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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

Vurdering og regulering af ernæringstilstanden hos salat (Lactuca sativa var. capitata *L. 'Ostinata') dyrket i vandkultur*
I. Modeller for diagnose og udbytteprognose

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Summary

Four fertilizer experiments with lettuce (*Lactuca sativa var. capitata* L. 'Ostinata') in water culture were carried out from June to November in 1978 and 1979 in order to develop models of diagnosis, yield prognosis, and therapy. The continuously circulating water culture solutions of the experiments differed as to concentration levels of NO_3^-, NH_4^+, $H_2PO_4^-$, and K^+.

A fixed dry matter weight level of 0.5 g per lettuce plant was selected as basis for the diagnosis and yield prognosis model.

A correction model is developed for concentrations of N, P, K, Na, Mg, and Ca in per cent of dry matter (DM). A diagnosis and yield prognosis model is developed for conditions of nutrient deficiencies. The latter model shows the yield and the relatively optimum concentrations of N, P, K, and Na in DM for various pure-effect concentrations of N, P, and K+½Na in DM.

The models are valid for lettuce 'Ostinata' grown under glasshouse conditions during a summer or an autumn period. It is suggested that the models are valid not only for water culture but also for lettuce grown in soil or other media.

A therapy model is presented in a following paper.

Key words: Nutritional status, diagnosis, yield prognosis, lettuce, water culture.

Resumé

Fire faktorielle gødningsforsøg er i 1978 og 1979 udført med hovedsalat (*Lactuca sativa var. capitata* L. 'Ostinata') dyrket i vandkultur med henblik på at udvikle modeller for diagnose, udbytteprognose og terapi. Forsøgene blev udført under væksthusforhold i perioden juni til november og omfattede forskellige koncentrationsniveauer af NO_3^-, NH_4^+, $H_2PO_4^-$ og K^+ i konstant cirkulerende vandkulturopløsninger.

Et tørstofvægttrin på 0,5 g pr. salatplante er valgt som grundlag for udvikling af modellerne.

En korrektionsmodel er fremstillet for koncentrationer af N, P, K, Na, Mg og Ca i procent af tørstof. En model for diagnose og udbytteprognose er udviklet for tilfælde af næringsstofmangler. Sidstnævnte model viser udbyttet samt de relativt optimale koncentrationer af N, P, K og Na i tørstoffet ved varierende ren ernæringstilstand for N, P eller K+½Na i tørstoffet. Ren ernæringstilstand angiver den absolutte koncentrationsmangel for det næringsstof, der er stærkest mangel på.

De udviklede modeller kan benyttes ved dyrkning af hovedsalat under væksthusforhold i en sommer- eller efterårsperiode. De er formentlig gyldige ikke blot for vandkultur, men også for salat dyrket i jord eller andre medier.

Udvikling af en terapimodel behandles i en efterfølgende beretning.

Nøgleord: Ernæringstilstand, diagnose, udbytteprognose, salat, vandkultur.

Introduction

Development of reliable quantitative fertilization methods which facilitate maximum yields at minimum costs is the basic goal in the field of plant nutrition.

For more than a century attempts have been made to develop useful methods for evaluation (diagnosis) and control (therapy) of the nutritional status of plants based on their chemical composition. Few of them have, however, proved satisfactory due to improper selection of evaluation bases. With the aid of new approaches and techniques more realistic attempts have been made by e.g. *Lagatu & Maume* (1926), *Mazy* (1936), *Lundegårdh* (1941), *Broeshart & Schouwenburg* (1961), *Baier* (1969), *Møller Nielsen* (1971, 1973) and *Beaufils* (1973).

Møller Nielsen (1973) and *Møller Nielsen* and *Friis-Nielsen* (1976 a, b, and c) suggested a *fixed weight level of the dry matter* (DM) of the young plant as an expression of the developmental stage and the *pure-effect* of a nutrient as an indication of the highest attainable final yield, due solely to the concentration of the nutrient in the aerial parts of the plant at the fixed DM weight level. It was defined that pure-effect of K refers to that of K + ½Na. The fixed level of the DM is well defined and integrates the effects of various growth factors. Thus, the recently developed Danish method seems to be founded on well defined and useable bases of evaluation.

The method of *Møller Nielsen* (1973) was originally developed for cereals under Danish conditions. During the past five years the adaptability of the method has been tested on rice and soybean cultivation in Thailand (*Møller Nielsen,* 1977; *Yoganathan,* 1977; *Murali & Møller Nielsen,* 1978). In the present study an attempt has been made to develop a model of diagnosis and yield prognosis for lettuce by using the same concept in order to examine whether similar rules are governing the chemical composition of lettuce plants grown in water culture under glasshouse conditions. In a following paper a model of nutrient therapy will be developed for lettuce grown under the same conditions (*Selvaratnam et al.,* 1982).

Materials and methods

Four factorial fertilizer experiments were 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.

Three of the experiments, No. 1, 2, and 4, will be dealt with in this paper. Experiment 3 exclusively designed for development of therapy models will be described further in the following paper (*Selvaratnam et al.,* 1982).

The nutrient concentrations of the water culture solutions at the start of the experiments were varied as follows:

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

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

(Concentrations of $H_2PO_4^-$ and K^+ were 0.45 and 3.0 meq/l, respectively).

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

(Concentrations of NH_4^+ and K^+ were 0 and 1.2 meq/l, respectively).

In the 3 experiments the treatments were completely randomized without replication.

In all 4 experiments, the initial concentrations of Na^+ varied from 0.7 to 1.6 meq/l, Ca^{++} from 7 to 57 meq/l, and SO_4^{--} from 2.5 to 10.4 meq/l, depending on the concentrations of NO_3^-, NH_4^+, $H_2PO_4^-$, and K^+. The initial concentrations of other nutrients of the water culture solutions were the same for all treatments of the 3 experiments: Cl^- 1.0 meq/l, Mg^{++} 2.2 meq/l, B 0.22 ppm, Fe 2.6 ppm as Fe-EDTA, Mn 0.37 ppm, Zn 1.6 ppm, Cu 0.04 ppm, and Mo 0.05 ppm.

Experimental conditions and procedures

Lettuce seeds were sown in rockwool cubes of the size 4 × 4 × 4 cm. They were watered regularly with a weak nutrient solution (¼ the concentration of the intermediate levels of N, P, and K in experiment 1). 6 or 7 days after sowing the seedlings were transferred to the water culture systems, one system for each treatment.

Each water culture system included a plastic tank and a plastic tray (0.48 m^2) with a thin fibertex sheet in the bottom. A tank contained 25 l of nutrient solution which continuously was pumped into the tray and recirculated. The flow rate at the tray outlet into the tank was 4.5 to 5.0 l/min. The trays were arranged on benches in the ratio of 10 per bench and 2 benches per glasshouse cell.

