1.2	3.4	6.3	6.5	6.5	6.1	6.2
N_1K_1	0.02	0.05	0.38	1.2	3.4	6.2	6.4	6.4	6.0	5.8
P_1K_1	0.02	0.06	0.39	1.3	3.5	6.2	5.9	6.3	6.2	6.1

No Top = No Top-dressing *Ingen eftergødskning*
Top-dressing at 26 days after sowing: N_1 and N_2 = 4 and 8 meq NO_3^-/l.
Eftergødskning 26 dage efter såning: P_1 and P_2 = 0.45 and 0.9 meq $H_2PO_4^-/l$.
K_1 and K_2 = 4 and 8 meq K^+/l.

Table 4. Concentrations of N, P, and K in % of dry matter (DM) at the fixed dry matter weight of 0.5 g per plant and actual yield of fresh weight per plant. Experiment 4.

Koncentrationer af N, P og K i % af tørstof (TS) på det valgte tørstofvægttrin 0,5 g pr. plante og udbytte i friskvægt pr. plante. Forsøg 4.

Treatment *Behandling*	No top-dressing *Ingen eftergødskning* % of DM at 0.5 g DM/pl. *% af TS ved 0,5 g TS/pl.* N	P	K	Actual yield *udbytte* g/pl.	Top-dressing of 20 meq NO_3^-/l *Eftergødskning med 20 mækv. NO_3^-/l* % of DM at 0.5 g DM/pl. *% af TS ved 0,5 g TS/pl.* N	P	K	Actual yield *udbytte* g/pl.
N_1P_1	3.9	0.30	5.4	52	4.8	0.78	6.6	20
P_2	4.0	0.60	5.7	43	5.3	0.84	4.6	35
N_2P_1	4.3	0.43	5.6	100	5.3	0.80	6.8	77
P_2	4.7	0.52	6.1	76	5.5	0.86	6.8	91
N_3P_1	4.5	0.49	6.0	116	5.7	0.84	7.3	88
P_2	5.1	0.80	7.8	203	5.7	0.94	7.6	140
N_4P_1	5.0	0.52	6.1	149	5.8	0.86	7.8	167
P_2	5.3	0.82	8.2	189	5.9	0.95	8.6	194
N_5P_1	5.7	0.80	7.8	166	6.2	0.96	9.6	140
P_2	5.8	0.83	8.8	217	6.3	0.96	10.0	207

N_1, N_2, N_3, N_4, and N_5 = 0.5, 2, 6, 18, and 54 meq NO_3^-/l.
P_1 and P_2 = 0.15 and 1.35 meq $H_2PO_4^-$/l.

% P in dry matter *P i % af tørstof* 18	26	34	46	75	% K in dry matter *K i % af tørstof* 18	26	34	46	75	% of DM at 0.5 g DM/pl. *% af TS ved 0,5 g TS/pl.* N	P	K	Actual yield *udbytte* g/pl. 75
0.98	0.96	0.92	1.03	0.83	8.8	9.2	9.9	9.0	9.4	5.8	0.83	8.5	70
1.02	1.00	0.96	0.98	0.86	9.0	9.1	10.1	9.7	10.0	6.1	0.96	9.7	120
1.00	0.96	0.93	1.04	1.01	8.5	8.8	9.8	9.8	9.6	6.4	0.98	9.4	116
1.18	0.99	0.86	0.92	0.90	9.0	8.7	10.3	9.8	9.8	6.2	0.88	7.7	85
1.16	1.03	1.04	0.97	0.92	8.8	9.2	9.8	9.9	10.1	6.3	1.02	9.6	108
1.12	1.00	0.89	0.92	0.75	9.2	9.3	10.2	9.6	9.6	6.2	0.87	9.5	132
1.17	1.12	0.98	0.92	0.80	8.7	8.9	10.7	9.9	10.1	6.2	0.96	10.2	79
1.03	0.99	0.99	0.93	0.85	9.2	9.0	10.4	9.5	9.8	6.2	0.98	9.3	108
0.99	0.99	0.99	0.86	0.82	8.9	8.8	9.3	9.9	10.1	6.3	0.93	9.7	113
0.99	0.92	0.90	0.96	0.83	8.6	9.2	10.4	10.1	10.1	6.1	0.88	10.1	122

