

AN EVALUATION OF SOME FACTORS
INFLUENCING THE MINERAL COMPOSITION
AND CHLOROSIS OF CELERY,
APIUM GRAVEOLENS L.

Thesis for the Degree of Ph. D.
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Arlon Ervin Elser
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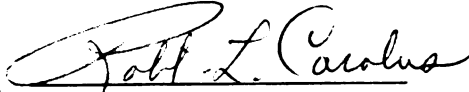
An Evaluation of Some Factors Influencing the
Mineral Composition and Chlorosis of Celery,
Apium Graveolens L.

presented by

Arlon Ervin Elser

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ABSTRACT

AN EVALUATION OF SOME FACTORS INFLUENCING THE MINERAL COMPOSITION AND CHLOROSIS OF CELERY, APIUM GRAVEOLENS L.

by Arlon Ervin Elser

Grower observations and experimental results have shown that chlorosis of celery was related to varietal and soil differences. To help elucidate the cause of the chlorosis frequently attributed to Mg deficiency, a series of field and greenhouse experiments was designed in which dry weight, nutrient-element composition, and chlorosis of various tissues from selections and varieties of celery as influenced by variable Mg and P levels were determined.

Growth and chlorosis of celery varieties were not closely associated with Mg composition, but Fe and Al composition of the blade and stem plate tissue decreased and chlorosis was less pronounced with increased applications of Mg. These apparent differences in nutrient-element content were consistently attributable to inherent variations regardless of the Mg treatment. However, chlorotic leaf tissue was observed when Fe, Al and occasionally P accumulated in the transition region.

Utah 52-10B, a chlorosis susceptible variety, contained relatively more Fe and Al and required greater amounts of Mg to correct or reduce Mg chlorosis than Spartan 162, a chlorosis resistant variety.

An increase in the concentration of Mg and P in the plant was associated with a simultaneous decrease in the Fe and Al content, and occurred independent of selection or variety of celery, but was differentially influenced by variable Mg levels.

Variety and Mg treatment occasionally did not exert their influences independently on the nutrient-element composition. A significant interactive effect of treatment and variety ascertains the interdependence of the nutrient-element content and precluded the unqualified use of overall varietal and treatment means.

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MINERAL COMPOSITION AND CHLOROSIS OF CELERY,
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INTRODUCTION

Wide variations in the yield of crop varieties are associated with differential rates of assimilation, absorption, transpiration, etc., of different races. More recently Lawrence (104) suggested the importance of selecting crop plants for efficiency in absorbing specific nutrients.

As crop yields are approaching a ceiling, more detailed attention to the metabolic functions associated with yield may be necessary to assure continued productivity and although factors such as net assimilation rate have received widespread attention, the possibility of selecting plants according to variation in nutrient uptake and assimilation has been comparatively neglected. It is possibly surprising that whereas nutritional mutants in Neurospora (7) and other organisms (40, 106, 153) have been extensively investigated, similar potential variabilities in the higher plants have generally been ignored.

One of the earliest citations of differential intraspecific uptake of an element is that by Bourcet (16) for I, while Hoffer and Carr (79) found differences in the uptake of Al by maize and related it to the incidence of root rot. Gregory and Crowther (64) showed that barley varieties responded differentially to the major elements, and noted that the possibility existed of developing varieties suited to mineral deficient soils.

Grower observations and experimental results (27, 41, 87, 88) over the past decade have indicated that the roots of certain Utah type Pascal celery varieties are unable to absorb adequate magnesium to prevent chlorosis of celery grown on muck soils. The yellowing originates at the tips of the older leaves and progresses along the margins and between the veins. Pronounced necrotic areas may eventually appear

and large sections of the leaf blades become senescent (41). Although a soil application of 1 ton per acre of MgSO_4 does not control the deficiency in the Utah 10-B variety (41), weekly foliar sprays of 7 to 10 pounds of MgSO_4 (Epsom salt) in 100 to 150 gallons of water have been effective in preventing the chlorosis (41,69,132).

Pope and Munger (132) reported that magnesium accumulation is controlled by a single dominant gene in the Utah 10-B celery variety. Burdine (27) also showed that high levels of potassium and calcium in the soil significantly increased magnesium chlorosis of celery. Therefore, it is not clear whether the cause of the yellowing is from Mg deficiency per se or other factors which might inhibit its absorption and/or subsequent utilization.

LITERATURE REVIEW

Differential Nutrient Uptake

There are many instances of differential nutrient uptake, but in comparatively few cases has the concentration of an element in the leaves or other plant parts been related to varietal differences in yield.

Hoffer (79) grew six lines of maize on clay and loam soils and found that the absorption abilities of selfed lines and crosses varied widely with respect to K, Fe, and Al. The amount of most minerals in the hybrids was intermediate between those of the parents, but K was higher and Fe and Al lower than either of the parents. Associated with hybrid vigor was a tendency to absorb less Fe and Al. It was found that the susceptibility of lines to develop a heritable type of leaf injury was associated with higher accumulation of Al and Fe.

Corn inbreds differ widely in Mg requirements (139). Foy and Barber (55) determined that a high requirement was due to reduced Mg translocation and high Mg accumulation in the outer-upper nodes (140). Schauble and Barber (140) postulated that Mg accumulation may be due to an enzymatic deficiency in the metabolic system.

Rabideau et al. (134) showed differences in the uptake of radioactive P by two inbred maize lines and their hybrids. Gorsline et al. (63) also working with maize, found that there was differential accumulation of Ca, Mg and K in the ear leaves of single crosses and inbreds. They found that the differential accumulation was inherited under an essentially gene additive scheme for Ca and Mg, while for K a more complicated inheritance scheme, including nonadditive gene action was indicated.

Maume and Dulac (122) were able to demonstrate varietal differences in the absorption of N, P, K, Ca and Mg by wheat grown under the same conditions, and later (121) showed varietal differences in the uptake of S. Giosan et al. (61) in a study of mineral nutrition in relation to frost resistance, compared twenty wheat varieties and found varietal differences in the uptake of P^{32} and K^{42} at low temperature.

The K, P and Fe contents of seedlings of a number of lines of rye varied between different genotypes of corresponding yield (136). Butler and Johnson (30) in a study of perennial ryegrass varieties obtained very great differences in I content. Results of diallel crosses showed that I content was a strongly inherited characteristic (32).

Twelve varieties of perennial ryegrass grown on three soils showed variation in K and Ca content and also in the K/Ca + Mg ratio (163, 164). Uptake of total cations and K showed high correlation with the plant cation-exchange capacity. Consistent features of certain varieties were high or low K content, and low cation ratio or Ca content.

Butler and Johns (31) found significant differences in Na, Ca, Mn, Al, Cu, Fe, Zn, nitrate, sulphate and acid soluble P content of seven plants of a ryegrass variety. A significant negative correlation with cation-exchange capacity was found for differences in nitrate and acid-soluble P.

Lawton and Cook (105) give references to varietal differences in K content or limiting value for a number of crops, including sugarcane, potatoes, apples, oranges, celery, sugarbeet, soybeans and tomatoes.

Browne (25) found that of five sugarcane varieties, the one that contained the highest K concentration when grown on organic soil contained the lowest on mineral soil.

The rice variety Siam 29, a poor accumulator of Mn, was more resistant to toxic levels of Mn than Pebifun.

Much data has come from studies of plants which are grown from scions grafted onto rootstocks. The stock variety influenced the N, K and P composition of the grape (100). Differential Mo transport (138), rootstock influence on nutrient deficiencies (45, 131), and the differential nutrient contents of leaves (5, 62, 161, 167), were associated with varietal differences in Malus spp. Therefore certain rootstocks might be more profitable for orchard crops on soils deficient in one or more nutrient elements. Also work on citrus (38, 65, 66, 67, 143, 146, 166) has shown the effect of the rootstock on leaf and peel composition necessitating a knowledge of rootstock variety when assessing fertilizer requirement from composition values (76).

Requirement for Specific Elements

A maize mutant, homozygous for yellow stripe, was unable to utilize ferric Fe while heterozygous plants were able to use both ferrous and ferric Fe (11).

Differences in varietal susceptibility to Mn deficiency as related to accumulation and requirement were found in oats (3, 39, 59, 60, 155, 159) and peas (169). Certain pea varieties susceptible to Mn deficiency were not accompanied by corresponding differences in Mn content (169), but with oats, a deficient-susceptible variety had more Mn than a resistant variety (162), indicating that varietal differences in Mn content were not associated with the symptoms of Mn deficiency, but with differential Mn requirement and accumulation.

The tomato variety Potentate had a lower Mg concentration and also more severe Mg deficiency symptoms than two other varieties (89). Certain oat varieties showed deficiency symptoms earlier and more pronounced than other varieties, and ultimately reflected a differential effect of Mg deficiency on yield (162).

Differences in Ca concentrations were found for some lines of maize (4), strawberry clones (108), populations of Trifolium repens, white clover (17), lead-tolerant population of Agrostis tenuis and for certain ecotypes adaptable to serpentine soils in California (99).

Fusarium wilt resistant varieties of cotton varied with respect to K requirement for normal development (154).

Varietal differences in B concentrations have been found in the grapevine (141), celery-deficiency determined by a single gene difference (133), and beet with a complex of responses from deficiency to excess tolerances indicating a masked heterogeneous genetic system (93, 94, 168).

The susceptibility of oat varieties to Cu deficiency was a factor in selection of varieties for land liable to "reclamation disease" (135). Also, the Zn requirement of oats varied between different regions (172).

Root Morphology

The number and type of roots may clearly have an influence on the nutrition of plants grown in soil, because of both the greater soil volume that a large root system can permeate and the variation in surface area caused by differences in proliferation. Phosphorus efficiency in maize varieties was directly related to the number of secondary roots (115, 145), with the largest root system absorbing the greatest amount of P (134). Similar results were found in perennial ryegrass (156), thus emphasizing the importance that variations in root type might have on varietal differences in nutrition (165).

There was no relationship between the absorbing surfaces and the total root length or weight of three varieties of sugarcane (52). A variety with a total root length only 54 percent of that of another had an absorbing system over eight times as extensive, indicating that

root hair proliferation and number and distribution of exchange sites are genetically dependent.

Exchange-absorption

The concept of exchange-absorption as the first step in nutrient salt uptake by the roots of higher plants (46, 86, 113) has lead to the determination of cation-exchange-capacity (C.E.C.) of roots and other plant parts. Data on C.E.C. of cultivated plants indicate that Leguminosae have approximately twice the C.E.C. of Gramineae (43, 72, 117, 124). Further, that within eight major groups, the species making most demands on soil fertility tend to have a higher C.E.C. than do those species which are less exacting in their requirements. Also, in accordance with the Donnan theory (47, 82, 119) low C.E.C. favors monovalent to divalent ions.

Significant correlations were observed for differences in the levels of the polyvalent cations Al, Ti and Fe and also for nitrate and acid-soluble P (31), while total cation content and K content of perennial ryegrass varieties were highly correlated with differences in C.E.C. (164).

Varietal differences in C.E.C. may be associated with the differential content of non-diffusible anions such as pectic compounds (91, 120) and uronic-acid content (97), which appeared as constituents of exchange sites.

Active Uptake

Many excellent reviews exist on salt absorption (18, 50, 103, 114) from which the "carrier" concept, originally developed by van den Honert (80) and subsequently modified (48, 49, 150) has achieved general acceptance. The concept is that the entrance of ions into living cells

is accompanied by binding to carrier molecules of some protoplasmic constituent. These ion-carrier complexes are able to traverse barriers of only limited permeability to free ions. Furthermore, the system may be regarded as selective with respect to various ions, and highly specific with regard to competition for absorption sites.