At the start of the experiments the spacing between seedlings was 5 cm. The plants were gradually thinned during the plant samplings resulting in a spacing of 20 cm between plants at the final stage of the crop.

After the second plant sampling, the plants were transferred to more voluminous rockwool cubes in order to ensure support for the forming heads.

The minimum air temperature inside the glasshouse was maintained at 15°C during the night and at 18°C during the day in experiments 1 and 4. In experiments 2 and 3 the same minimum temperatures were kept during the first month of growth but then they were reduced to 13°C and 16°C and finally to 10°C and 13°C along with the decrease in solar radiation during autumn. – The windows opened at 2°C above the minimum day temperature.

The nutrient solutions were prepared using tap water with a pH of 7.9 and with a chemical composition in meq/l of Ca^{++} 7.0, Mg^{++} 0.8, SO_4^{--} 2.5, Na^+ 0.7, Cl^- 1.0, Zn^{++} 0.05, and HCO_3^- 4.3. These nutrient concentrations are included in the values given for the nutrient solutions. The pH of the solutions was adjusted to 5.5 in experiment 1, initially by using sulphuric acid and during the growing period by using nitric acid. In experiments 2, 3, and 4 a pH of 6.0, 5.5, and 5.5 respectively was maintained during the growing period by using a mixture of nitric and phosphoric acid (N:P = 8:1 on molecular basis).

The every day measurements started with the determination of pH in the water culture solutions. Then tap water was added to bring the water level in the tanks to the 25 l mark. After correcting the pH by adding the acid solution (supplementary solution 1 in Table 1) the electrical conductivities (EC) of the solutions were measured. EC of each plot was corrected to its level at the start of the experiment by adding the supplementary solution 2 (Table 1), which accounts for the nutrient concentrations of the tap water and is composed on the basis of requirement of nutrients (*Willumsen,* 1978; unpublished data).

In the first experiment the EC levels of all the solutions were raised by 0.4 mS/cm 22 days after sowing. This was in order to make allowance for the accumulation of excess ions from tap water (Ca^{++}, Na^{+}, SO_4^{--}, Cl^{-}). In the experiments 2, 3, and 4, the initial electrical conductivity levels were as far as possible maintained throughout the growing period.

Plant sampling and chemical analyses

In all experiments, plant samples were collected five times during the growing period. After measuring the fresh and the dry matter weight of the total aerial parts, the nutrient concentrations in the DM were determined by chemical analysis.

As a control measure, samples of the nutrient solutions were collected three times and analysed for nutrients.

Methods of chemical analysis of plants:

Total N – by spectrophotometer after reduction of nitrate with salicylic acid and sulphuric acid.

P – by spectrophotometer (ammonium molybdate and ammonium vanadate).

K & Na – by flame photometer.

Ca & Mg – by atomic absorption at spectrophotometer.

NO_3-N – by nitrate specific electrode.

Cl – by cloride specific electrode.

Results

Yield

The growing periods were 50, 75, and 57 days in experiments 1, 2, and 4, respectively. Final yield obtained per plant varied from 1 to 267 g fresh weight in the summer experiment, exp. 1 (Table 2), from 80 to 125 g in the autumn experiment, exp. 2 (Table 3), and from 43 to 217 g in the summer-autumn experiment, exp. 4 (Table 4). In experiments 1 and 4, increasing application of N and P had a significant ($P < 0.01$) and positive effect on yield, while increasing application of K in experiment 1 had very little effect on yield.

In experiment 2 only the increased application of total N was found to have a significant effect on yield. Differences in the ratio between NH_4^+ and NO_3^- did not significantly affect yield. However, the yields tended to be highest from the plots with 20 and 30% NH_4-N out of total N.

Concentrations of nutrients in dry matter

The concentrations of N, P, K, Na, Mg, and Ca in dry matter and the corresponding DM weight per

Table 1. Chemical composition of supplementary solutions
Kemisk sammensætning af suppleringsopløsninger

Solution *Opløsning*	Nutrient *Nær.stof*	Experiment *Forsøg* 1 mmol/l	2, 3, and 4 mmol/l	Source *Tilført som*
1	N	54	48	HNO_3
	P	0	6	H_3PO_4
2	N	86	92	KNO_3,$Mg(NO_3)_2 \cdot 6H_2O$
	P	16	10	KH_2PO_4
	K	96	96	KNO_3, KH_2PO_4
	Mg	3	3	$Mg(NO_3)_2 \cdot 6H_2O$
	Fe	1.51	1.51	FeEDTA
	Mn	0.108	0.108	$MnSO_4 \cdot H_2O$
	Cu	0.011	0.011	$CuSO_4 \cdot 5H_2O$
	Mo	0.005	0.005	$Na_2MoO_4 \cdot 2H_2O$
	B	0.322	0.322	H_3BO_3

plant of the aerial plant parts were determined 5 times during each experiment for various levels and combinations of N, P, and K application. All these results are not presented in this paper, but will be commented on shortly below (the results for N, P, and K in DM and the DM weights may be ordered as separate tables from the secretariat of the Danish Research Service for Plant and Soil Science. Address: Statens Planteavlskontor, Kongevejen 83, DK-2800 Lyngby).

In experiment 1, the concentrations of N, P, and K in DM tended to decrease with age. The decreases were probably due to an increasing DM production relative to that of nutrient uptake, often referred to as the dilution effect (*Møller Nielsen & Friis-Nielsen,* 1976 a).

Comparing the different treatments of experiment 1, the effects of application of nutrients on the concentrations of N, P, and K in DM were found to be rather clear. Thus in most cases, increased application of N, P, and K increased the concentration of the applied nutrient in DM. Also, an increased application of one nutrient was found to increase the concentration of the other two nutrients in DM, particularly at the lowest level of application of the other two nutrients. Especially the application of N had a very significant effect on the concentration of K in DM. In the light of these relationships it seems possible and justified to develop diagnosis and therapy models for lettuce based on the present results of plant analyses.

In experiment 2 higher concentrations of N and P in DM were found than in the first experiment. Increased application of N had a significant and positive effect on the concentration of N in DM. The percentage of K in DM was decreased by the presence of NH_4^+ ions in the water culture solution. This antagonistic effect of NH_4^+ ions on the uptake of K^+ ions was clearest during the earliest stages of growth. Later in the growing period the effect disappeared along with a gradual depletion of NH_4^+ in the solutions. The effects of N source are, however, not as important for the development of models of diagnosis and prognosis as for therapy models (*Møller Nielsen,* 1973). Therefore, the question of N source will not be further dealt with until the following paper concerning therapy models (*Selvaratnam et al.,* 1982).

In experiment 4 the concentrations of N, P, and K in DM followed the same trends as in experiment 1 except that the concentration of P in DM in many cases increased with time.