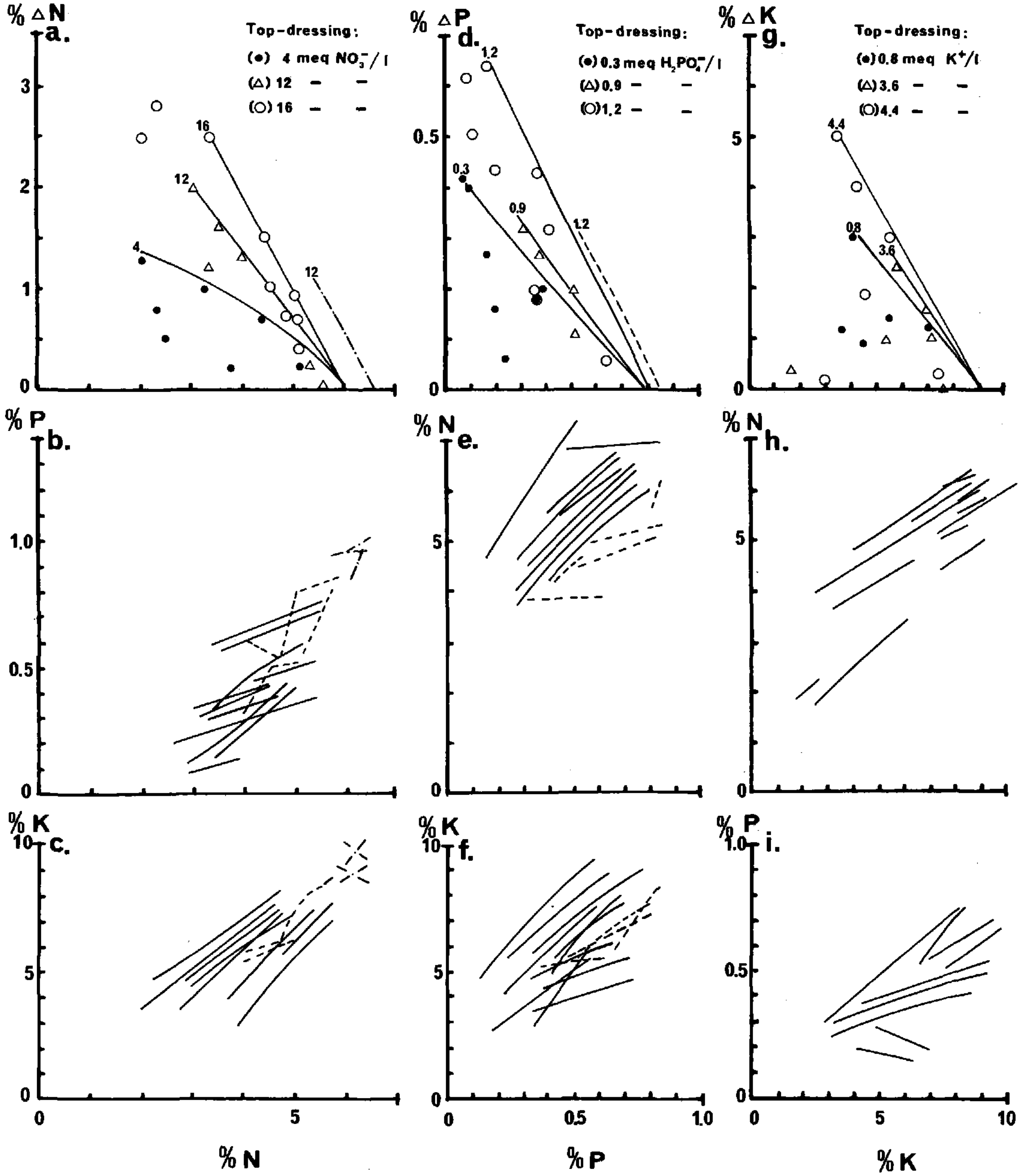

Fig. 1. Basis of N, P, and K therapy model for a fixed dry matter weight of 0.5 g per lettuce plant, based on *imaginary top-dressing*. Experiments 1 (———), 2 (–.–.–), and 4 (-------). Each of the numbers in the co-ordinate systems *a, d,* and *g* refers ot the difference in meq/l between two initial concentration levels of the nutrient in question in two different water culture solutions. The points of the co-ordinate systems *a, d,* and *g* refer to experiment 1 only. N, P, and K are shown as per cent of dry matter.