At least nine major factors seem possible variables: (1) the chemical nature of the carrier, (2) the specificity of the carrier, (3) the concentration of the carrier, (4) the speed of turnover of the carrier, (5) certain ions may be transported by more than one carrier, (6) the existence of multiple absorption sites, i. e., carriers which carry more than one type of ion, (7) the relative proportions of carriers, (8) the possible adaptive synthesis of carriers, (9) the rate of removal of ions from the internal "sink" (165).

The nature of the carriers has been suggested as ribonucleoproteins (101, 151, 152); the nucleic acid portion binding the cation, and the protein complexing with the anions. Kessler (96) supported this hypothesis with data on Prunus stocks which showed that Ca uptake was inversely related to RNA concentration at the root surface. It appeared that either the activity or synthesis of RNA-ase was more limited in resistant varieties, and although the activity of RNA-ase increased at high bicarbonate concentrations the activity of resistant varieties remained far below that of more sensitive rootstocks.

The existence of highly selective carriers and also of a carrier able to carry more than one type of ion has been postulated in cation uptake (4, 48). Apparently K, Rb and Cs compete for the same site, while Li is competitive for the Na site (48).

Differences have been demonstrated in phosphate absorption between monovalent H_2PO_4^- and divalent HPO_4^{--} ions (80). Although H_2PO_4^- and HPO_4^{--} ions are absorbed by two different sites, the hydroxide ion is in competition with phosphate at each absorption site (68). The concentration

of the carriers was found to vary, but with little relationship to the size of the roots (129).

A specific carrier for nitrate uptake was postulated (81) while Becking (8) proposed that uptake of NH_4 was accompanied by first binding to specific carriers.

Leggett and Epstein (107) found that Se competed with sulphate but that neither nitrate nor phosphate competed for this common site.

Multiple site uptake of Rb, K, Sr and Na by excised barley roots has been shown (56).

Adaptive synthesis of carriers does not appear to have been demonstrated, but following the close parallelism of carrier properties with enzyme systems, adaptive synthesis seems possible. Such adaptation might partially explain the varying response to ammonium and nitrate N, shown by both species and varieties (70).

The rate of removal of ions from the sink might be the rate-limiting factor in carrier systems. In this connection, the production of organic acids may be of importance, as the high correlation between total cations and organic-acid anions is well established (28, 84, 160). In effect, ion balance is maintained by compensatory alteration in the concentration of organic acids. It is conceivable that efficiency of organic-acid metabolism might affect the removal of ions from the sink.

It is apparent that there exist mechanisms of selectivity which might be responsible for the wide diversity of ion content and response found among varieties.

Differential utilization of Fe by soybean varieties (170) has been shown to result from the more efficient variety having a root system more adapted to absorb Fe from a relatively low Fe supply (22). However, part of the difference in efficiency was associated with a reduction in Fe translocation through phosphatidic precipitation, which was greater in the inefficient variety (23).

Brown and Hendricks (19) compared the activities of ascorbic acid oxidase, catalase and peroxidase in a number of crop plants. The catalase activity (20) was lower in lime-induced chlorotic plants than in normal plants. Roots of soybeans resistant to Fe chlorosis had a much greater reductive capacity than those of plants susceptible to chlorosis (24).

Nitrate reductase activity is dependent on Mo as an electron carrier (128), and it is known that nitrate accumulates in plants suffering from Mo deficiency (75, 126). Thus, differences in nitrate reductase activity, and hence the efficiency of N utilization, might basically be due to differences in Mo uptake by the plant.

Aspects of Magnesium as Related to Nutrition

Role of Magnesium in the Plant

The most important role of Mg in green plants is in chlorophyll synthesis (35, 53, 148, 175). Though Mg forms 2.7 percent of the chlorophyll molecule, it is but a fraction of the total Mg in the leaf (33, 85). Furthermore, albino corn seedlings like etiolated barley seedlings (144), contained ether-soluble Mg far in excess of the Mg which may be attributed to the chlorophyll present, but insufficient for all the chlorophyll produced during greening, indicating that Mg accumulates concomitantly with age.

An important specific role of Mg is the activation of enzymes containing sulphhydryl groups and especially those involving P metabolism (74). Some of the principal enzymes containing or activated by Mg were reviewed by Lardy (102) and Najjar (127). Magnesium affects the arrangement of the chloroplasts around the walls of cells of the palisade tissue (13), causing them to move to ends of cells away from the light and thus may indirectly affect P accumulation (6), phototropic and chlorophyll protection responses.

It was found that adequate levels of Mg and/or Ca prevent the toxic effect from Al (42).

Mameli (118) grew plants in nutrient solutions low in Mg and found smaller amounts of Mg in the etiolated and chlorotic parts than were present in normal portions on the same plants. Other losses due to Mg deficiency were xanthophylls and carotenes (76). With sub-marginal levels of available soil Mg, a deficiency chlorosis was associated with normal seed formation in developing fruits (57, 58).

Magnesium and Phosphorus Relationship

The relation of Mg to P accumulation and translocation has been the subject of many investigations (10, 92, 111, 116, 157, 158, 171, 173). The results of most of these experiments reveal a positive correlation between P and Mg contents of plants or between the efficiency of phosphate fertilizers and the supply of available Mg.

Influence of the Age of the Plant on Magnesium Composition

It is well-known that there are variations in the composition of plants at different stages of growth. Maximum concentrations of Mg are generally attained early (9) and remain constant or decrease depending on the tissue samples (20). However, it has been reported for some crops that Mg is absorbed in increasing amounts with advancing age (34, 71, 73) and concomitantly depending on Mg supply, Mg losses from stem and leaf tissue may appear (15, 25, 123, 125). Also, minimum Mg contents vary from year to year under apparently similar conditions (88).

Sufficient magnesium increases carbohydrate production (14, 44, 130) and nitrogen fixation (1, 2), but when deficient, increases in free amino acids have been noted (29, 147).

The availability of Mg once within the plant system may be related to direct or indirect inter-nutrient relationships (12, 90, 142, 177).

Magnesium and Celery

Experimental results (26, 41, 69, 87, 109, 178) have indicated that celery varieties containing germ plasm of certain Utah Pascal selections are unable to absorb adequate Mg to prevent chlorosis. The yellowing originates at the tips of the older leaves and progresses along the margins and between the veins. Although soil applied Mg did not control the deficiency in the Utah 10-B variety (41), weekly foliar applications have been effective in preventing the chlorosis.

Pope and Munger (132) reported that the mechanism which influences the accumulation of magnesium is controlled by a single dominant gene expressed as a 3:1 ratio in Utah 10-B. Burdine (27) showed that high soil levels of potassium and calcium significantly increased Mg chlorosis of celery. Therefore, whether the cause of the yellowing is related to Mg deficiency per se or to other factors, such as those inhibiting the absorption and/or subsequent utilization, are not clear.

Summary of Literature

Varieties of many kinds of crops accumulate certain ions with more intensity than others as influenced by many different mechanisms which in turn are dependent on inherent characteristics (21, 22, 54, 55, 63, 128, 174). Also, varieties of identical parentage (clones, rootstocks, scions) grown under diverse environmental conditions express a wide array of phenotypic, ion accumulation and translocation patterns (5, 66, 131, 137, 161, 166). Celery, Apium graveolens, Utah 10-B is one such cultivar on which it has been reported that the lack of a magnesium

accumulating mechanism is controlled by a single dominant gene (132). However, expression of this control is manifested only under certain environmental conditions.

MATERIALS AND METHODS

(GENERAL)

Celery plants harvested from the four studies were usually separated into: roots, stem plate (the fleshy stem which bears the spiral rosette of leaves), lower petiole (plate to first node), upper petiole (remainder of the petiole), leaf blades, and heart (the small immature centrally located leaves). The samples were washed, weighed, dried and analyzed spectrographically for Mg, P, Ca, Mn, Fe, Cu, Zn, B, and Al (95). Nitrogen was determined by the modified Kjeldahl method (95) and Na and K with a Model B (Beckman) flame spectrophotometer.

Based on a statistical analysis of composition data for 13 nutrient-elements only significant data are reported in detail.

PART I

INFLUENCE OF HEREDITY ON NUTRIENT COMPOSITION

Introduction

In order to ascertain the nature, association and possible causes of this anomaly, the nutritional behavior of selfed lines and varieties, which were grown under controlled conditions and in commercial plantings was investigated.

Procedure

Normal plants of acceptable horticultural characteristics were selected from a commercial field of celery (cv. Greenlite). Plants grown from seed of sixteen of these selections produced by selfing by the Joseph Harris Company, Rochester, New York, were set on Carlisle muck soil fertilized with 125-88-415 pounds of N, P, and K per acre respectively.

At the time of harvest, four of the selections that had the most desirable horticultural and market characteristics and free of chlorosis were designated normal; four other selections that had the most pronounced yellowing were designated chlorotic. These 8 selections were sampled for evaluation of their nutritional status.

Results and Discussion

The distribution of plant weight among the various tissues is shown in Table 1.

A statistical analysis of the nutrient values of the six tissues sampled, indicated that the most pronounced differences in nutrient concentration occurred between blade and stem plate tissues of the normal and chlorotic selections. Means and coefficients of variation (C.V.) for the concentration of each element in these tissues are shown in Table 2. The Mg concentration was 42 percent higher in the blade and 27 percent higher in the stem plate from normal than from chlorotic selections. However, the stem plates of the chlorotic selections contained 56 percent more Fe and 100 percent more Al than the normal selections. The K concentration was higher in the stem plate and lower in the blades of normal than of chlorotic plants. The lower K values in the blades of the normal plants as contrasted with chlorotic plants were associated with higher Ca and Mg concentrations.

Table 1. Celery Plant Weight Distribution

Tissue	Weight/Plant (g)*		Percent D. Wt.	Percent of Total D. Wt.
	Fresh	Dry		
Root	102	16.6	16.3	9.1
Stem plate	161	14.9	9.3	8.2
Lower petiole	1,557	52.6	3.4	29.0
Upper petiole	662	23.3	3.5	12.9
Blades	560	67.5	12.1	37.2
Heart	120	6.5	5.4	3.6
Totals	3,162	181.4	5.7	100.0

* Average of 20 plants.

Table 2. Average Nutrient Values of Blades and "Stem Plates" from Four Normal and Four Chlorotic Celery Selections

Element	Blades				Stem Plate			
	Normal		Chlorotic		Normal		Chlorotic	
	D. Wt.	C. V.	D. Wt.	C. V.	D. Wt.	C. V.	D. Wt.	C. V.
% P	.33	25	.36	16	.95	17	.85	12
% K	5.62	21	6.08	9	4.82	26	3.96	19
% Ca	5.34	16	4.78	29	.76	10	.79	6
% Mg	.41*	12	.29	27	.54*	13	.43	8
% Na	.29	31	.36	55	.44	22	.36	62
Ppm Mn	105	15	128	21	29	17	35	16
Ppm Fe	124	18	153	37	165	9	260**	28
Ppm Al	75	11	88	44	81	13	160**	17
Ppm Zn	114	15	124	21	71	10	72	14
Ppm B	52	13	51	32	101	21	91	6
Ppm Cu	178	19	177	27	101	38	98	20

* Means differ at odds of 95:1.

** Means differ at odds of 99:1.

With the exception of K, Na and Cu, nutrient element coefficients of variation were lower in the stem plate than in the blades (Table 2), indicating a lower differential accumulation among selections in stem plates than blades. With the exception of P and K, the C.V. for nutrient elements in the blades was higher among chlorotic than normal selections. However, in the stem plate the C.V. for P, K, Ca, Mg, B and Cu were lower among chlorotic than normal plants.

Interrelationships between the Mg, P, Fe and Al concentration in the various tissues of normal and chlorotic selections are indicated by the data in Table 3. These four nutrient elements are reported because from a critical evaluation of all composition data they appeared to be most closely related to the chlorosis observed. Milligrams per plant (Table 3) were determined from the fresh weight values and dry weight percentages shown in Table 1.