Fixed dry matter weight level

For lettuce 0.5 g DM per plant was selected as the fixed DM weight level, because it represents a young stage of the lettuce crop with clear differences in the nutrient concentrations in DM. In most cases in all 3 experiments, 0.5 g DM per plant was obtained between 25 and 40 days after sowing. Further details about the selection of the fixed DM weight level are given by *Selvaratnam et al.* (1982).

Correction model

The nutrient concentrations in DM and the corresponding DM weights at the various sampling dates during plant growth were used to develop a DM correction model for N, P, K, Na, Mg, and Ca. The purpose of such a model is to correct nutrient concentrations at any obtained DM weight of a young plant to their expected value at the selected fixed DM weight level. For all 3 experiments the actual relationships between DM weight per plant and the nutrient concentrations in DM are shown in Fig. 1. Each curve of Fig. 1 is smoothed out to eliminate the effects of irregular variations of the nutrient concentrations of the water culture solutions.

The relationships of Fig. 1 are generalized in Fig. 2, which constitutes the correction model. The fixed DM weight level of 0.5 g per plant is marked in the model.

Diagnosis and yield prognosis model

Fig. 3a shows for the 3 experiments the relationships between final yield per plant and concentrations of N, P, and K+½Na in DM at the fixed DM weight of 0.5 g per plant. In the case of lettuce, the complementary effect between Na and K was found to be high. The concentration of K was therefore, as for other crops (*Møller Nielsen,* 1973), replaced by the percentage of K+½Na.

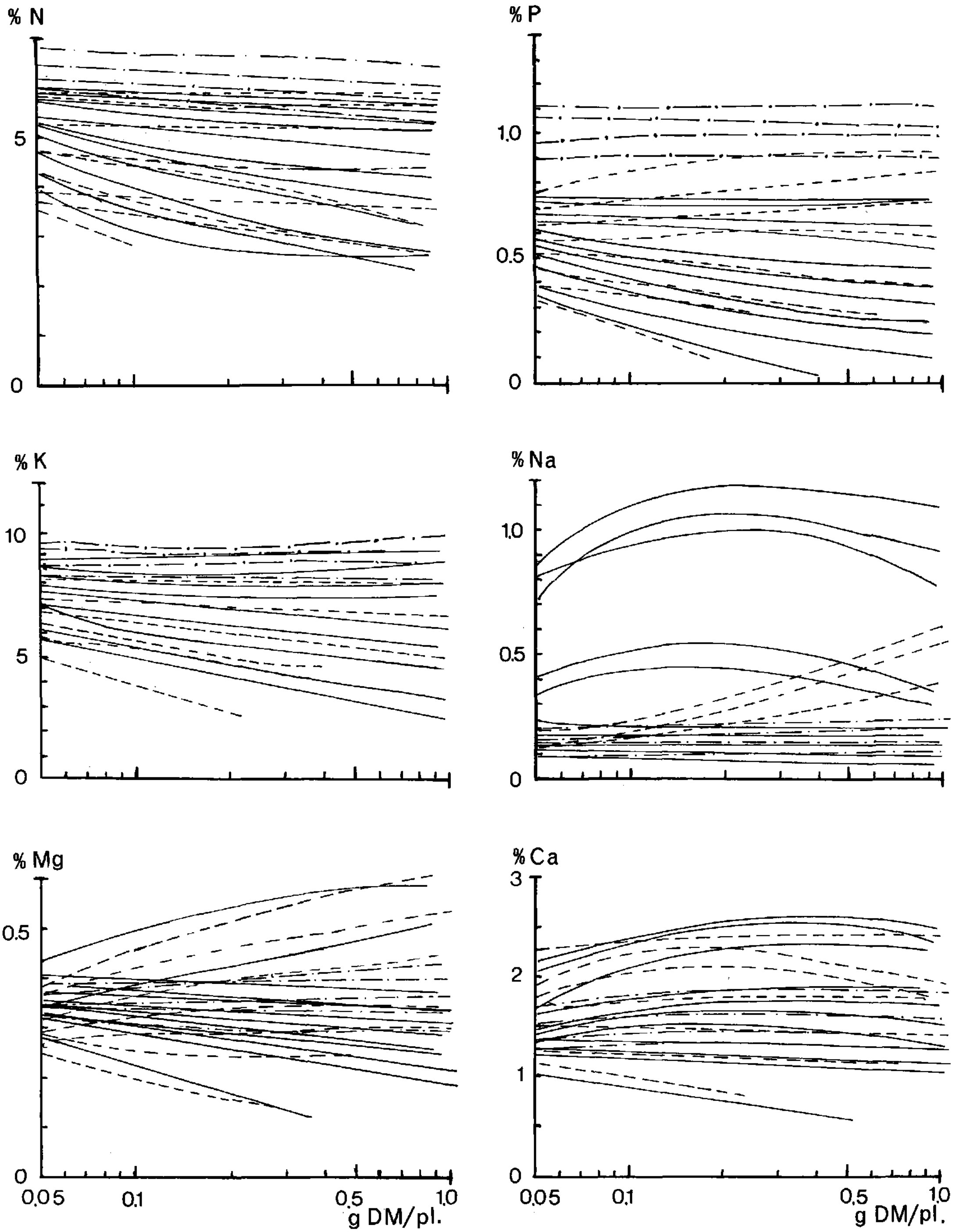


Fig. 1. Basis of correction model for N, P, K, Na, Mg, and Ca in dry matter (DM) of lettuce 'Ostinata'. Experiments 1 (——), 2 (–.–.–), and 4 (------).

Grundlag for korrektionsmodel for N, P, K, Na, Mg og Ca i tørstoffet (DM) hos salatsorten 'Ostinata'. Forsøg 1 (——), 2 (–.–.–) og 4 (------).