Grundlag for N-, P- og K-terapimodel gældende for et fastlagt tørstofvægttrin på 0,5 g pr. salatplante og baseret på imaginær forøgelse af næringsstofkoncentrationen *i en vandkulturopløsning. Forsøg 1* (———), *2* (–.–.–) *og 4* (-------). *Hvert af tallene i koordinatsystemerne* a, d *og* g *henviser til forskellen i mækv./l mellem to startkoncentrationer af det pågældende næringsstof i to forskellige vandkulturopløsninger. Punkterne i koordinatsystemerne* a, d *og* g *refererer udelukkende til forsøg 1. N, P og K er angivet i procent af tørstof.*

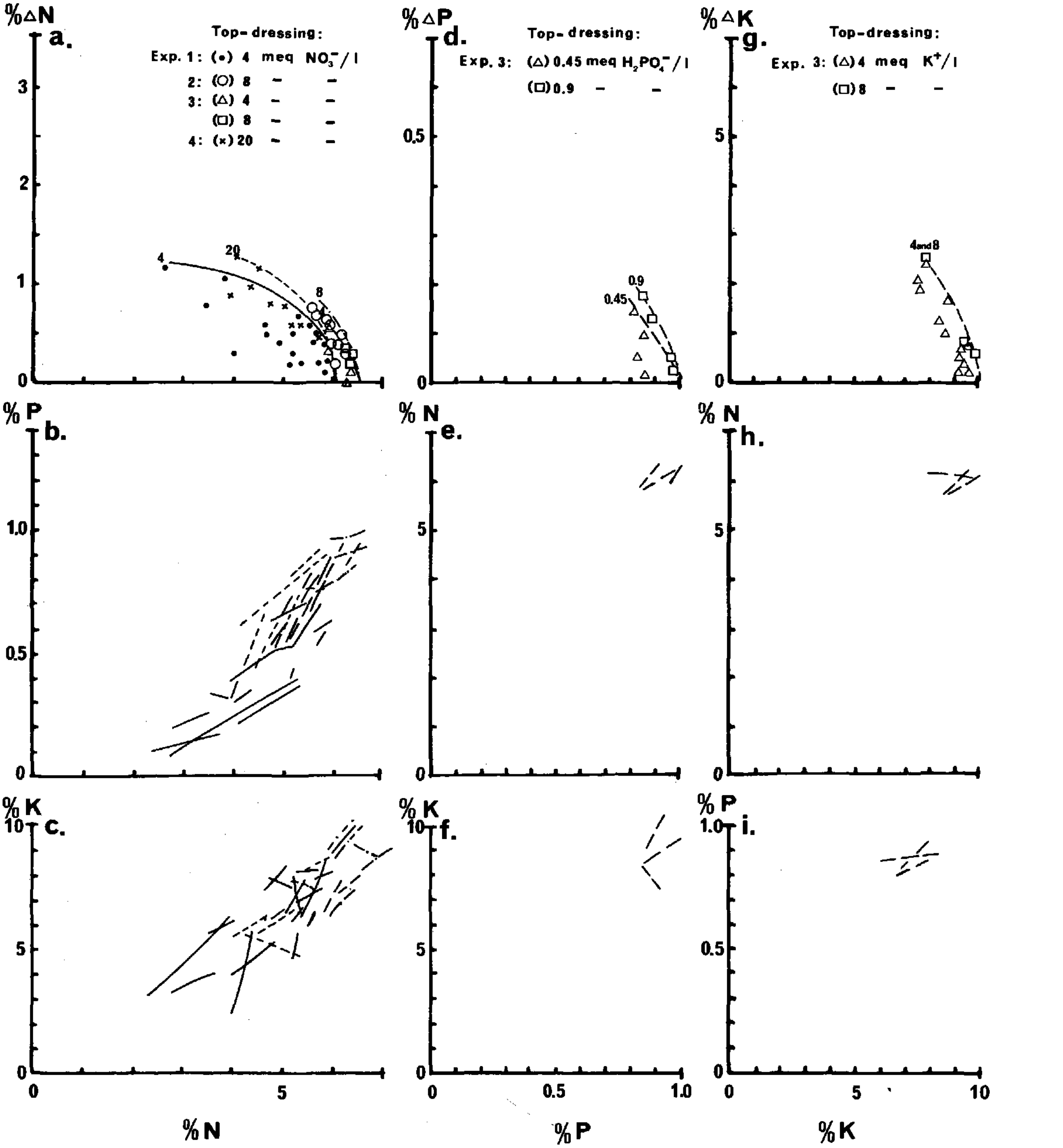

Fig. 2. Basis of N, P, and K therapy model for a fixed dry matter weight of 0.5 g per lettuce plant, based on *actual top-dressing*. Experiments 1 (———), 2 (– .– .–), 3 (– – – –), and 4 (-------). Each number in the co-ordinate systems *a*, *d*, and *g* refers to an actual top-dressing in meq/l, i.e. an increase in concentration of the nutrient in question in one of the water culture solutions. N, P, and K are shown as per cent of dry matter.