The total Mg and P contents of normal plants were significantly higher and the Fe and Al contents significantly lower than from chlorotic selections; with the high contents of Mg in lower petiole and blade tissues in part due to the large quantity of these tissues. Plants from normal selections contained approximately 35 percent more Mg and 25 percent more P, but only about 75 percent as much Fe and Al as chlorotic selections. With the exception of the heart tissue, the average concentration of Mg ranged from 0.41 to 0.54 percent in normal selections as contrasted with 0.29 to 0.47 percent in chlorotic plants.

In root and heart tissues, a close agreement existed between the average Mg contents of normal and chlorotic selections. There was a wide range in variation in Mg in the upper petiole, blade, and heart tissues of chlorotic selections as indicated by high coefficients of variation. The greatest difference in Mg concentration between normal and chlorotic selections was found between averages of upper petiole samples, with normal plants containing 54 percent more Mg than the chlorotic selections.

Table 3. Average Mg, P, Fe and Al Composition Values of Celery
Tissues from Four Normal and Four Chlorotic (Greenlite)
Selections

Element	Tissue	Normal		Chlorotic		Milligrams/Plant	
		D. Wt.	C. V.	D. Wt.	C. V.	Normal	Chlorotic
% Mg	Root	.48	11	.47	14	80	78
	Stem plate	.54	13	.43	8	81*	65
	L. petiole	.51	15	.37	6	270*	196
	U. petiole	.43	14	.28	33	100*	65
	Blades	.41	12	.29	27	278*	190
	Heart	.26	21	.27	36	17	18
	Total per plant					826	612*
% P	Root	.46	19	.40	18	76	66
	Stem plate	.95	17	.85	12	143	128
	L. petiole	1.13	56	.78	25	598	413
	U. petiole	.83	45	.53	38	193	123
	Blades	.33	25	.36	16	224	244
	Heart	.91	26	1.03	38	59	67
	Total per plant					1,293	1,041*
Ppm Fe	Root	272	7	404	49	4.5	6.7
	Stem plate	165	9	260	28	2.5**	3.9
	L. petiole	77	35	120	37	4.1	6.3
	U. petiole	82	36	94	63	1.9	2.2
	Blades	124	18	153	37	8.4	10.4
	Heart	115	32	263	82	0.8	1.7
	Total per plant					22.2	31.2**
Ppm Al	Root	251	26	322	29	4.2	5.3
	Stem plate	81	13	160	17	1.2**	2.4
	L. petiole	91	53	116	63	4.8	6.1
	U. petiole	86	60	81	60	2.0	1.9
	Blades	75	11	88	44	5.1	6.0
	Heart	59	45	129	87	0.4	0.8
	Total per plant					17.7	22.5**

* Means differ at odds of 19:1.

** Means differ at odds of 99:1.

Average P concentrations were more variable than Mg values among the tissues, ranging from 0.33 in blades to 1.13 percent in the lower petioles of normal plants. As the low percentages of P in the blades and the high values in the lower petioles are probably related to the high dry weight percentages of blades and low dry weight percentages of lower petioles, they may not represent an accurate portrayal of the physiologically active P distribution in these tissues. Average P concentrations in each tissue were more variable than Mg as indicated by higher coefficients of variation.

The upper petioles of normal plants contained 57 percent more P than observed in chlorotic plants. In chlorotic selections, the average P concentration in the upper petiole was only 53 percent of that found in the stem plate, while in normal selections it was 87 percent. This indicated the possibility of differential permeability to P in the stem plate region. Stem plates of chlorotic lines also contained 57 percent more Fe than was present in normal selections. Iron and Al in root and heart tissues of chlorotic selections were also much higher than in normal plants.

Celery varieties which contain certain germ plasm of Utah type Pascal did not exhibit chlorosis on the soils on which they were developed and selected. Magnesium deficiency appeared, however, when they were introduced and grown in areas not indigenous to their development and selection. For example, Utah 10-B, which was developed and selected in California on mineral soils, even developed Mg deficiency chlorosis when introduced and grown on organic soils adequately supplied with Mg (87). While some varieties express this anomaly, others containing germ plasm of similar parentage do not exhibit this phenomenon. Imposing differential environmental factors presumably result in phenotypic expressions otherwise masked.

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Normal and chlorotic plants taken from selfed selections of desirable uniform specimens of the same variety not only exhibited a wide variation in Mg content, but also in some other nutrients. There was apparently no restriction in root absorption or accumulation of Mg as indicated by comparable Mg root composition values from normal and chlorotic lines. Therefore, either a structural modification within the transition region or a complexing agent modifying the translocation of nutrients may be hypothesized.

Since Fe and Al values were higher in stem plate tissues of chlorotic rather than normal selections, and differences in P values between tissues of chlorotic plants were not related to increases from root to top to the same extent as observed in normal plants, it is possible that Fe and Al interfere with P mobility and activity by complexing with phosphate (135). This might result in an immobilization of the P by precipitation and incorporation on or into cellular tissues (142). Also, Fe and Al may be pectinized or act as "flocculating" agents and thereby decrease permeability and nutrient transport (150). A reduced permeability may be indicated in lower Mg concentrations of the stem plate, lower and upper petiole, and blades in chlorotic as contrasted with normal selections.

The Mg values observed generally agree with previous findings (87, 176, 178). However, Mg values in the "leaves" and petioles reported by Pope and Munger (132) for celery grown on muck soil in New York were much lower than those observed in this study. Substantial differences in Ca and K compositions in relation to Mg have been reported (87, 109, 176) between normal and chlorotic plants. However, there was little indication of the occurrence of these nutritional phenomena in this study. The high Ca values observed might be attributed to the high calcium carbonate content of the soil on which the celery was grown. But a higher Ca concentration in the blades of normal than chlorotic tissue was associated with higher not lower Mg values.

Summary

The observation that the nutrient variation among the selections of either normal or chlorotic lines was lowest in the stem plate, indicates that hereditary factors influencing accumulation in this tissue are probably more specific than in other tissues. The relative low coefficient of variation for all nutrients except Na and Cu in the stem plate indicates that it would be a satisfactory tissue for determining the nutrient status of celery.

The high coefficients of variability of some nutrients in the blades of the chlorotic selections indicate an unstable, complex genetic relationship to nutrition that was not apparent when the original plants were selected. This study indicates a high variability in nutrient accumulation among the progeny of selfed plants, which suggests that hybrids or true breeding lines be employed in nutritional investigations.

The chlorosis developed in selections containing Utah type Pascal germ plasm when grown on muck soils which were much lower in Fe and Al than the mineral soils on which they were selected. As either Fe and/or Al appear to be associated in some manner with chlorosis, mineral soils on which Utah lines were evaluated probably contained properties or elements which modified their deleterious effects.

PART II

INFLUENCE OF VARIETY AND MAGNESIUM ON NUTRIENT COMPOSITION

Introduction

In order to help elucidate the interactive effects of Mg and variety on growth and composition, four relatively homogeneous genetic celery varieties were selected for additional experimentation.

Procedure

For this study, Spartan 162 (Sp. 162), was selected because of its non-susceptibility chlorosis, and Utah 52-10B (U. 10B), because of its susceptibility to "Mg yellows" on soil containing high levels of Mg (41). Greenlite selections, chlorotic (Gl. Chl.) and Acceptable (Gl. Acc.) were also selected to represent intravarietal strains which had been determined previously to differ in nutrient-element content. For purposes of this study, the varieties U. 10B and Gl. Chl. will be referred to as "susceptible," and Sp. 162 and Gl. Acc. as "resistant" to chlorosis attributed to an apparent Mg deficiency.

Seed of the four celery varieties, Sp. 162 (first mass of seven generations of selfing), U. 10B (Ferry Morse 0539), Gl. Chl. (Harris 370/47), and Gl. Acc. (Harris 370/60) was germinated in Vermiculite. The seedlings were transplanted into 2-inch clay pots 35 days before transplanting in the field on June 8, 1962.

The experiment was conducted in polyethylene-lined 55-gallon steel barrels with the top one-third removed. All drums exposed a surface area of 3 sq. ft. The 32 barrels, equipped with external tile drains, were embedded in a 4 x 8 arrangement, in soil to within 3 inches of the top, and filled with Plainfield sand with a pH value of 6.5, and which contained 0.3 lbs. of available Mg per acre, and was otherwise generally low in fertility.

One plant of each of the four varieties was planted in every barrel in a split pot design with four replicates of eight treatment main effects and four varietal sub-plots.

Each plot received 5.9g N, 3.2g P, and 13.5g K in four applications applied at 4-week intervals beginning on the date of transplanting. The variable treatments, Table 4, were applied in four equal increments; soil at 2-week intervals and foliar at 7 to 14-day intervals

Table 4. Growth (Dry Weight) of Varieties of Celery as Influenced by Soil and Foliar Applied Magnesium

Variety	Application of magnesium as MgSO ₄ .7H ₂ O (lbs. per acre)								
	Soil								
	0		25		100		400		
	Foliar								
	0	25	0	25	0	25	0	25	Avg.
(Expressed as grams per plant; average of 6 plants)									
U. 10B*	24	30	<u>28</u>	<u>42**</u>	32	25	23	20	28
Gl. Chl.	15	15	24	23	<u>24</u>	<u>33</u>	24	23	23
Cl. Acc.	23	24	18	24	22	23	<u>27</u>	<u>42</u>	26
Sp. 162	17	18	19	23	19	21	26	22	21
Avg.	21		25		25		26		25
Rel. D. Wt. 100			120		120		124		

* Utah 52-10B (U. 10B), Greenlite Chlorotic (Gl. Chl.), Acceptable (Gl. Acc.), and Spartan 162 (Sp. 162).

** Paired means within soil magnesium treatment columns subtended by the same line differ at odds of 99:1.

beginning 3 weeks after transplanting. Deionized water was used to supplement natural precipitation.

The plants were harvested 120 days after transplanting and divided into stem plate, lower petiole, blade and heart tissue.

In general, U. 10B and Gl. Chl. plants were chlorotic when grown with only the control, the control plus 25 lbs. of foliar applied Mg, and the 25 lbs. soil applied Mg treatments, but otherwise appeared similar to Sp. 162 and Gl. Acc.

Results and Discussion

Dry Weight

The differential response in dry weight of the four varieties of celery associated with soil and foliar applied Mg is indicated in Table 4. The treatment averages indicate that in general, an increase in dry weight was associated with increased soil Mg rates.

The dry weight of U. 10B on the average was most and Sp. 162 least influenced by Mg treatment.

Magnesium applied to the foliage of U. 10B on soils supplied with 25 lbs. of Mg, resulted in a 50 percent increase in dry weight, but with 100 lbs of Mg applied to the soil, a 22 percent decrease. Also, the application of Mg to the foliage of U. 10B on soil which received no Mg treatment, resulted in a 17 percent greater increase in dry weight, and with 25 lbs. of Mg applied to the soil, a 43 percent greater increase than in other varieties. These differences may indicate that soil Mg and variety modify the influence of foliar absorption or utilization.

The dry weight of Gl. Chl. plants, which were associated with an application of 100 lbs. of Mg to the soil, increased 38 percent when Mg was applied to the foliage. Similarly, the dry weight of Gl. Acc. plants associated with the application of 400 lbs. of Mg to the soil

increased 55 percent when Mg was applied to the foliage. However, at lower soil Mg rates, the dry weight of Gl. Acc. associated with Mg applied to the foliage did not differ from the no Mg treatment, indicating that selections within a variety contained mechanisms which initiate very different responses to variable Mg levels.

The dry weight of Sp. 162 plants remained relatively unchanged regardless of Mg treatment. These data indicate that the dry weights of the "susceptible" varieties increased at a greater rate and to a higher level with soil Mg treatments to 100 lbs. Mg. per acre than the "resistant" varieties.