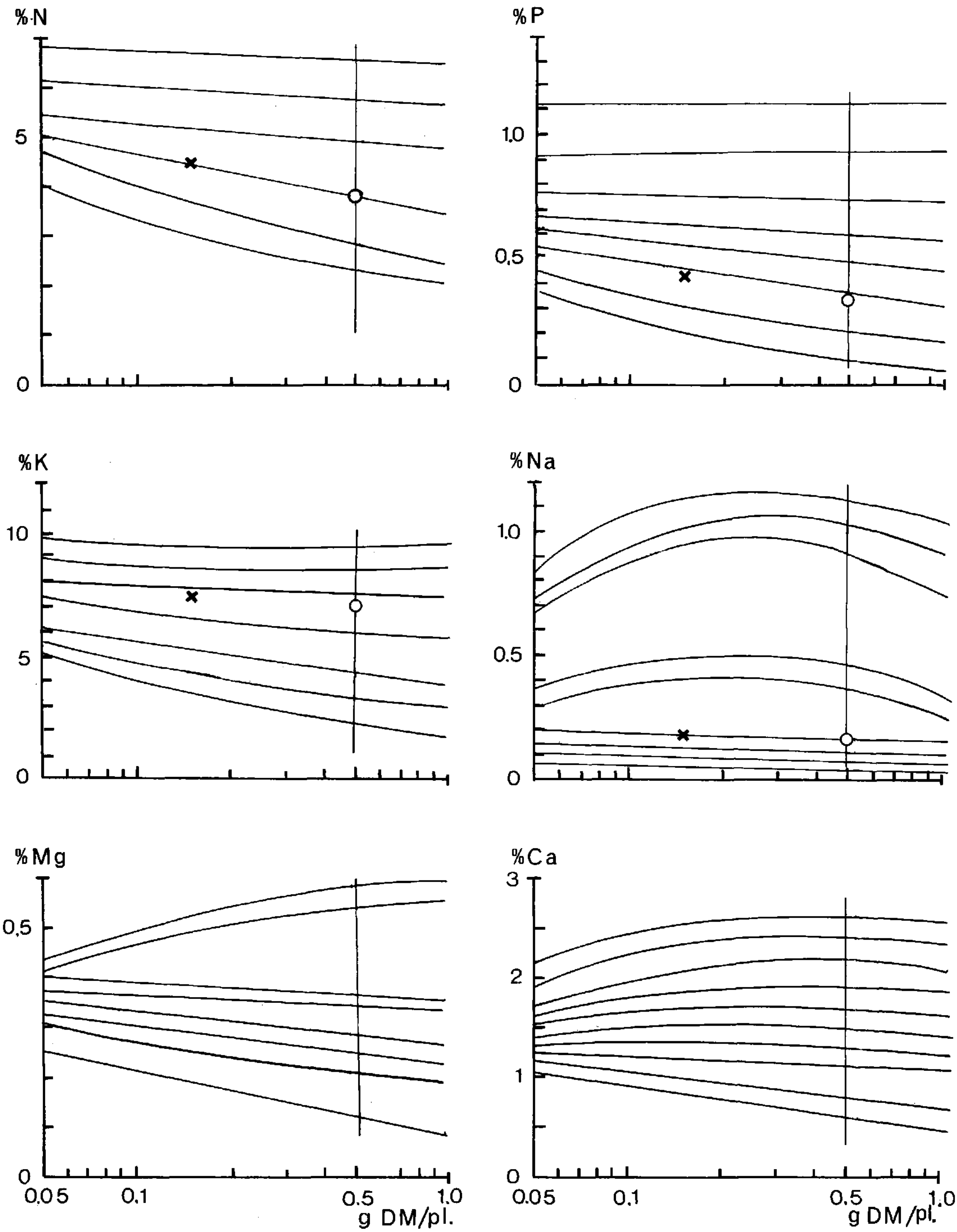


Fig. 2. Correction model for N, P, K, Na, Mg, and Ca in dry matter (DM) of lettuce 'Ostinata' based on the experiments 1, 2, and 4. The symbols (x) and (o) refer to the example given in the text.

Korrektionsmodel for N, P, K, Na, Mg og Ca i tørstoffet (DM) hos salatsorten 'Ostinata', baseret på forsøg 1, 2 og 4. Symbolerne (x) og (o) refererer til det i teksten givne eksempel.