Grundlag for N-, P- og K-terapimodel gældende for et fastlagt tørstofvægttrin på 0,5 g pr. salatplante og baseret på virkelig udførte koncentrationsforøgelser *af N, P, og K i vandkulturopløsningerne. Forsøg 1* (———), *2* (– .– .–), *3* (– – – –) *og 4* (-------). *Hvert af tallene i koordinatsystemerne* a, d *og* g *henviser til en forøgelse i mækv./l af det pågældende næringsstofs koncentration i en af vandkulturopløsningerne. N, P og K er angivet i procent af tørstof.*

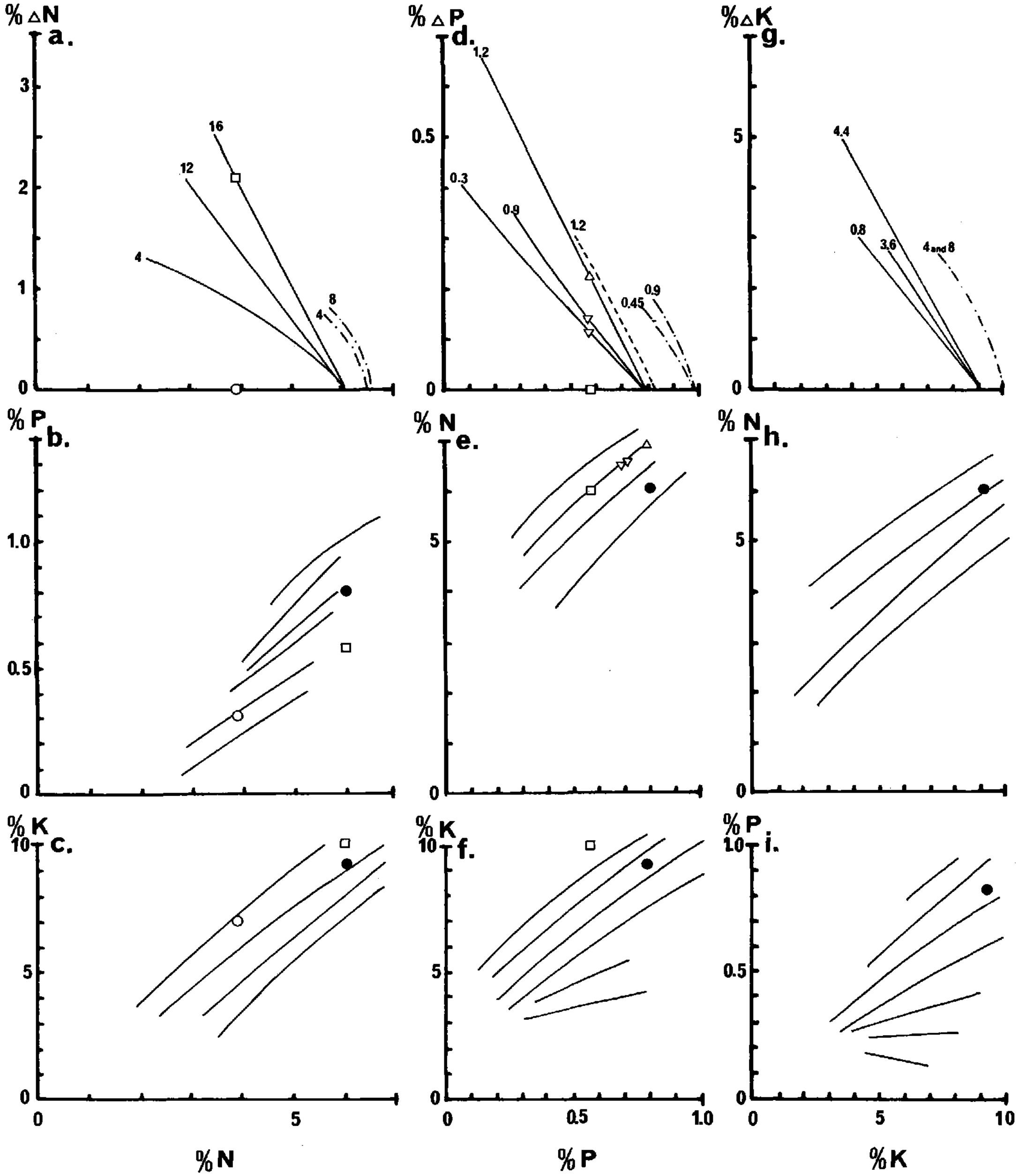

Fig. 3. N, P, and K therapy model for lettuce 'Ostinata' grown in water culture under glasshouse conditions. N, P, and K are shown as per cent of dry matter at 0.5 g dry matter per plant. The numbers in the co-ordinate systems *a, d,* and *g* refer to various quantities of top-dressing presented as increases in concentration of the nutrient in question in the water culture solution (meq NO_3^-, $H_2PO_4^-$ or K^+ per l). The models are derived from Figs 1 and 2. The symbol (●) shows the absolutely optimum concentration of the two nutrients in question for a summer crop (*Yoganathan et al.,* 1982). The symbols (o), (□), (△), and (▽) refer to the example given in the text.

N-, P- og K-terapimodel for salatsorten 'Ostinata' dyrket i vandkultur under væksthusforhold. N, P og K er angivet i procent af tørstof ved 0,5 g tørstof pr. plante. Tallene i koordinatsystemerne a, d *og* g *angiver forskellige muligheder for forøgelse af det pågældende næringsstofs koncentration i vandkulturopløsningen, i mækv.* NO_3^-, $H_2PO_4^-$ *eller* K^+ *pr. l. Modellerne er udviklet på grundlag af figur 1 og 2. Symbolet (●) viser den absolut optimale koncentration af de pågældende to næringsstoffer for en sommerkultur* (Yoganathan et al., *1982). Symbolerne (o), (□), (△) og (▽) refererer til det i teksten givne eksempel.*

a, d, and *g:*

—— valid for *gælder for:* June–July (summer)

------ valid for *gælder for:* Aug.–Sept. (summer–autumn)

–.–.– valid for *gælder for:* Sept.–Oct. (autumn) concentrations of P; here the curves show antagonism between K and P.

When comparing the co-ordinate systems *a, d,* and *g* of Figs 1 and 2 the curves for imaginary and actual top-dressing do not agree very well.