In a statistical analysis of the composition data for 13 nutrient-elements in six celery plant tissues, differences were consistently found for Mg, P, Fe and Al concentrations in the stem plate, petiole, blade, and heart tissues, Table 5.

Magnesium Composition

The Mg concentration was higher in the blade and petiole than in the stem plate or heart tissues. The Mg concentrations in the chlorosis susceptible varieties were higher than in the resistant varieties in all tissues except the blades of Gl. Chl., indicating that even though chlorosis occurred in the susceptible varieties, a higher Mg requirement may be necessary to prevent expression of this anomaly. In general, the Mg concentration in all plant tissues increased with increased soil application of Mg with the greatest concentration found in petiole and blade tissues of plants grown with the 100 and 400 lbs. soil application.

In the stem plate tissue, the Mg concentration of chlorosis susceptible varieties was higher than in the resistant varieties, indicating a differential accumulation of Mg which may be genetically influenced. When foliar Mg was applied without a soil Mg treatment, a decrease in Mg concentration was observed in the stem plates of all varieties, but

Table 5. Magnesium Concentration in Celery Varieties as Influenced by Soil and Foliar Applied Magnesium

Application of magnesium as $MgSO_4 \cdot 7H_2O$ (lbs per acre)										
Tissue	Soil									
	0		25		100		400			
	Foliar									
	0	25	0	25	0	25	0	25	Avg.	
(Expressed as percent of dry weight; average 2 plants)										
A. Stem Plate										
U. 10B*	.44	.37	.36	.41	.44	.54	.51	.47	.45	
Gl. Chl.	.49	.35**	.34	.37	.38	.41	.44	.47	.40	
Gl. Acc.	.40	.34	.27	.26	.39	.47	.28	.37	.35	
Sp. 162	.23	.19	.14	.23	.14	.23	.24	.28	.21	
Avg.	.35		.30		.37		.39		.35	
Rel. Conc.	100		86		106		111			
B. Petioles										
U. 10B	.42	.41	.48	.52	.36	.63	.80	.70	.55	
Gl. Chl.	.52	.51	.52	.56	.52	.59	.31	.56	.52	
Gl. Acc.	.41	.36	.31	.30	.31	.56	.41	.44	.39	
Sp. 162	.43	.43	.40	.47	.44	.44	.49	.55	.46	
Avg.	.44		.45		.48		.53		.48	
Rel. Conc.	100		102		109		120			
C. Blades										
U. 10B	.57	.40	.48	.53	.29	.64	.88	.96	.60	
Gl. Chl.	.54	.44	.43	.56	.63	.30	.59	.72	.53	
Gl. Acc.	.39	.25	.24	.18	.23	.68	.53	.62	.39	
Sp. 162	.55	.44	.41	.49	.57	.80	.55	.89	.59	
Avg.	.45		.42		.52		.72		.53	
Rel Conc.	100		93		116		160			
D. Heart										
U. 10B	.36	.34	.36	.38	.26	.36	.37	.36	.35	
Gl. Chl.	.28	.31	.33	.32	.36	.47	.34	.36	.37	
Gl. Acc.	.31	.21	.27	.24	.23	.36	.32	.28	.28	
Sp. 162	.28	.25	.31	.30	.18	.30	.31	.34	.29	
Avg.	.30		.32		.32		.34		.32	
Rel. Conc.	100		107		107		113			

* Utah 52-10B(U. 10B), Greenlite Chlorotic (Gl. Chl.), Acceptable (Gl. Acc.) and Spartan 162 (Sp. 162).

** Paired means within soil magnesium treatment columns subtended by the same line differ at odds of 99:1.

at higher soil Mg levels, an increase in Mg resulted, indicating that the decrease in concentration was due to increased plant growth. On the other hand, the application of Mg to the foliage of Sp. 162 on soils supplied with 25 and 100 lbs. of Mg, resulted in a 64 percent increase of Mg concentration, but with the 400 lbs. soil Mg treatment, no change in Mg concentration was observed, indicating that a certain threshold level may exist in the stem plate tissue of Sp. 162.

The Mg concentration in the petiole tissue generally increased with the application of Mg to the soil (Table 5). The greatest increase in Mg concentration in the petioles attributed to the application of Mg to the foliage occurred with the 100 or 400 lb. rates of Mg applied to the soil in all varieties except Sp. 162. Also, the Mg concentration increased in all tissues of all varieties when 100 lb. of Mg was applied to the soil and to the foliage, indicating a slight accumulation of Mg, since growth was not increasing proportionally, except in the blade tissue of Gl. Chl., which significantly decreased in Mg concentration and concomitantly increased in total growth (Table 4). In general, when compared with the no Mg treatment, the relative Mg concentrations ranged from 5 percent more in the stem plate to 44 percent more in the blades from plants with 400 lb. of soil Mg than with the 100 lb. rate (Table 5), indicating an accumulation of Mg within the plant and Mg residue on the leaves due to foliar applied Mg.

Phosphorus Composition

Magnesium applied to the foliage, in general, resulted in a decrease in P concentration in the blade and petiole tissues (Table 6). The P concentration was highest in the heart and lowest in the petiole tissue, indicating a high P requirement in the tissue of high metabolic activity. There was a tendency for the P concentration to increase in stem plate and petiole tissue, decrease in blade and remain unchanged

Table 6. Phosphorus Concentration in Celery Varieties as Influenced by Soil and Foliar Applied Magnesium

Application of magnesium as $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ (lbs. per acre)										
Tissue	Soil									
	0		25		100		400		Avg.	
	Foliar									
	0	25	0	25	0	25	0	25		
(Expressed as percent of dry weight; average of 2 plants)										
A. <u>Stem Plate</u>										
U. 10B*	.40	.34	.43	.46	.61	.48	.36	.43	.44	
Gl. Chl.	.37	.45	.41	.50	<u>.51</u>	<u>.20**</u>	.46	.53	.43	
Gl. Acc.	.41	.47	.49	.33	<u>.52</u>	<u>.70**</u>	.31	.38	.45	
Sp. 162	.46	.34	.31	.45	.24	.39	.32	.42	.37	
Avg.	.41		.43		.46		.40		.43	
Rel. Conc.	100		105		112		98			
B. <u>Petiole</u>										
U. 10B	.19	.18	.19	.23	.25	.23	.19	.18	.21	
Gl. Chl.	.22	.17	.21	.19	<u>.26</u>	<u>.14</u>	.32	.28	.23	
Gl. Acc.	.29	.22	.23	.14	<u>.30</u>	<u>.26</u>	.28	.21	.24	
Sp. 162	.24	.15	.14	.20	.18	.20	.14	.23	.20	
Avg.	.21		.19		.23		.23		.22	
Rel. Conc.	100		90		110		110			
C. <u>Blade</u>										
U. 10B	.27	.25	.24	.26	.30	.23	.24	.23	.25	
Gl. Chl.	.27	.26	.22	.26	.27	.27	.34	.33	.29	
Gl. Acc.	<u>.62</u>	<u>.20</u>	<u>.31</u>	<u>.15</u>	.28	.25	.35	.26	.30	
Sp. 162	<u>.34</u>	<u>.20</u>	<u>.20</u>	<u>.25</u>	.31	.25	.19	.29	.26	
Avg.	.31		.24		.27		.28		.28	
Rel. Conc.	100		77		89		90			
D. <u>Heart</u>										
U. 10B	.52	.54	.61	.63	.59	.57	.58	.57	.59	
Gl. Chl.	.71	.57	<u>.54</u>	<u>.78</u>	<u>.69</u>	<u>.40</u>	.65	.73	.64	
Gl. Acc.	<u>.77</u>	<u>.56</u>	<u>.63</u>	<u>.51</u>	<u>.67</u>	<u>.67</u>	.68	.51	.62	
Sp. 162	<u>.71</u>	<u>.47</u>	.37	.53	.35	.45	.47	.64	.51	
Avg.	.61		.58		.55		.61		.59	
Rel. Conc.	100		95		90		100			

* Utah 52-10B (U. 10B), Greenlite Chlorotic (Gl. Chl.), Acceptable (Gl. Acc.) and Spartan 162 (Sp. 162).

** Paired means within soil magnesium treatment columns subtended by the same solid line differ at odds of 99:1; with the same broken line at odds of 999:1.

in the heart tissue with increased rates of soil Mg, indicating that P was precipitated.

Magnesium foliar applied to Gl. Chl. on soils with the 100 lb. Mg rate, resulted in reductions in the P concentration of 60, 46 and 42 percent in the stem plate, petiole, and heart tissues respectively, but had no influence on the P concentration in blade tissue. However, associated with the same conditions was a 38 percent increase in the dry weight of Gl. Chl. (Table 4), indicating that the reduction in P concentration in petiole and heart tissue may have resulted from an increase in growth; in stem plate tissue, from growth and translocation, while the constancy of the P concentration in the blade tissue was apparently associated with a 38 percent increase in P content.

Although lower in the petiole than in all other tissues, the P concentration tended to increase with soil Mg application, but was not influenced by foliar applied Mg, except in the petioles from Gl. Chl. with an application of 100 lb. of Mg to the soil. However, associated with the use of foliar Mg on the resistant varieties without soil applied Mg, was a decrease in P concentration in blade and heart tissue, and no apparent change in dry weight, indicating that the P content did decrease.

Iron Composition

The concentration of Fe in blade and heart tissues were higher than in stem plate and petiole tissues (Table 7). Soil applied Mg, in general, resulted in lower concentrations of Fe in all tissues except the heart.

A decrease in Fe concentration characterized all significant changes associated with foliar applied Mg with the 0 and 25 lb. soil Mg rate, except in blade tissue of Gl. Acc. However, an increase in Fe concentration characterized all significant changes associated with

foliar applied Mg at the 100 and 400 lb. soil Mg rate, except in heart tissue of Gl. Acc. (Table 7). These data indicate that the Fe concentration may be more closely associated with chlorosis than Mg, and that the apparent deleterious effect of high Fe concentrations may be modified by the application of Mg.

Magnesium applied to the foliage of varieties resistant to chlorosis on soils without added Mg resulted in a 41 to 53 percent decrease in the Fe concentration in the stem plate, but a similar decrease in Fe concentration in chlorosis susceptible varieties was observed with the 25 lb. soil Mg level. These data indicate that resistant selections, Sp. 162 and Gl. Acc., effectively distributed Mg and grew at lower soil Mg levels, whereas chlorosis susceptible varieties, U. 10B and Gl. Chl. required higher soil Mg levels before Fe concentration was significantly reduced as compared to the control. However, the 51 percent increase in Fe concentration in Gl. Acc. due to foliar applied Mg with the 400 lb. soil Mg level, indicates a treatment-varietal interaction and that the Fe content increased since the dry weight increased (Table 4). With the exception of Gl. Acc., which increased 46 percent with the 25 lb soil Mg rate, the Fe concentration in all selections was lower with all soil Mg rates than the concentration of the respective selections grown in the absence of soil or foliar applied Mg.

With foliar applied Mg, the Fe concentration in the petiole tissue remained relatively unchanged except in Gl. Acc., which decreased 54 percent without added soil Mg, and increased 50 percent when 400 lb. of Mg was applied to the soil, indicating that Fe was not preferentially accumulated with respect to Mg.