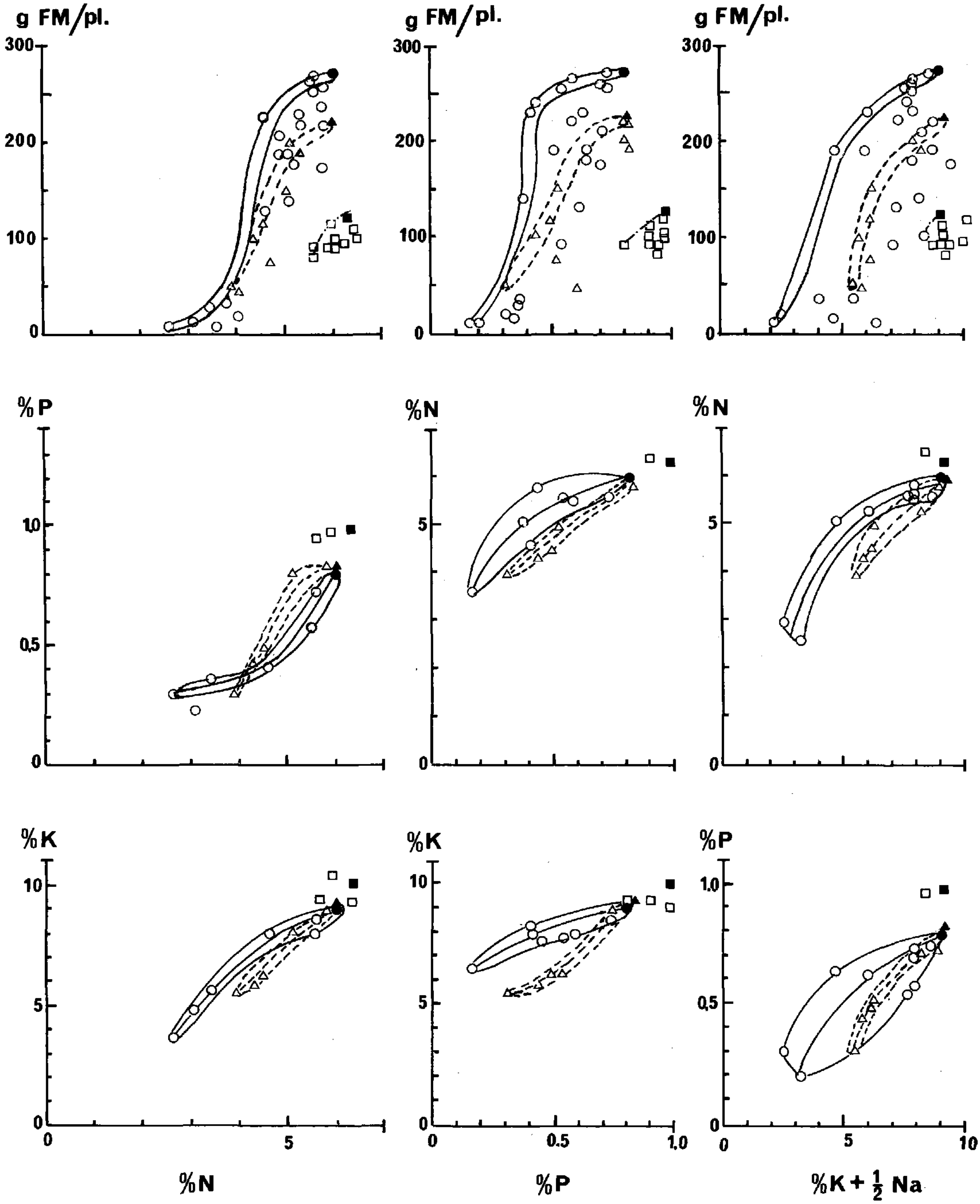
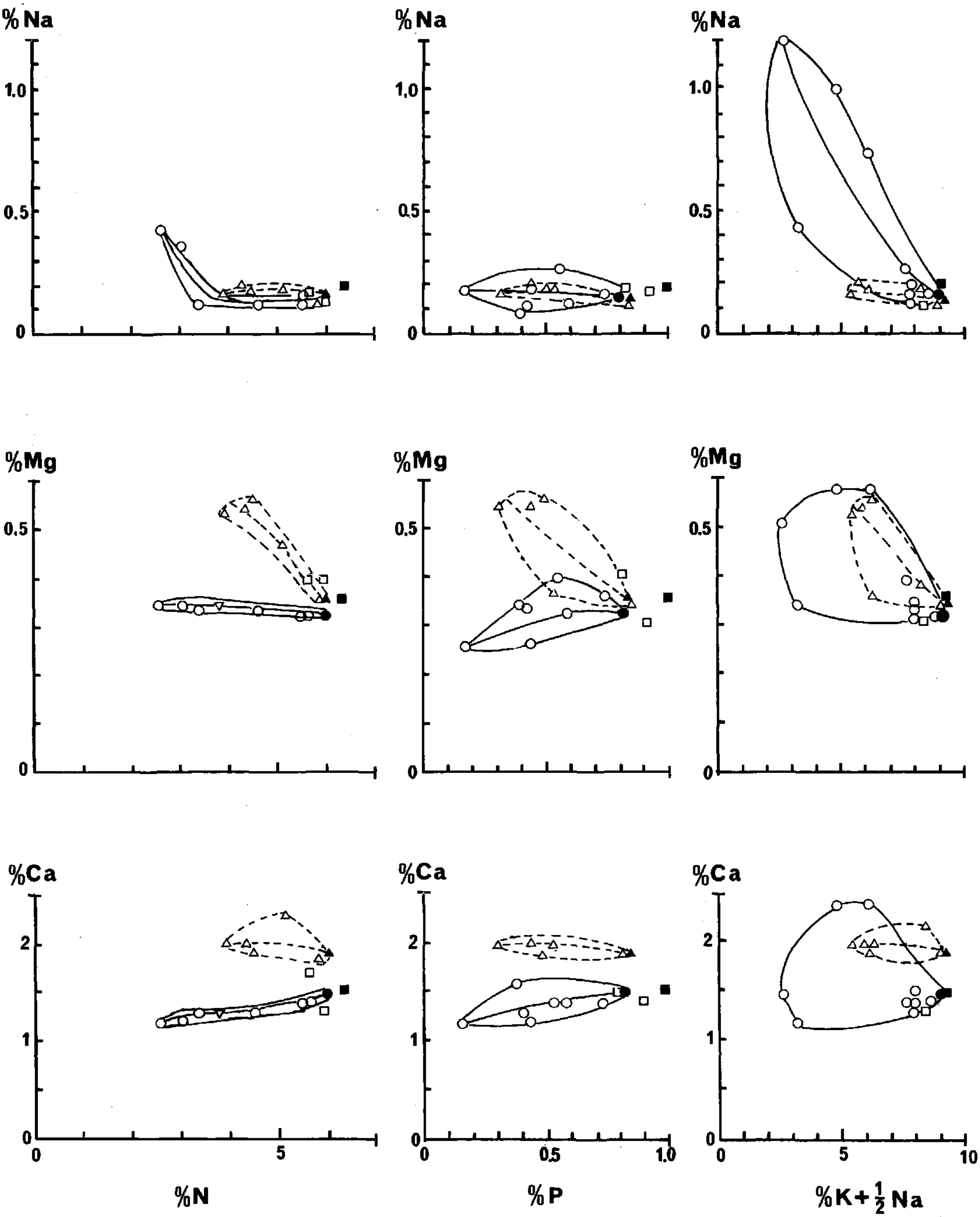


Fig. 3 a and b. Basis of diagnosis and yield prognosis model for lettuce 'Ostinata'. – Yield as g fresh matter (FM) per plant is related to nutrient concentrations in dry matter (DM) at the fixed DM weight level of 0.5 g per plant. Absolutely optimum concentrations (●, ■, ▲), areas of pure-effect concentrations of N, P, and K+½Na, and areas of relatively optimum concentrations of N, P, K, Na, Mg, and Ca are shown.

Grundlag for model til diagnose og udbytteprognose for salatsorten 'Ostinata'. – Udbytte i g friskvægt (FM) per plante i relation til næringsstofkoncentrationer i tørstoffet på det fastlagte tørstofvægttrin 0,5 g per plante. Absolut optimale næringsstofkoncentrationer (●, ■, ▲), arealer for renvirkninger af N, P og K+½Na og arealer for relativt optimale koncentrationer af N, P, K, Na, Mg og Ca er vist.

Experiment	1: ——	, abs. opt. conc. ●
Forsøg	2: –.–.–	, abs. opt. conc. ■
	4: -------	, abs. opt. conc. ▲


%Na
1.0
0.5
0
%Na
1.0
0.5
0
%Na
1.0
0.5
0
%Mg
0.5
0
%Mg
0.5
0
%Mg
0.5
0
%Ca
2
1
0
%Ca
2
1
0
%Ca
2
1
0
0
5
0
0.5
1.0
0
5
10
%N
%P
%K + ½ Na

The boundary line areas shown in the figure for the relationships between yield and N, P, and K+½Na indicate the pure-effect concentrations of these nutrients. The pure-effect is defined as the highest attainable final yield, due solely to the concentration of the nutrient in question. The points inside the selected boundary line areas form the bases for determining the relatively optimum concentrations of other nutrients. These relationships between pure-effect concentrations of N, P, and K+½ Na and relatively optimum concentrations of other nutrients (N, P, K, Na, Mg, and Ca) are presented in Figs 3a and 3b. The relationships are shown as more or less narrow areas with a median in each area to represent the estimated true relationship. – The absolutely optimum concentrations of N, P, K, Na, Mg, and Ca are shown in the figures for each of the experiments.

The shapes of the boundary line areas of experiment 1 in the upper 3 coordinate systems of Fig. 3a are very similar to those of experiment 4. The only difference is the yield levels.

The boundary lines of experiment 2 are more uncertain, but it is important to notice that the yield level of this experiment is much lower than those of the other 2 experiments. The reason is that the lettuce in experiment 2 was harvested in November. At that time of the year, when the day lenght is short and the solar radiation is low, the commercial glasshouse growers usually harvest lettuce at a lower weight level than during times of the year with more solar radiation. This practice was followed in the experiments. Experiment 2 also differed from experiments 1 and 4 in another way. The absolutely optimum concentrations of N and P in DM were higher.