Therefore, it was only possible to combine and generalize the curves of Figs 1 and 2 for the co-ordinate systems *b, c, e, f, h,* and *i*. Fig. 3 shows the generalized curves. In the co-ordinate systems *a, d,* and *g* of Fig. 3, the curves of Figs 1 and 2 considered the most reliable ones are presented, not as generalized curves, but as individual curves obtained in this study. Fig. 3 constitutes the therapy model for N, P, and K, although somewhat uncertain as to the upper 3 co-ordinate systems.

Discussion

Fixed dry matter weight level

Concentrations of nutrients in lettuce plants at an early stage of growth can be determined through chemical analyses 20–30 days after sowing when the plants have attained a reasonable size. By means of the correction model presented by *Yoganathan et al.* (1982), the nutrient concentrations determined can be corrected to the fixed dry matter weight level of 0.5 g per plant, and on the basis of these data possible deficiencies of nutrients can be identified according to the diagnosis model developed by *Yoganathan et al.* (1982).

From the time of plant sampling for determination of nutrient concentrations until the availability of the analysis results, perhaps a week will pass. During that time the plants are in the process of continuous growth, and they will attain a higher dry matter weight than at the time of plant sampling. Therefore, a fixed dry matter weight of 0.5 g per plant from the middle of the growing season (25–40 days after sowing in most treatments in the four experiments) was selected.

When comparing the co-ordinate systems *a* of Figs 1 and 2 it can be seen that the curve for actual top-dressing of 20 meq NO_3^-/l in experiment 4 is more bent than those for imaginary top-dressings. This seems to indicate that the actual top-dressing for the lower concentrations of N in dry matter took place too late to attain optimal chemical composition of the lettuce plants early enough to ensure maximum yield in combination with the shortest possible growing period. It is probable, therefore, that the top-dressings indicated by the therapy model may be done profitably at dry matter weight levels lower than 0.5 g per plant, for instance already at 0.1 g per plant.