Iron concentration in the blades increased or remained unchanged in all cases associated with Mg applied to the foliage, except the control treatment of Sp. 162 where a 39 percent decrease in Fe concentration

Table 7. Iron Concentration in Celery Varieties as Influenced by Soil and Foliar Applied Magnesium

Application of magnesium as MgSO ₄ .7H ₂ O (lbs. per acre)										
Tissue	Soil									
	0		25		100		400		Avg.	
	Foliar									
	0	25	0	25	0	25	0	25		
(Expressed as ppm dry weight; average of 2 plants)										
A. Stem Plate										
U. 10B*	169	147	116	66**	114	97	119	110	118	
Gl. Chl.	145	97	128	67	95	76	118	133	108	
Gl. Acc.	137	81	200	115	79	81	100	151	118	
Sp. 162	160	75	74	71	107	78	54	84	88	
Avg.	127		105		91		109		108	
Rel. Conc.	100		83		72		86			
B. Petioles										
U. 10B	137	127	95	72	124	102	105	178	118	
Gl. Chl.	113	106	87	54	116	90	101	93	95	
Gl. Acc.	234	107**	73	67	166	114	93	139	125	
Sp. 162	149	122	118	88	127	114	82	118	115	
Avg.	137		81		119		114		113	
Rel Conc.	100		59		87		83			
C. Blades										
U. 10B	219	153	130	146	204	256	153	220	186	
Gl. Chl.	191	137	202	141	133	133	138	215	162	
Gl. Acc.	280	282	139	271	179	210	157	207	216	
Sp. 162	245	152	175	187	196	206	106	179	181	
Avg.	212		174		189		171		187	
Rel. Conc.	100		82		89		81			
D. Heart										
U. 10B	144	189	137	169	189	357	181	429	224	
Gl. Chl.	137	173	189	149	222	196	208	205	185	
Gl. Acc.	252	151	124	191	138	147	307	155	183	
Sp. 162	205	132	106	141	103	117	92	208	138	
Avg.	173		151		183		223		183	
Rel. Conc.	100		87		106		129			

* Utah 52-10B (U. 10B), Greenlite Chlorotic (Gl. Chl.), Acceptable (Gl. Acc.), and Spartan 162 (Sp. 162).

** Paired means within soil magnesium treatment columns subtended by the same solid line differ at odds of 99:1; with the same broken line at odds of 999:1.

occurred. However, when additional Mg was applied to the soil, the Fe concentration decreased or remained unchanged in all instances and marked decreases of 50 percent occurred over the no soil Mg level in Gl. Acc. with 25 lbs and 57 percent in Sp. 162 with the 400 lb. soil Mg level (Table 7). A significant reversal in the concentration of Fe in the blades of Sp. 162 occurred with the 400 lb. Mg soil treatment when Mg was applied to the foliage and, at a significantly lower Fe concentration than the control.

These data indicate that Mg applied to the soil decreases Fe uptake and accumulation in the plant, whereas Mg foliarly applied to celery plants growing on soil adequately supplied with Mg increases the Fe concentration in the blades.

Aluminum Composition

The blades were highest and the stem plate tissue lowest in Al concentration (Table 8). In general, Al accumulation was similar to Fe and decreased with increased soil Mg in all tissues except the heart, indicating increased growth and repressed Al absorption due to available Mg. Also, the Al concentration decreases or remains unchanged when Mg was applied to the foliage within a soil Mg foliar treatment, except in blade tissue from Gl. Acc. with the 100 lb. and heart tissue from U. 10B with 400 lb. soil Mg treatments.

The stem plate tissues from all selections decreased in Al concentration when Mg was foliar applied with the no Mg soil treatment. Also, the stem plate tissue of Gl. Acc. decreased 71 percent in Al concentration when Mg was foliar applied to the 25 lb. Mg soil treatment, indicating that foliar applied Mg influenced Al uptake and accumulation. Even though the stem plate tissue of Gl. Acc. decreased in Al concentration when Mg was foliar applied with the 25 lb. soil Mg treatment, the selection expressed no apparent Mg deficiency, whereas Gl. Chl. did,

Table 8. Aluminum Concentration in Celery Varieties as Influenced by Soil and Foliar Applied Magnesium

Application of magnesium as MgSO ₄ ·7H ₂ O (lbs. per acre)									
Tissue	Soil								
	0		25		100		400		Avg.
	0	25	0	25	0	25	0	25	
Foliar									
	0	25	0	25	0	25	0	25	Avg.
(Expressed as ppm dry weight; average of 2 plants)									
A. Stem Plate									
U. 10B*	171	46	104	88	78	55	109	78	92
Gl. Chl.	185	43**	127	38	106	62	82	99	93
Gl. Acc.	128	37	180	53	44	56	57	98	82
Sp. 162	187	33	53	29	106	69	35	69	73
Avg.	104		84		73		78		85
Rel. Conc.	100		81		70		75		
B. Petiole									
U. 10B	150	139	105	114	136	119	116	178	134
Gl. Chl.	131	91	168	68	150	148	201	86	131
Gl. Acc.	385	97	243	59	218	128	287	110	191
Sp. 162	163	141	142	110	130	147	95	123	132
Avg.	163		127		148		150		147
Rel. Conc.	100		78		91		92		
C. Blade									
U. 10B	203	152	125	145	151	223	141	214	170
Gl. Chl.	190	109	237	134	131	102	125	173	152
Gl. Acc.	355	301	125	150	114	215	146	150	195
Sp. 162	285	158	167	153	151	231	106	157	176
Avg.	219		155		169		153		173
Rel. Conc.	100		71		77		70		
D. Heart									
U. 10B	125	146	110	111	119	180	130	313	155
Gl. Chl.	89	108	209	108	156	155	175	141	143
Gl. Acc.	237	111	83	79	78	91	238	127	131
Sp. 162	181	80	91	86	53	103	52	133	98
Avg.	135		110		117		164		132
Rel. Conc.	100		81		87		121		

* Utah 52-10B (U. 10B), Greenlite Chlorotic (Gl. Chl.), Acceptable (Gl. Acc.) and Spartan 162 (Sp. 162).

** Paired means within soil magnesium treatment columns subtended by the same line differ at odds of 99:1.

indicating a small but finite genetic control system which governs the interaction of Mg and Al in these two Greenlite selections.

The Al concentration in the petiole tissue generally decreased when Mg was foliar applied on all soil Mg treatments. However, a marked decrease of 75 percent occurred in petiole tissue of Gl. Acc. plants grown on the control and 25 lb. soil Mg treatments, and 61 percent with the 400 lb. soil Mg rate.

Aluminum concentration in the blades of all selections grown with low soil Mg treatments tended to decrease when Mg was foliarly applied, as indicated by the reduction in Al concentration in Sp. 162 and Gl. Chl., but generally increased with the 100 and 400 lb. soil Mg treatments, as indicated by an 87 percent increase in Al concentration of Gl. Acc. on soil treated with 100 lb. Mg indicating divergent varietal responses and possibly a non-functional selective ion mechanism or enzyme at Mg concentrations much greater than minimal or optimum requirement.

The Al concentration of the heart tissue from varieties resistant to chlorosis decreased about 54 percent when Mg was foliar applied to the no Mg treatment. The heart is the only tissue from U. 10B plants to show a difference in Al concentration attributed to foliar applied Mg indicated by a 140 percent increase in Al concentration in heart tissue of plants from the 400 lb. soil Mg treatment. Also, U. 10B was the only selection to manifest a slight decrease in Al concentration in the stem plate tissue due to foliar applied Mg on all soil Mg treatments and a concomitant increase in Al composition in the aboveground tissues indicating that the stem plate may be the tissue in which a physico-chemical precipitation of Al and P occurs.

Utah 52-10B contained a higher content of all nutrient-elements except Al, Cu and B, and Sp. 162 a lower content with the exception of Cu than all other varieties, which was most probably associated with the fact that U. 10B had a high and Sp. 162 plants a low dry weight (Table 9).

Table 9. Nutrient-Element Content of Celery as Related to Variety and Soil Treatment

Nutrient Element	Variety				Soil Treatment			
	U. 10B*	Cl. Chl.	Gl. Acc.	Sp. 162	Lbs. Mg/acre as Epsom salt			
					0	25	100	400
(Expressed as milligrams per plant; average of 16 plants)								
Mg	153	107	92	88	92	98	107	138
K	671	568	669	430	495	490	638	695
Ca	349	245	277	180	307	281	228	221
P	82	72	80	54	72	70	71	73
N	503	373	419	310	400	394	385	414
Na	35	30	34	21	30	28	28	34
Fe	4.6	3.0	4.2	2.7	3.9	3.3	3.5	3.6
Al	4.2	3.0	4.2	2.6	3.9	3.3	3.1	3.4
Mn	3.9	2.9	2.5	2.0	2.6	3.2	2.6	2.7
B	.6	.6	.6	.5	.6	.6	.5	.7
Zn	1.0	.7	.8	.6	.8	.9	1.1	.8
Cu	.5	.3	.5	.4	.4	.4	.3	.2

* Utah 52-10B (U. 10B), Greenlite Chlorotic (Gl. Chl.), Acceptable (Gl. Acc.), and Spartan 162 (Sp. 162).

The Mg and K increased, while Ca decreased, and the content of the other nutrient-elements remained unchanged with additional increments of soil applied Mg, indicating that Mg and K content is directly related to Mg application, and that the rate of Ca, Cu and Al accumulation is reduced probably due to mass action, cation constancy or other electrical charge differences.

Summary

The data in this experiment indicated that soil and variety were influential factors associated with foliar absorption, and that inter- and intra-varietal differences in dry weight and differential amounts of nutrient-element accumulation occurred.

Associated with the chlorosis of U. 10B was an apparently higher Mg composition than with the non-chlorotic plants. However, associated with foliar applied Mg on plants with the 100 lb. soil Mg treatment, was an apparent accumulation of Mg in all tissues of all varieties at a greater rate than dry weight increased, indicating a slight "luxury consumption" of Mg.

When Mg was applied to the foliage, all changes in Fe concentration in the plant tissues were characterized by decreases with the low and increases with 400 lbs. of Mg applied to the soil.

Although the effect of the application of Mg on the Al concentration was similar to Fe in both chlorosis susceptible and resistant varieties, the resistant varieties expressed no apparent Mg deficiency associated with the high Al concentrations especially in the stem plate.

The general overall decrease in the relative concentration of Fe and Al with the 25 lb. soil Mg treatment was partly associated with the 10 percent increase in relative dry weight (Table 10), and repressed uptake associated with competitive mass action of the Mg ions.

Table 10. Nutrient-Element Concentration and Dry Weight of Celery Varieties as Influenced by Soil and Foliar Applied Magnesium

Application of magnesium as $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ (lbs. per acre)										
Soil										Rel. Conc.
Foliar										
0 25 100 400										
0 25 0 25 0 25 0 25 Avg.										
(Expressed as percent of dry weight; average of 8 plants)										
A. <u>Magnesium</u>										
S. P.*	.38ab	.32a**	.28a	.32a	.34a	.41b	.37ab	.40ab	.35	100
Pet.	.45ab	.43a	.43a	.46ab	.41a	.56b	.50ab	.56b	.48	137
Blade	.51b	.38a	.39a	.44ab	.43ab	.61c	.64c	.80d	.53	151
Heart	.31ab	.28ab	.32ab	.31ab	.26a	.37b	.34ab	.34ab	.32	91
B. <u>Phosphorus</u>										
S. P.	.41ab	.40ab	.41ab	.44b	.47b	.44b	.36a	.44b	.43	100
Pet.	.24b	.18a	.19ab	.19ab	.25b	.21ab	.23ab	.23ab	.22	51
Blade	.39b	.23a	.24a	.23a	.29ab	.25a	.28ab	.28ab	.28	65
Heart	.67b	.54a	.54a	.61b	.58ab	.52a	.60b	.61b	.59	137
(Expressed as ppm dry weight; average of 8 plants)										
C. <u>Iron</u>										
S. P.	153c	100ab	130bc	80a	99ab	83a	98ab	120abc	108	100
Pet.	158c	116b	93ab	69a	133bc	105b	95a	132bc	113	105
Blade	234c	181ab	162ab	186abc	178ab	201bc	138a	205bc	187	173
Heart	185b	161ab	139a	163a	163a	204bc	197b	249c	183	169
D. <u>Aluminum</u>										
S. P.	168c	40a	116b	52a	84ab	61a	71a	86ab	85	100
Pet.	210c	117ab	165bc	88a	159bc	136ab	175c	124ab	147	173
Blade	258c	180b	164b	146ab	137a	193bc	130a	175b	173	204
Heart	158bc	111a	123ab	96a	102a	132a	149bc	179c	132	155
E. <u>Total Dry Weight per Plant</u> (grams)										
	20a	22a	22a	28b	24ab	26ab	25ab	27ab	25	

* Stem Plate (S.P.) and Petiole (Pet.).