Figs 3a and 3b show that the relationships between pure-effect concentrations of N, P, and K+½Na and relatively optimum concentrations of N, P, K, and Na are narrow and almost coincide when comparing the 3 experiments. The relationships show clear synergism between N, P, and K, but antagonism between K and Na. Increase in the concentration of N caused a decrease in the concentration of Na through the synergism between N and K and the antagonism between K and Na.

The relationships in Fig. 3b between pure-effect concentrations of N, P, and K+½ Na and relatively optimum concentrations of Mg and Ca are not quite clear when taking all 3 experiments into account. Either the relationships are not narrow or they do not coincide from one experiment to the other. For instance the relationship between P and Mg shows synergism in experiment 1, but antagonism in experiment 4. The reasons for the discrepancies are not known.

The relationships of Figs 3a and 3b are combined and generalized in Figs 4a and 4b excluding the relationships between pure-effect concentrations of N, P, and K+½Na and the relatively optimum concentrations of Mg and Ca on account of their uncertainty. Figs 4a and 4b present the model of diagnosis and yield prognosis for the lettuce variety 'Ostinata'. The figures show different relationships between yield and pure-effect concentrations of N, P, and K+½ Na corresponding to 3 different crops sown on the dates: 14th June, 8th August, and 8th September. The relationships between pure-effect concentrations of N, P, and K+½Na and relatively optimum concentrations of N, P, K, and Na are common for all 3 crops except the relationship between K+½ Na and P. In this case the relationship for the crop sown on 8th September is positioned at a higher level than for the other 2 crops.

The absolutely optimum concentrations of N, P, and K+½ Na at 0.5 g DM per plant corresponding to a maximum yield of 275 g fresh weight per plant of a summer crop or 225 g of a summer-autumn crop are marked in the models of Figs 4a and 4b and have the values of 6.0, 0.83, and 9.2% of DM respectively. The similar absolutely optimum concentrations of N, P, and K+½ Na corresponding to a maximum yield of 125 g fresh weight per plant of an autumn crop are also shown and have the values of 6.3, 0.98, and 9.1 per cent of DM respectively.

Discussion

The relationships between the pure-effect concentrations of N, P, and K+½ Na and the relatively optimum concentrations of N, P, K, and Na in Figs 3a and 3b are sufficiently clear and narrow to form the basis of a diagnosis model. The trends, shapes, and positions of the curves and areas show close similarities to those obtained with spring sown cereals (*Møller Nielsen,* 1973) and other crops (*Møller Nielsen,* 1977). Thus, the selected relationships have shown the necessary and sufficient characteristics for the development of a diagnosis and yield prognosis model for lettuce.

Figs 4a and 4b show the model of diagnosis and yield prognosis developed for summer and autumn grown lettuce. The model clearly demonstrates the relationships between final yield and chemical composition of young lettuce plants and the relationships between concentrations of various nutrients in the dry matter. However, since the models are based on the boundary line concept, which demands a great number of experimental data, future additional results from lettuce experiments may improve and expand the models of Figs 2 and 4. Extension of the models into the region of nutrient excess was not possible from the results obtained in this study.

Due to the various levels of maximum yield in the different seasons, time of the year has to be included as a factor in a diagnosis and yield prognosis model for lettuce, similar to a model developed for *Hedera canariensis* (*Møller Nielsen & Willumsen,* 1981). This is clearly demonstrated in the present paper. However, whether the maximum yield level is higher or lower does not really matter, if using the model for diagnosis solely. It is the relationships between the nutrients which are important in this context. We found that the selected relationships between nutrient concentrations in DM are common in most cases for summer and autumn conditions. An exception is the higher absolutely optimum concentration of P for an autumn crop compared to a summer crop.

The similarity in the selected relationships for lettuce 'Ostinata' and other crops grown under various conditions seems to indicate that the models of diagnosis are valid not only for water culture but also for lettuce grown in soil or other media and possibly valid for a number of lettuce varieties.

The use of the models is described in detail by *Møller Nielsen* and *Friis-Nielsen* (1976c) and, in addition, illustrated by the following example.

Example of diagnosis and yield prognosis

One of the treatments of the summer experiment (exp. 1) – $N_2P_2K_2$ (top-dressed with N 22 days after sowing) – is chosen as an example in order to show, step by step, how to use the correction model and the diagnosis and yield prognosis model.

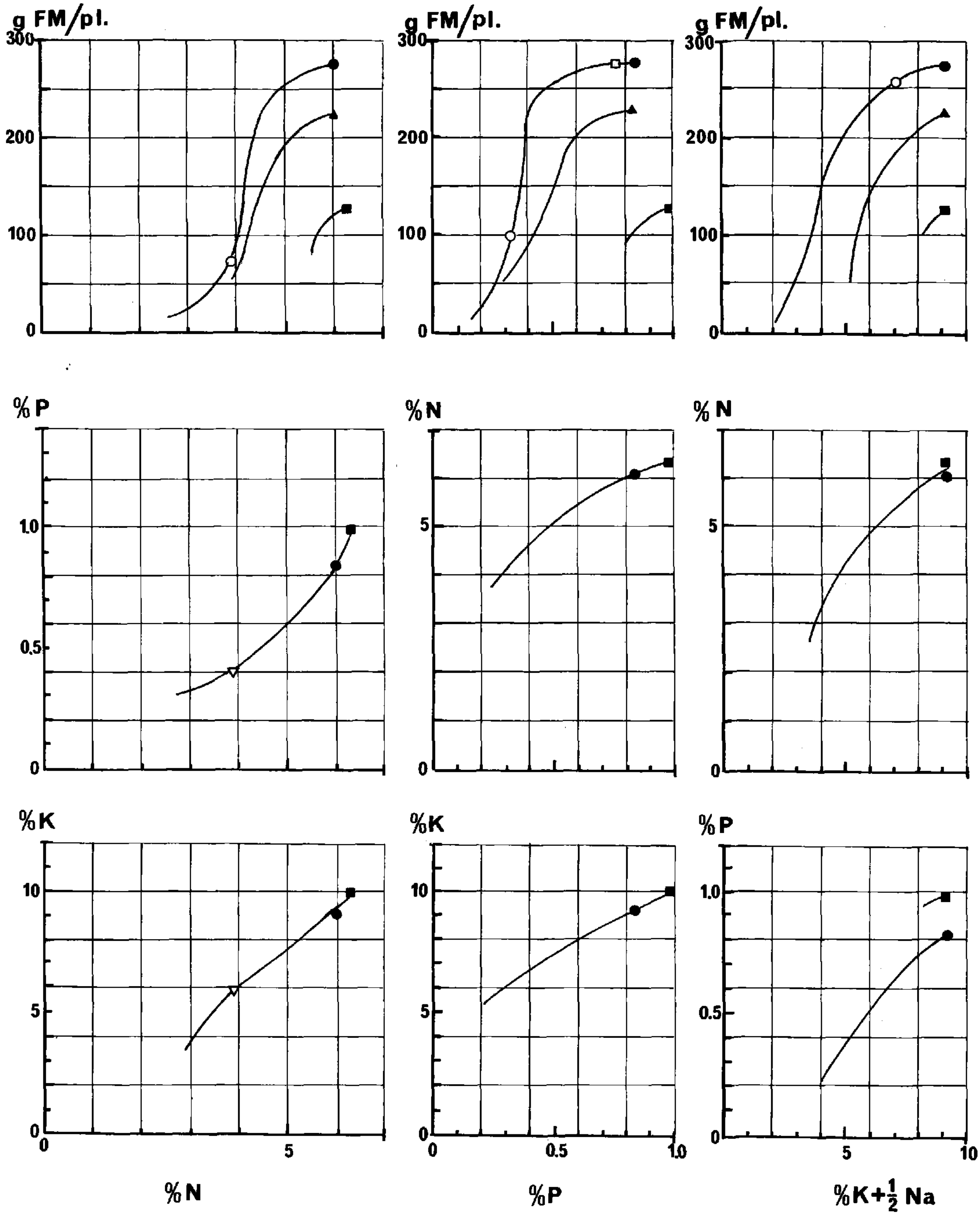
For the selected treatment nutrient concentrations in DM were determined by chemical analyses at a DM weight of 0.15 g per plant obtained 22 days after sowing. The concentrations of N, P, K, and Na were 4.5, 0.42, 7.4, and 0.18% of DM, respectively.