Applicability of the models

The curves of Figs 1 and 2, based on imaginary and actual top-dressings, form the basis of the final N, P, and K therapy model of figure 3. N was added as actual top-dressing in all four experiments (one level in each of the experiments 1, 2, and 4 and two levels in 3), while P and K were added as actual top-dressing in experiment 3 only (two levels of P and two levels of K).

When comparing the co-ordinate systems *a, d,* and *g* in Figs 1 and 2, an effect due to season can be identified mainly for the P therapy but also for N and K therapy. The figures show that the maximum nutrient concentrations in dry matter varies with season, the value for summer being lower than that for summer-autumn and autumn, the value for summer-autumn being lower than that for autumn. As a consequence, the curves for autumn were positioned at higher values than those for summer. The same trend has been found for *Hedera* for the P therapy model showing different curves for two different seasons with lower maximum concentration of P in dry matter for summer than for winter (*Møller Nielsen & Willumsen,* 1981).

There was a clear agreement between the curves for summer and autumn conditions shown in the co-ordinate systems *b, c, e, f, h,* and *i* of Figs 1 and 2. Therefore, it was possible to combine and generalize these curves in the final N, P, and K therapy model of Fig. 3. This indicates that the model as to *b, c, e, f, h,* and *i* in Fig. 3 is valid for lettuce grown in different seasons.

The co-ordinate systems *b, c, e, f, h,* and *i* in Fig. 3 show that an increase in concentration of N, P, or K in dry matter due to top-dressing with the respective nutrient is usually followed by an increase in concentration of the other two nutrients in the dry matter. This phenomena agrees with N, P, and K therapy models developed for other crops such as spring wheat and oats (*Møller Nielsen,* 1979a), rice (*Sumitra,* 1977), soybean (*Selvaratnam,* 1977), and *Hedera* (*Møller Nielsen & Willumsen,* 1981) and indicates a general biological rule for the relationships between the concentrations of N, P, and K in the plant. Such a general rule makes transfer of the models to other crops easier.

In the present study, it was not possible to develope a therapy model for conditions of nutrient excesses. Furthermore, it was not possible to find a clear trend in the variation of the concentrations of Na, Mg, and Ca in dry matter as a result of the changes in N, P, and K also in dry matter. Therefore, Na, Mg, and Ca has not been included in the therapy model.

Various ratios of ammonium-N to nitrate-N, from 0 to 2/3, in the water culture solutions did influence the chemical composition of the young lettuce plants of experiment 2 at the very early stages of growth. But the effects were not clear at later stages, because the ratios of ammonium-N to nitrate-N decreased gradually during the growing period. However, the results indicate similar to those from other crops (*Møller Nielsen,* 1973 and 1979 a) that the N source has to be taken into account, when a therapy model for lettuce is developed. Consequently, the therapy model of this paper is valid exclusively for top-dressings without ammonium or with a low concentration of ammonium.

The therapy model (N, P, and K) of Fig. 3 was developed for lettuce in water culture under glasshouse conditions. The top-dressings indicated in the figure refer to increases in nutrient levels in water culture solutions. The question arises whether the curves may also refer to increases in nutrient levels of soil solutions or solutions in other growing media under conditions different from water culture. For a recirculating water culture solution, which continuously passes the roots, the nutrient concentrations required for maximum plant growth are usually lower than the concentrations necessary in cases of more steady solutions in soil, peat, and other growing media (*Olsen,* 1950; *Winsor & Massey,* 1978). Therefore, it seems doubtful to use the here given values of top-dressing for growing methods other than water culture with a recirculating solution.

In general, it is uncertain to what extent changes of growth factors not related to season effect therapy models of N, P, and K, especially factors affecting the availability of the nutrients in the root zone. Among such factors are the pH, the electrical conductivity, the temperature, the chemical composition of the nutrient solution of the root zone, and the physical and chemical properties of the growing medium; rockwool cubes were used as growing medium in the present experiments. All these factors may differ considerably from one crop to another, from one grower to another, and during the growing period of each crop. Further research may clarify this uncertainty.