** Means within an element and tissue across all treatments not subtended by the same letter differ at odds of 99:1.

In general, the Mg concentration increased in all tissues with added Mg, but the highest Mg concentration occurred in blade tissue from plants grown with the 100 and 400 lb. of soil applied Mg, indicating that plant requirement for Mg was approached by available soil Mg and less Mg was absorbed and transported from the leaves than at lower rates of Mg. Although the relative P concentration associated with 25 lb. soil Mg treatment tended to increase in the petiole and stem plate and decrease in the heart and blade, the P concentration which was associated with the 400 lb. soil Mg treatment, was 10 percent higher in the petiole and 10 percent lower in the blades than in the heart or stem plate tissue, indicating differential rates of tissue growth and/or nutrient accumulation.

The relative concentration in the blade tissue indicates that Mg increased up to 60 percent and the P, Fe and Al decreased 20 percent with the initial soil Mg amendment and remained unchanged with additional soil Mg application.

PART III

INFLUENCE OF VARIETY, MAGNESIUM AND SOIL TYPE ON PLANT NUTRIENT COMPOSITION

Introduction

Magnesium was added as a variable to Plainfield sand and two soils indigenous to celery-producing areas and the effects on Mg chlorosis and nutrient-element composition determined.

Procedure

Seed of the previously described selections was germinated in Vermiculite and the seedlings transplanted into 2-inch clay pots.

Three sets of 32 sterilized 10-inch clay pots were filled with three soils; a loam soil from California 9.0 kg., Plainfield sand 12.0 kg., or Houghton muck 6.5 kg. Soil analysis of the exchangeable nutrients indicated that expressed as pounds per acre the loam soil contained Mg 48, N 40, P 63, (Bray P_1), K 558, Ca 1188, 800 Cl and a trace of Mn and Fe; Plainfield sand no Mg, N 16, P 8, K 160, Ca 148, 40 Mn and a trace of Fe and Cl; and Houghton muck Mg 48, N 40, P 5, K 44, Ca 656, and a trace of Mn, Fe, and Cl. The pH was 7.8, 6.3 and 6.5 for the loam, Plainfield sand and Houghton muck, respectively. Single plants were transplanted into each pot on April 16, 1962.

A factorial arrangement of 4 Mg treatments x 4 varieties x 3 soils was fitted to a randomized complete block design with one replication. A standard solution, which supplied the equivalent of 180-225-500 pounds per acre of NPK respectively, was added to all pots. A soil treatment, of 100 lbs. of Mg per acre, was applied in four applications at two-week intervals and the foliar treatment, 50 lbs. of Mg per acre in six applications at 7-10-day intervals, both beginning at the time of final transplanting. Tap water was used daily to recharge the respective soils to field capacity.

The plants were harvested on August 12, 1962, evaluated, weighed and prepared for chemical analysis.

Results and Discussion

Spartan 162 and Gl. Acc. appeared chlorosis-free, while U. 10B and Gl. Chl. were chlorotic even when sprayed with Mg and slightly chlorotic in Plainfield sand, treated with Mg, but otherwise appeared to be normal, healthy plants.

There was an average increase of 10 percent in the dry weight of the plants that had received the soil Mg treatment, and an average increase of 29 percent in the dry weight of the plants grown on organic soil as compared to those grown on the sandy soil. On the average, dry weight production was lower from susceptible than resistant varieties (Table 11).

Treating the foliage of Sp. 162 with Mg resulted in an increase of 17 percent in growth and in the accumulation of 26, 35, and 29 percent more Mg, P and Al by the plant. In U. 10B, foliage treatment of plants that received the soil Mg treatment, resulted in a growth increase of 28 percent and an increase of 36, 28, 19 percent in the Mg, P and Al contents of the plant. In both varieties, the increase in the Mg content of the plant also was related to a higher concentration. Relative to the growth and Mg content of U. 10B; Gl. Chl., Gl. Acc., and Sp. 162 produced 31, 49 and 22 percent more dry matter which contained 44, 69, and 52 percent more Mg, respectively. As neither P, Fe or Al contents of the other varieties, relative to U. 10B, were appreciably different from U. 10B, it appears that their abilities to differentially accumulate Mg are related to their growth difference.

Even though Mg chlorosis of the susceptible varieties was corrected by an application of Mg to the foliage or soil, the Mg content and dry weight did not increase (Table 11). The accumulation of Mg in the plant with Mg treatment increased more rapidly than dry weight. The Mg content of U. 10B was lowest and apparently not influenced by differences in soil type.

Increases in P content occurred with the same Mg treatments as increases in Mg and dry weight (Table 11). In addition, an increase in P content of all varieties was associated with an application of Mg to the foliage and the 100 lb. soil treatment on the loam soil. Also, the P content of Gl. Chl. non-treated plants and those treated with foliar

Table 11. Total Dry Weight and Nutrient-Element Content of Celery as Influenced by Soil Type and Soil and Foliar Applied Magnesium

Application of Mg as MgSO ₄ .7H ₂ O (Lbs. per acre)		Variety				Soil			Rel.	
Soil	Plant	U. 10B	Gl. Chl.	Gl. Acc.	Sp. 162*	Sand	Loam	Muck*	Avg.	Value
(Average of 6 Plants)						(Average of 8 Plants)				
Dry Weight (Expressed as grams per plant)										
0	0	61	91	88	71a**	64	78	92	78a	100
0	50	61	82	88	83b	70	72	99	78a	100
100	0	61a	81	102	86	74	75	102	83ab	106
100	50	78b	86	109	77	81	80	94	88b	113
Avg.		65a	85b	97b	79ab	72a	76a	97b	82	
(Expressed as milligrams per plant)										
Magnesium										
0	0	253	399	341	333a	305	343	348	330a	100
0	50	248	372	336	419b	323	373	353	344a	104
100	0	231a	380	539	472	394	411	412	406b	123
100	50	314b	404	557	383	431	381	432	415b	126
Avg.		262a	389b	443b	402b	363	373	386	375	
Phosphorus										
0	0	361	378	360	331a	309	489	274	358a	100
0	50	345	352	380	446b	361	471	311	381a	106
100	0	556a	561	593	619	531	584a	632	582b	163
100	50	712b	654	732	538	654	728b	596	659b	184
Avg.		494	486	517	484	464a	568b	453a	495	
Iron										
0	0	8.2	9.2b	7.9	9.9	8.9	7.0	10.1	8.8a	100
0	50	8.6	8.6a	7.7	9.8	7.2	8.8	10.8	8.6a	98
100	0	10.5	13.8	9.8	12.8b	9.4	13.0b	14.3b	11.8b	131
100	50	11.2	12.1	10.5	9.2a	9.7	10.8a	12.7a	11.0b	122
Avg.		9.6a	10.7b	8.9ab	10.4b	8.5a	9.8ab	12.0b	10.1	
Aluminum										
0	0	4.9	6.2	7.0	5.1a	4.5	6.1	6.9	5.8a	100
0	50	5.4	6.2	6.3	6.6b	4.5	6.9	7.3	6.2ab	107
100	0	6.3a	6.1	6.9	6.7	5.6	6.6	7.6	6.4ab	110
100	50	7.5b	6.2	8.5	5.7	6.3	6.4	8.1	7.0b	121
Avg.		6.0a	6.2a	7.2b	6.1a	5.2a	6.5a	7.4b	6.4	

* Utah 52-10B (U. 10B); Spartan 162 (Sp. 162); Greenlite Chl. grotic (Gl. Chl.); and Acceptable (Gl. Acc.); Plainfield sand (sand), California loam (loam) and Houghton muck (muck).

** Paired means within a soil Mg. treatment and overall treatment, variety, and soil averages not subtended by the same letter differ at odds of 99:1.

applied Mg was less than the Mg content, whereas in plants from the other varieties and treatments, P is equal to or exceeds the Mg content. The possibility is indicated that chlorosis of this selection of Greenlite may be associated with an unbalanced P-Mg relationship.

The total Fe content in the plant increased up to 30 percent with soil applied Mg, but decreased with foliar applied Mg within a given soil Mg treatment (Table 11). For example, with the use of foliar Mg, the Fe content decreased 13 percent in Gl. Chl. without the addition of Mg to the soil, and 26 percent in Sp. 162 with an application of Mg to the soil. Also, the average Fe content of all varieties decreased when Mg was applied to the foliage of plants grown on loam and muck soils supplied with 100 lbs. of Mg, indicating a marked decrease in Fe concentration. The overall Fe content was 48 percent lower in plants grown on sand than on muck soil.

The overall Al content as influenced by treatment and soil type approximately paralleled dry weight changes (Table 11). However, a varietal influence on differential accumulation was indicated by Gl. Chl. which contained less Al than Gl. Acc., but statistically contained the same dry weight.

Magnesium application to the soil markedly increased the P contents of the two chlorosis susceptible varieties, but had little influence on their Mg contents. On the other hand, in the chlorosis resistant varieties both the P and Mg contents of the plant were enhanced by applications of Mg to either the soil or the foliage (Figure 1).

With Mg application, the Fe and/or Al content of susceptible varieties tended to increase with P content, indicating that in overall content, the chlorosis of susceptible varieties may be influenced by a complex Mg-Fe-Al inter-relationship, which was characterized by low Mg and high Fe and Al contents in varieties susceptible to chlorosis.