1. By use of the correction model Fig. 2 the above nutrient concentrations (crosses in Fig. 2) valid for a DM weight of 0.15 g per plant are corrected to the fixed DM weight level of 0.5 g per plant = the corrected concentrations (open circles in Fig. 2).
2. Estimation of absolute deficiency.

	Per cent of DM at 0.5 g DM/pl.				
	N	P	K	Na	K+½Na
Absolutely optimum conc. (• in Fig. 4)	6.0	0.83			9.2
Corrected conc. (o in Figs. 2 and 4)	3.9	0.32	7.0	0.17	7.1
Absolute deficiency	2.1	0.51			2.1

The results indicate absolute deficiencies of N, P, and K+½Na.

3. Finding of the dominant deficiency.
As shown by the open circles in Fig. 4a the corrected concentrations of N, P, and K+½ Na correspond to yields of 75, 100, and 255 g fresh weight per plant respectively if the corrected concentration represents the pure-effect concentration of the nutrient in question. The N deficiency indicates the lowest yield. Therefore, N deficiency was dominating.



g FM/pl.
300
200
100
0
g FM/pl.
300
200
100
0
g FM/pl.
300
200
100
0
% P
1.0
0.5
0
% N
5
0
% N
5
0
% K
10
5
0
% K
10
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1.0
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5
10
% N
% P
% K + ½ Na

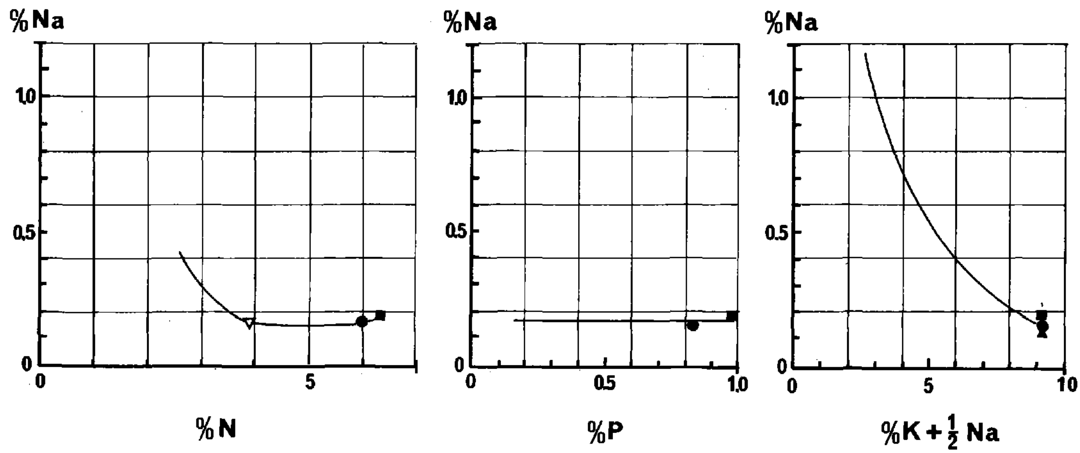

Fig. 4 a and b. Diagnosis and yield prognosis model for lettuce 'Ostinata' grown under glasshouse conditions. Yields are shown as g fresh matter (FM) per plant and the nutrient concentrations as per cent of dry matter (DM) at 0.5 g DM per plant. The absolutely optimum concentrations (●, ▲, ■) are shown. The symbols (o), (▽), and (□) refer to the example given in the text.

Model til diagnose og udbytteprognose for salatsorten 'Ostinata' dyrket under vækshusforhold. Udbytter er vist som g friskvægt (FM) per plante og næringsstofkoncentrationer som procent af tørstof ved 0,5 g tørstof pr. plante. De absolut optimale koncentrationer (●, ▲, ■) er vist. Symbolerne (o), (▽) og *(□) refererer til det i teksten givne eksempel.*

-● valid for *gælder for:* June–July (summer)
-▲ valid for *gælder for:* Aug.–Sept. (summer–autumn)
-■ valid for *gælder for:* Sept.–Oct. (autumn)

4. Estimation of relative deficiency.

	Per cent of DM at 0.5 g DM/pl.		
	P	K	Na
Relatively optimum conc. for pure-effect of 3.9% N (▽ in Fig. 4)	0.40	5.9	0.17
Corrected conc. (o in Figs 2 and 4)	0.32	7.0	0.17
Relative deficiency	0.08	−1.1	0

At the corrected N concentration of 3.9%, the relatively optimum concentrations compared to the corrected concentrations indicate a relative deficiency of P and a relative excess of K.

5. Thus the *diagnosis* is:
Absolute deficiency: N: 2.1% of DM.
Relative deficiency: P: 0.08% of DM.
Relative excess: K: 1.1% of DM.

6. Reduction in yield relative to maximum yield of a summer crop (275 g fresh weight per plant), due to the above estimated relative deficiency of P, is calculated by using the yield curve for P in Fig. 4a (symbol □):

Rel.defic. % of DM	Corresp. yield, g/pl.	Reduction of max. yield g/pl.	%
P: 0.08	273	2	1

7. Estimation of yield.
Due to the deficiency of N (dominant nutrient) yield is expected to be reduced to 75 g fresh weight per plant (symbol o in Fig. 4a). Due to the deficiency of P yield is expected to be reduced by 1 per cent of 75 g = about 1 g to 74 g per plant.