Practical application of the therapy model

Methods of diagnosis and yield prognosis are of limited interest from a practical point of view if not used in connection with methods of therapy with the aim to obtain a higher quantity and/or a better quality of the final yield. The concentrations of nutrients in aerial parts of lettuce at any stage of growth can be corrected to a fixed dry matter weigth of 0.5 g per plant by the correction model developed in the previous paper (*Yoganathan et al.,* 1982). On the basis of these data, possible deficiencies of nutrients can be identified according to the diagnosis model (*Yoganathan et al.,* 1982), and adjusted by supplementary application of deficient nutrients according to the therapy model of the present paper.

The use of the therapy model can be illustrated by the following example.

Example of nutrient therapy

The same treatment ($N_2P_2K_2$ of experiment 1 – a summer crop) as used in the previous paper (*Yoganathan et al.,* 1982) for the example of diagnosis and yield prognosis is also in the present paper chosen as example in order to show, step by step, how to use the therapy model.

In this example the actual concentrations of N, P, and K in dry matter (DM) are 3.9, 0.32, and 7.0 per cent respectively when corrected to the fixed DM weight level of 0.5 g per plant. According to diagnosis, N deficiency is dominant.

1. The N therapy model, Fig. 3a, shows that in order to obtain optimal N concentration in DM (6.0 per cent), it will be necessary to increase the N concentration in the plant with 2.1% (6.0% – 3.9%) by increasing the N concentration of the water culture solution with 16 meq NO_3^- per litre (symbols o → □ in Fig. 3a).
2. Figs 3b and 3c show that the suggested increase in N concentration will also change the concentrations of P and K in DM (symbols o → □). Comparison with the relatively optimal – here the absolutely optimal – concentrations of P and K (• in Figs 3b and 3c) will predict relative deficiency or excess of P and K:

	Per cent of DM at 0.5 g DM/pl. N	P	K
Initial concentrations	3.9	0.32	7.0
Defic. of dominant nutrient	2.1		
Conc. after sugg. increase of 16 meq NO_3^-/l	6.0	0.58	10.0
Rel. opt. conc. at 6.0% N		0.80	9.1
Relative defic. at 6.0% N		0.22	–0.9

The results indicate relative deficiency of P and relative excess of K. The deficiency of P is now the dominant deficiency.

3. The P therapy model of Fig. 3d shows that in order to obtain optimal P concentration in DM (0.80%), it will be necessary also to increase the P concentration of the water culture solution with 1.2 meq $H_2PO_4^-$/l (symbols □ → △ in Fig. 3d).
4. Figs 3e and 3f show that the suggested increase in P concentration will also change the concentrations of N and K in DM (symbols □ → △). Comparison with the relatively optimal – here the absolutely optimal – concentrations of N and K (• in Figs 3e and 3f) will predict relative deficiency or excess of N and K:

	Per cent of DM at 0.5 g DM/pl. N	P	K
Initial concentrations	6.0	0.58	10.0
Defic. of dominant nutrient		0.22	
Conc. after sugg. increase of 1.2 meq $H_2PO_4^-$/l	6.9	0.80	>10.0
Rel. opt. conc. at 0.80% P	6.0		9.1
Relative excess at 0.80% P	0.9		> 0.9

The results indicate relative excesses of N and K.

5. In order to avoid or reduce the excesses of N and K 2 alternative suggestions of P therapy will be considered (symbols □ → ▽ in Figs 3d, 3e, and 3f):

	Per cent of DM at 0.5 g DM/pl. N	P	K
Initial concentrations	6.0	0.58	10.0
Defic. of dominant nutrient		0.22	
1. Conc. after sugg. increase of 0.9 meq $H_2PO_4^-$/l	6.6	0.72	>10.0
2. Conc. after sugg. increase of 0.3 meq $H_2PO_4^-$/l	6.5	0.69	>10.0
1. Rel. opt. conc. at 0.72% P	5.8		8.6
2. Rel. opt. conc. at 0.69% P	5.7		8.4
1. Relative excess at 0.72% P	0.8		> 1.4
2. Relative excess at 0.69% P	0.8		> 1.6

The results indicate deficiency of P and relative excesses of N and K not smaller than those calculated above.

6. Conclusively, *the recommended therapy* would thus be to increase the N and P concentration of the water culture solution with 16 meq NO_3^-/l and 1.2 meq $H_2PO_4^-$/l.

Conclusion

In this study we have succeeded in developing a preliminary N, P, and K therapy model for a fixed dry matter weight level of 0.5 g per plant with the aim of improving the final yield quantitatively. It seems profitable to use the mode, in combination with the correction model, as early as possible during plant growth, i.e. at dry matter weight levels lower than 0.5 g per plant, for instance at 0.1 g per plant.