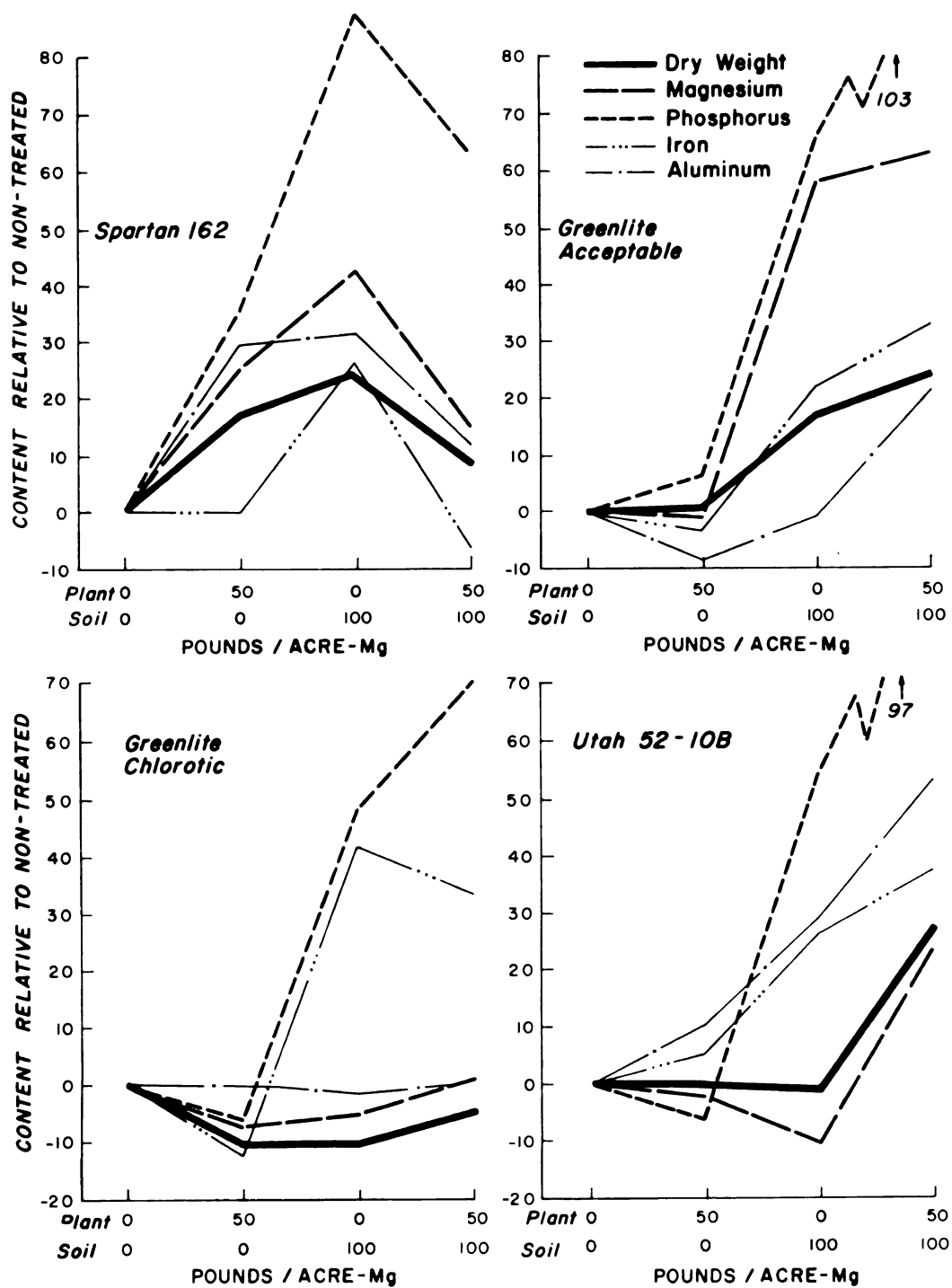


Figure 1. Total dry weight and nutrient-element content of celery varieties as influenced by soil and foliar applied Magnesium.

The dry weight of Gl. Acc. increased and Gl. Chl. decreased and remained unchanged with increased Mg levels, while the dry weight of U. 10B increased with the highest Mg application.

Addition of Mg to the two soils that were low in available P (Plainfield sand and Houghton muck) evidently influenced the availability of the native soil P or the plant in some way that facilitated greater P accumulation (Figure 2). Phosphorus accumulation by celery plants was not as markedly enhanced by Mg application to the California soil, due in part perhaps to the soils high pH value and in part to the high level of available P in the soil (Figure 2). The Mg, Al and dry weight content tended to vary in plants grown on all soils, while the Fe content of plants grown on loam and muck soil decreased at the highest Mg rate. However, associated with increased Mg levels on Plainfield sand, was a tendency for dry weight to increase and the Fe content to decrease or remain unchanged, reaffirming that Mg is more influential in promoting growth when applied to a deficient rather than a soil adequately supplied with Mg and P.

Magnesium P, Fe, and Al contents were lower in the stem plate tissue from Sp. 162, and higher in Gl. Acc. than in the other varieties, but only Mg was influenced in the blade tissue by variety (Table 12).

The low stem plate and high blade tissue accumulation of Mg, P, Fe and Al in Sp. 162 in general, indicates that this variety apparently does not contain a mechanism which restricts nutrient translocation from stem plate to blade tissue. However, the low Mg content, which is the product of Mg concentration by blade dry weight, of blade tissue from U. 10B may be associated with a low dry weight and restricted Mg translocation. Although the Mg content of blade tissue from Gl. Chl. is equivalent to that of the resistant varieties, chlorosis did occur, indicating a greater rate of chlorophyll turnover and/or incorporation of Mg into cell wall pectates and unavailability of Mg for synthesis in the susceptible than in the resistant varieties (26).

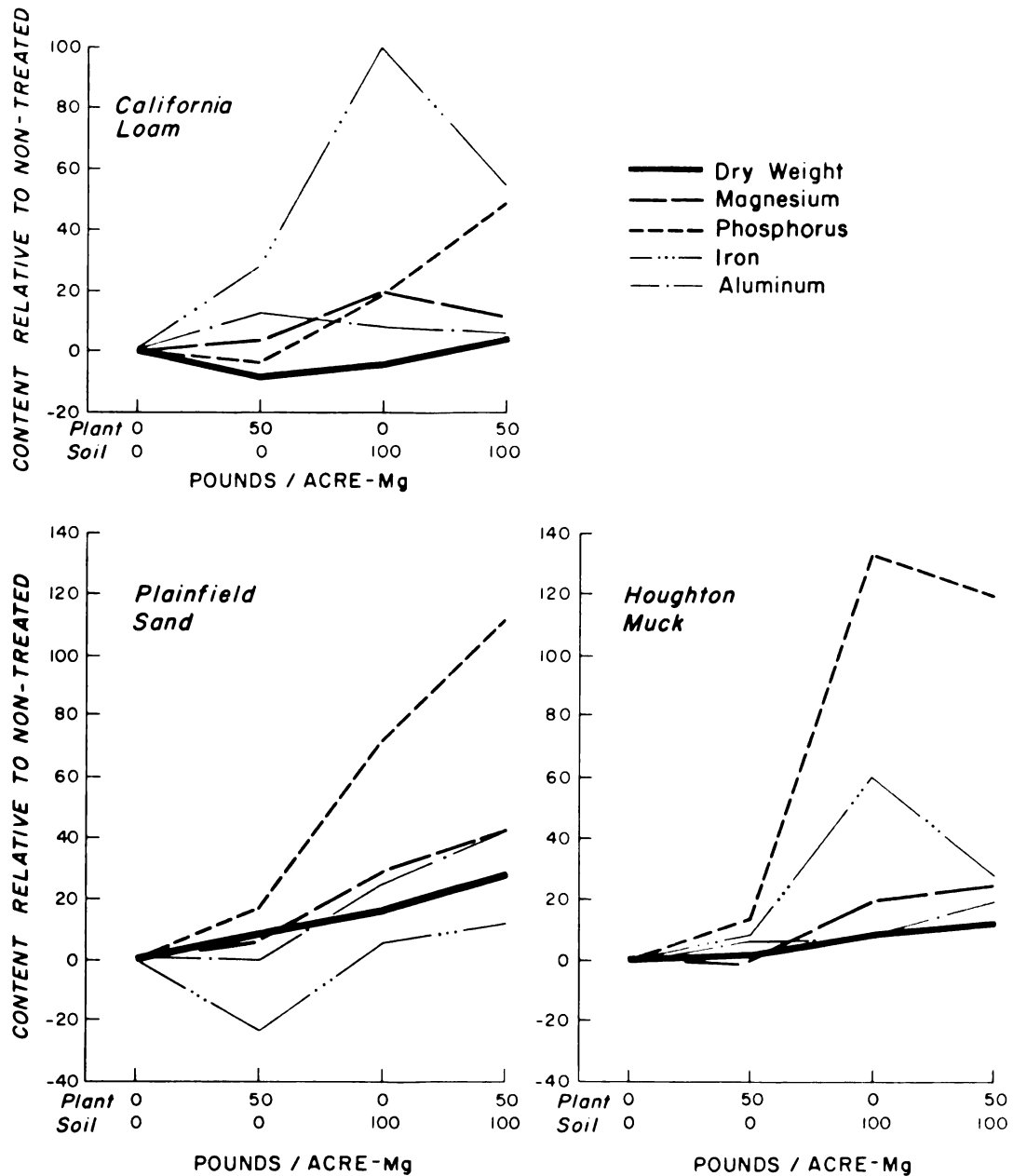


Figure 2. Total dry weight and nutrient-element content of celery as influenced by soil type and soil and foliar applied Magnesium.

Table 12. Nutrient Element Content of Celery Varieties as Related to Soil and Foliar Applied Magnesium

Application of Magnesium as $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ (lbs. per acre)					
	Soil				
	0		100		
	Foliar				
	0	50	0	50	Avg.
(Expressed as milligrams per tissue; average of 6 plants)					
Magnesium:					
Stem Plate					
U. 10B*	24ab**	25b	15a	22ab	21ab
Gl. Chl.	33b	28b	24ab	29b	29bc
Gl. Acc.	30b	24b	38b	29b	35c
Sp. 162	16a	12a	19a	15a	15a
Blade					
U. 10B	84a	99a	103a	125a	103a
Gl. Chl.	158b	142b	166ab	178ab	161b
Gl. Acc.	136ab	119ab	218b	233b	177bc
Sp. 162	154b	194c	235b	181ab	191c
Phosphorus:					
Stem Plate					
U. 10B	38	40	46a	51ab	43a
Gl. Chl.	46	42	51ab	71bc	52ab
Gl. Acc.	40	36	77b	88c	60b
Sp. 162	34	36	54ab	43a	42a
Blade					
U. 10B	78a	81a	157ab	205b	130
Gl. Chl	85ab	83a	125a	147a	110
Gl. Acc.	105b	108b	153ab	205b	142
Sp. 162	103ab	107b	198b	178ab	146

Continued

Table 12 - Continued

Application of Magnesium as $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ (lbs. per acre)					
	Soil				
	0		100		
	Foliar				
	0	50	0	50	Avg.
(Expressed as milligrams per tissue; average of 6 plants)					
Iron:					
Stem Plate					
U. 10B	2.9b	2.4ab	3.0ab	4.0ab	3.0ab
Gl. Chl.	2.9b	2.6ab	2.9ab	3.0ab	2.9ab
Gl. Acc.	2.7ab	4.2b	4.9b	6.6b	4.6b
Sp. 162	2.0a	1.8a	2.6a	2.6a	2.3a
Blade					
U. 10B	5.1a	6.5ab	8.3ab	8.6	7.2
Gl. Chl.	6.5ab	5.1a	10.6b	8.5	8.0
Gl. Acc.	5.8ab	4.7a	6.2a	6.7	5.9
Sp. 162	6.9b	7.7b	14.9c	6.9	9.1
Aluminum:					
Stem Plate					
U. 10B	.21ab	.16ab	.10a	.15ab	.16ab
Gl. Chl.	.23b	.15ab	.13ab	.14ab	.15ab
Gl. Acc.	.17a	.17b	.18b	.20b	.18b
Sp. 162	.20ab	.11a	.12a	.10a	.13a
Blade					
U. 10B	3.7a	3.9a	4.9	5.0	4.4
Gl. Chl.	3.9ab	4.2ab	4.4	4.5	4.3
Gl. Acc.	4.9b	3.8a	4.7	5.8	4.8
Sp. 162	3.6a	5.1b	4.8	3.9	4.3

* Utah 52 - 10B (U. 10B), Greenlite Chlorotic (Gl. Chl.), Acceptable (Gl. Acc.) and Spartan 162 (Sp. 162).

** Means within a tissue and magnesium treatment not subtended by same letter differ at odds of 99:1.

On the average, with the control treatment (Table 12), the stem plate from susceptible varieties contained more and the blade tissue less Mg, P, Fe and Al than resistant varieties, indicating that resistant varieties translocated and utilized nutrients present in sub-optimum concentrations.

However, the use of foliar Mg without added soil Mg, resulted in no change in Mg, P and Fe contents, but the Al content of the stem plate tissues from Gl. Chl. decreased 35 percent and from Sp. 162 about 45 percent (Table 13).

With the application of 100 lbs. Mg to the soil (Table 13), the Mg and Al content of the stem plate from U. 10B and the Al content of Gl. Chl. decreased and concomitantly the P and Mg content of the blade tissue increased, indicating that the Al content of the stem plate may interfere with P and Mg translocation to the blades. However, the resistant varieties apparently increased in Mg and P content without decreasing in Fe or Al.