8. *Yield prognosis.*
74 g fresh weight per plant after a growing period – from sowing to harvest – of 50 days for a summer grown lettuce.

Actually obtained yield:

172 g fresh weight per plant after a growing period of 50 days from June to August, which is more than predicted by the yield prognosis. The reason is probably that the plants were top-dressed with 4 meq NO_3^-/l 22 days after sowing (Table 1 of the following paper, *Selvaratnam et al.*, 1982).

Conclusion

The correction model and the diagnosis and yield prognosis model presented in this paper for conditions of nutrient deficiencies are valid for the lettuce variety 'Ostinata' when grown under glasshouse conditions during a summer or an autumn period. The diagnosis and yield prognosis model shows that the absolutely optimum concentrations of N and P in DM at the fixed DM weight level of 0.5 g per plant are 5 and 18% higher, respectively, during autumn than during summer.

It is suggested that the models are unaffected by various growth factors such as type of growing medium. Future experimental results may improve and expand the models, for instance by taking more nutrients into account as well as conditions of nutrient excesses. It also has to be clarified to what extent the present models are valid for winter and spring grown lettuce and for other lettuce varieties.

A quantitative control of the nutritional status of young lettuce plants through a therapy model with the ultimate aim of improving the yield will be treated in the following paper (*Selvaratnam et al.*, 1982).

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Table 2. Concentrations of N, P, K+½ Na, Na, Mg, and Ca 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 1
Koncentrationer af N, P, K+½Na, Na, Mg og Ca i % af tørstof (TS) på det valgte tørstofvægttrin 0,5 g pr. plante og udbytte i friskvægt pr. plante. Forsøg 1

Treatment *Behandling*	% of DM at 0.5 g DM/plant *% af TS ved 0,5 g TS/plante*						Actual yield *Udbytte*
	N	P	K+½Na	Na	Mg	Ca	g/pl.
$N_1P_1K_1$	2.6	0.20	3.2	0.42	0.34	1.2	10
K_2	2.1	0.10	2.9	0.12	0.19	1.3	1
K_3	2.4	0.08	3.3	0.18	0.09	0.7	1
P_2K_1	3.8	0.36	4.1	0.90	0.58	2.4	35
K_2	4.9	0.50	5.9	0.24	0.39	1.5	187
K_3	5.1	0.50	8.7	0.18	0.40	1.3	194
P_3K_1	5.1	0.64	4.7	1.00	0.58	2.4	193
K_2	4.6	0.61	7.3	0.12	0.48	2.4	130
K_3	4.9	0.70	8.3	0.15	0.36	1.8	212
$N_2P_1K_1$	3.1	0.24	4.7	0.36	0.34	1.2	16
K_2	3.4	0.36	5.5	0.12	0.33	1.3	35
K_3	3.6	0.16	6.5	0.18	0.25	1.2	8
P_2K_1	4.0	0.30	2.5	1.20	0.51	1.5	23
K_2	5.6	0.54	7.6	0.26	0.39	1.4	255
K_3	5.8	0.43	7.6	0.18	0.26	1.2	240
P_3K_1	5.3	0.62	6.0	0.74	0.58	2.4	228
K_2	5.6	0.54	7.1	0.20	0.48	2.7	91
K_3	5.8	0.80	8.7	0.15	0.36	2.1	223
$N_3P_1K_1$	5.1	0.38	8.2	0.08	0.34	1.6	139
K_2	4.6	0.41	7.9	0.12	0.33	1.3	231
K_3	5.2	0.64	7.9	0.14	0.36	1.6	182
P_2K_1	5.3	0.58	7.3	0.16	0.33	1.7	218
K_2	5.6	0.73	8.5	0.16	0.32	1.4	267
K_3	5.8	0.70	9.5	0.18	0.34	1.5	176
P_3K_1	5.5	0.58	7.9	0.12	0.32	1.4	266
K_2	5.6	0.73	7.9	0.20	0.35	1.5	255
K_3	5.8	0.70	7.9	0.15	0.33	1.3	258

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.

Table 3. Concentrations of N, P, K+½Na, Na, Mg, and Ca 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, K+½Na, Na, Mg og Ca i % af tørstof (TS) på det valgte tørstofvægttrin 0,5 g pr. plante og udbytte i friskvægt pr. plante. Forsøg 2

Treatment *Behandling*	% of DM at 0.5 g DM/plant *% af TS ved 0,5 g TS/plante*						Actual yield *Udbytte*
	N	P	K+½Na	Na	Mg	Ca	g/pl.
N_1R_1	5.9	0.90	9.0	0.10	0.41	1.6	90
R_2	6.0	0.90	9.4	0.18	0.40	1.5	88
R_3	5.9	0.94	8.8	0.12	0.38	1.8	88
R_4	5.9	0.97	10.3	0.12	0.35	1.3	117
R_5	5.6	0.94	9.3	0.16	0.39	1.7	80
N_2R_1	6.0	0.90	9.1	0.24	0.31	1.6	100
R_2	6.2	0.96	10.0	0.20	0.33	1.5	94
R_3	6.3	0.98	9.1	0.19	0.35	1.5	125
R_4	6.4	0.90	9.3	0.17	0.30	1.4	112
R_5	6.5	0.96	8.3	0.12	0.31	1.3	101

N_1 and N_2 = 2 and 14 meq $NH_4^+ + NO_3^-$/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 4. Concentrations of N, P, K+½Na, Na, Mg, and Ca 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, K+½Na, Na, Mg og Ca i % af tørstof (TS) på det valgte tørstofvægttrin 0,5 g pr. plante og udbytte i friskvægt pr. plante. Forsøg 4

Treatment *Behandling*	% of DM at 0.5 g DM/plant *% af TS ved 0,5 g TS/plante*						Actual yield *Udbytte*
	N	P	K+½Na	Na	Mg	Ca	g/pl.
N_1P_1	3.9	0.30	5.4	0.16	0.53	2.0	52
P_2	4.0	0.60	5.8	0.24	0.44	1.5	43
N_2P_1	4.3	0.43	5.7	0.20	0.54	2.0	100
P_2	4.7	0.52	6.2	0.18	0.40	1.7	76
N_3P_1	4.5	0.49	6.1	0.17	0.56	1.9	116
P_2	5.1	0.80	7.9	0.18	0.46	2.3	203
N_4P_1	5.0	0.52	6.2	0.18	0.36	2.0	149
P_2	5.3	0.82	8.3	0.18	0.38	2.2	189
N_5P_1	5.7	0.80	7.9	0.12	0.38	1.8	166
P_2	5.8	0.83	8.9	0.12	0.34	1.9	217

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.