The therapy model is valid for the lettuce variety 'Ostinata' grown in water culture with a recirculating solution and under glasshouse conditions. The model is developed for conditions of nutrient deficiencies.

An effect due to season was found in the relationships between initial concentrations of N, P, and K in dry matter and the maximum obtained increment of these concentrations as a result of top-dressing with the nutrient in question: The curves for autumn were positioned at higher values than those for summer.

It is uncertain to what extent changes of various other growth factors, especially factors of importance for the availability of the nutrients in the root zone, affect the therapy model. In future studies the effects of such factors should be studied and if necessary included in the therapy model in order to improve and expand the model.

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Literature

Ahmed, M. (1978): Effect of irrigation and phosphorous fertilization on maize crop in acid sulphate soils. M. Eng. thesis, Asian Inst. of Techn., Bangkok.

Khan, R. (1978): Combined effect of water and nitrogen on maize crop in acid sulphate soil. M. Eng. thesis, Asian Inst. of Techn., Bangkok.

Kumar, V. & Nielsen, J. Møller (under preparation): Nitrogen diagnosis and therapy of maize.

Nielsen, J. Møller (1973): Kornplanters ernæringstilstand vurderet og reguleret ud fra planternes kemiske sammensætning. (The nutritional status of cereals, evaluated and adjusted on the basis of the chemical composition of the plants). Dissertation, DSR Forlag, Royal Vet. Agric. Univ., Copenhagen. 247 pp.

Nielsen, J. Møller & Friis-Nielsen, B. (1976a): Evaluation and control of the nutritional status of cereals. I. Dry matter weight level. Plant and Soil 45, 317–338.

Nielsen, J. Møller & Friis-Nielsen, B. (1976b): Evaluation and control of the nutritional status of cereals. II. Pure-effect of a nutrient. Plant and Soil 45, 339–351.

Nielsen, J. Møller & Friis-Nielsen, B. (1976c): Evaluation and control of the nutritional status of cereals. III. Methods of diagnosis and yield prognosis. Plant and Soil 45, 647–658.

Nielsen, J. Møller (1979a): Evaluation and control of the nutritional status of cereals. IV. Quantity of final yield controlled by nutrient therapy. Plant and Soil 52, 229–244.

Nielsen, J. Møller (1979b): Evaluation and control of the nutritional status of cereals. V. Quality of final yield controlled by nutrient therapy. Plant and Soil 52, 245–268.

Nielsen, J. Møller (1979c): Potential yield levels and fertilizer requirements of high yielding varieties of rice. U.N. report, Geneva.

Nielsen, J. Møller, Payboon, P., Murali, N. S., Sumitra, P. & Alva, A. K. (1979): Paddy fertilization based on chemical composition of the plants. Research report No. 108, Asian Inst. of Techn., Bangkok. 199 pp.

Nielsen, J. Møller & Willumsen, J. (1981): Undersøgelser af vækstfaktorer ved produktion af potteplanter (*Hedera*) i væksthus. V. Introduktion af et kvantitativt gødskningssystem til væksthuskulturer. Tidsskr. Planteavl 85, 259–279.

Olsen, C. (1950): The significance of concentration for the rate of ion absorption by higher plants in water culture. Physiologia Plantarum 3, 152–164.

Selvaratnam, W. V. (1977): Nutrient therapy of soybeans. M. Sc. thesis No. 1262. Asian Inst. of Techn., Bangkok, 94 pp.

Sumitra, P. (1977): Nutrient therapy of paddy. M. Sc. thesis No. 1265. Asian Inst. of Techn., Bangkok.

Sumitra, P. & Møller Nielsen, J. (1979): Study of evaluating the nutritional status of rice plants based on their chemical composition. Thai. J. Agric. Sci. 12, 277–289.

Winsor, G. W. and *Massey, D. M.* (1978): Some aspects of the nutrition of tomatoes grown in recirculating solution. Acta Horticulturae 82, 121–132.

Yoganathan, P., Selvaratnam, W. V. & Willumsen, J. (1982): Evaluation and control of the nutritional status of lettuce (*Lactuca sativa var. capitata* L. 'Ostinata') grown in water culture. I. Models of diagnosis and yield prognosis. Tidsskr. Planteavl 86, 211–226.

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