The decrease in Mg, P, Fe and Al content in blade tissue from Sp. 162 associated with foliar applied Mg on soils treated with Mg was related to a decrease in dry weight (Table 11), indicating that these levels of applied Mg may be toxic to Sp. 162. The stem plate and blade tissue from susceptible varieties increased in Mg and P, but the Fe content of blade tissue from Gl. Chl. decreased 20 percent, indicating that high rates of Mg may depress Fe concentration by exerting a beneficial effect on growth.

Summary

The data indicate that differences resulting from variety and differential Mg treatments are greater and may be more vindicative of nutrient-element uptake and translocation than different soil types. Also, the usual symptoms of chlorosis were more associated with

Table 13. Changes in Nutrient-Element Content of Celery Varieties as Influenced by Foliar and Soil Applied Magnesium

Classification								
Susceptible					Resistant			
Application of Mg as MgSO ₄ ·7H ₂ O (lbs. per acre)								
Soil	0		100		0		100	
Foliar	0	50	0	50	0	50	0	50
Utah 52-10B					Spartan 162			
Magnesium								
S. P. *	0**		-	0	0		0	0
Blade	0		+	+	+		+	-
Phosphorus								
S. P.	0		+	0	0		0	0
Blade	0		+	+	0		+	-
Iron								
S. P.	0		0	0	0		0	0
Blade	0		+	0	0		0	-
Aluminum								
S. P.	0		-	0	-		0	0
Blade	0		0	0	0		0	-
Greenlite Chlorotic					Greenlite Acceptable			
Magnesium								
S. P.	0		0	0	0		0	+
Blade	0		+	+	0		+	0
Phosphorus								
S. P.	0		0	+	0		+	0
Blade	0		+	+	0		+	+
Iron								
S. P.	0		0	0	0		+	+
Blade	-		0	-	0		0	0
Aluminum								
S. P.	-		-	0	0		0	0
Blade	0		0	0	0		0	0

* Stem plate (S. P.)

** Zero indicates no change, plus (+) an increase, and minus (-) a decrease significant at the 1% level and associated with the indicated treatment.

cultivar and differential Mg treatment than soil type. Different soil types and the application of Mg apparently failed to modify the deleterious effect attributed to Fe and Al.

When compared with the control treatment, the dry weight of Sp. 162 increased with an application of 50 lbs. of Mg, however, the dry weight of U. 10B increased only with the application of 150 lbs. of Mg. These data also indicate that Sp. 162 may lack the heritable characteristic which controls the mechanism that restricts Mg translocation from stem plate to blade tissue.

The relative P content was apparently not related to varietal influence, but Mg, Fe and Al contents were affected by inherent varietal variation as modified by Mg treatment. Also, the P content, as influenced by applied Mg, was not appreciably modified by soil type.

Associated with the observed chlorosis of Gl. Chl., was a Mg content equivalent to that found in the resistant varieties and a lower P than Mg content on the control soil treatment. Although chlorosis was primarily associated with the blade tissue, the stem plate apparently contained a biochemical and/or physico-chemical mechanism which controlled the translocation and accumulation of soil appropriated nutrients. Relatively minute quantities of Fe and Al in the stem plate, when associated with low Mg availability or accumulation may by complexing with P, reduce the translocation of the Mg absorbed.

PART IV

INFLUENCE OF VARIETY, MAGNESIUM, AND PHOSPHORUS
ON NUTRIENT COMPOSITIONIntroduction

Since the differences in composition as influenced by soil type were minimal, U. 10B and Sp. 162, which characterized the maximum and minimum varietal differences in response to differential Mg treatment, respectively, and apparently possessed a minimal genotypic heterogeneity, were selected for solution culture studies designed to help elucidate the role of the stem plate in nutrient-element translocation and differential Mg and P accumulation. The stem plate, three anatomically distinct tissues, may be an intermediate zone of nutrient accumulation.

Procedure

Seeds of Sp. 162 and U. 10B were germinated in Vermiculite and six weeks later the seedlings were transplanted into glazed 8-liter crocks, which contained a continuously aerated Hoagland's No. 2 solution (77). The plants were grown at 70°F day and 60°F night temperature with supplemental lighting to provide a 13-hour day.

The total fresh weight of each plant was recorded 60 days later at the inception of the experimental treatments. An additional six plants (three of each variety) were weighed, dried, and the dry weights recorded in order to determine the extent dry weight regresses on fresh weight. The remaining plants were placed in five nutrient solution cultures; (a) no nutrients-distilled water, (b) minus Mg and P (-Mg and -P), (c) minus Mg (-Mg), (d) minus P (-P), and (e) complete-1/2 Hoagland's

No. 2 solution, prepared as outlined by Hoagland (77). Minor elements were added to all treatments except the no nutrient solution. The solution cultures were changed every two weeks and replenished three times each week--twice with the appropriate stock solution and once with distilled water.

A factorial arrangement of two varieties by five treatments was fitted to a completely randomized design with two single plant observations. The crocks were rerandomized at the time the solutions were changed in order to minimize confounding between treatment and position effects.

The tissues were sampled and prepared for spectrographic analysis, but in addition the "stem plate" was divided into three anatomically distinct tissues (51), fleshy roots, transition region and stem.

Results and Discussion

A critical evaluation and statistical analysis of the concentration data for 13 nutrient-elements in six celery plant tissues indicated marked changes in the Mg, P, Fe and Al concentration in the fleshy root, transition region, stem, and blade tissues.

Although chlorotic plants appeared to be associated with all except the complete treatment, the first chlorosis was associated with the -(Mg and P) treatment and the U. 10B. variety. Symptoms of chlorosis on Sp. 162 appeared simultaneously with -Mg and -P treatments. Plants grown in distilled water were last to exhibit chlorotic symptoms indicating that a uniformly "starved" plant may be less symptomatic than a plant with single or multiple imposed limiting factors.

Since there was a correlation coefficient of .967 between initial fresh and dry weight of the plants which were harvested at the inception of the treatments, the initial dry weight of each treated plant was

predicted from its fresh weight. The average initial dry weight of the blade tissue from U. 10B was 3.8 g. while Sp. 162 contained 4.0 g.

The combination treatment -(Mg and P) resulted in a 30 percent lower dry weight of Sp. 162 than U. 10B (Table 14). The relative dry weight of blade tissue from Sp. 162 with the -P treatment was 38 percent higher and the -Mg treatment only 18 percent greater than the combination, indicating that Mg may be more directly associated with growth than P.

The complete treatment was generally associated with the highest Mg and P concentration in all tissues except the P concentration in U. 10B (Table 14). However, associated with the -(Mg and P) treatment was the lowest Mg and P concentrations in all tissues except the blade tissue of Sp. 162.

Associated with the high Mg and P concentration in blade tissue of Sp. 162 was the lowest Fe and Al concentration for all treatments. On the other hand, the highest Fe and Al concentration in the blade tissue of U. 10B was associated with the lowest Mg and P concentration for all treatments.

The transition region apparently accumulated more Mg and Fe than the other tissues in the stem plate regardless of treatment (Table 14). However, an apparent differential varietal effect on nutrient-element concentration was indicated by the average nutrient concentration in the blade tissue from Sp. 162, which contained 68 percent more Mg, 40 percent more P, 22 percent less Fe and 149 percent less Al than U. 10B.

Utah 10B had a lower and Sp. 162 a higher Fe and Al concentration in the blade tissue from plants grown with Mg rather than P in the ambient milieu when compared with the -(Mg and P) treatment.

The degree of chlorosis of U. 10B may be directly associated with the concentration of Fe and Al in the blade tissue (Table 14). On the

Table 14. Dry Weight and Nutrient-Element Concentration in Celery Varieties as Influenced by Magnesium and/or Phosphorus Treatments

Dry Weight and Nutrient Element Concentration											
	Actual						Relative				
	No Nut.*	-Mg -P	-Mg -P	-P -P	Comp.	Avg.	No Nut.	-Mg -P	-Mg -P	-P -P	Comp.
(Average of 2 plants)											
Dry Weight of Blades (grams)											
U. 10B**	8.8	8.0	9.8	6.9	12.6	9.2	100	91	111	78	143
Sp. 162	8.6	5.6	6.7	7.7	14.5	8.6	100	65	78	90	170
(Expressed as percent of dry weight)											
Magnesium											
U. 10B											
F.R.**	.19	.15	.20	.22	.26	.20	100	79	105	116	137
T.R.	.19	.18	.26	.27	.34	.25	100	95	137	142	179
Stem	.16	.13	.17	.19	.39	.21	100	81	106	119	124
Blade	.23	.15	.20	.16	.53	.25	100	65	87	70	230
Sp. 162											
F.R.	.14	.13	.15	.17	.20	.16	100	93	107	121	143
T.R.	.16	.13	.15	.19	.36	.20	100	81	94	119	225
Stem	.13	.10	.11	.14	.36	.17	100	77	85	108	277
Blade	.30	.42	.34	.30	.73	.42	100	140	113	100	243
Phosphorus											
U. 10B											
F.R.	.68	.52	.64	.74	.84	.68	100	76	94	109	124
T.R.	.54	.50	.57	.77	.71	.62	100	93	106	143	131
Stem	.53	.47	.60	.76	.77	.63	100	89	113	143	145
Blade	.43	.25	.52	.45	.49	.43	100	60	121	105	114
Sp. 162											
F.R.	.64	.62	.81	.75	1.17	.80	100	97	127	117	183
T.R.	.65	.47	.81	.72	1.02	.73	100	72	124	111	157
Stem	.69	.59	.79	.71	.96	.75	100	86	114	103	139
Blade	.64	.56	.63	.34	.84	.60	100	88	98	53	131

Table 14 - Continued

Dry Weight and Nutrient Element Concentration											
Actual						Relative					
No	-Mg					No	-Mg				
Nut.*	-P	-Mg	-P	Comp.	Avg.	Nut.	-P	-Mg	-P	Comp.	
(Expressed as ppm of the dry weight)											
<u>Iron</u>											
U. 10B**											
F.R.	85	84	100	139	145	111	100	99	118	164	171
T.R.	114	109	128	161	213	145	100	95	112	141	187
Stem	86	61	111	131	100	98	100	71	129	152	116
Blade	186	242	234	182	161	201	100	130	126	98	81
Sp. 162											
F.R.	100	149	80	109	103	108	100	149	80	109	103
T.R.	131	280	83	174	216	177	100	214	63	133	165
Stem	90	134	64	124	117	106	100	149	71	138	130
Blade	168	135	152	191	179	165	100	80	90	114	107
<u>Aluminum</u>											
U. 10B											
F.R.	16	17	17	14	15	16	100	106	106	88	94
T.R.	12	28	15	14	16	17	100	233	125	117	133
Stem	12	17	17	12	15	15	100	142	142	100	125
Blade	472	478	429	187	98	333	100	101	91	40	21
Sp. 162											
F.R.	35	21	19	39	14	26	100	60	54	111	40
T.R.	21	29	11	33	23	27	100	138	52	252	110
Stem	14	21	10	17	17	16	100	150	71	121	121
Blade	108	87	94	311	159	152	100	81	87	288	147

* Nutrients absent (No Nut.); Minus Mg and P (-Mg -P); Minus Mg (-Mg); Minus P (-P); and Complete (Comp.).

** Utah 52-10B (U. 10B) and Spartan 162 (Sp. 162). Fleshy roots (F.R.) and Transition region (T.R.).

other hand, the concentration of Fe and Al in the blade tissue from Sp. 162 which appeared non-chlorotic was just the reverse for the -(Mg and P), -Mg and -P treatments. The relative Mg and P concentrations in Sp. 162 celery plants which were grown in the complete nutrient solution were much greater than Fe or Al in a given tissue, indicating that Mg and P absorption and translocation were intimately associated and modified Fe and Al distribution and accumulation.

Phosphorus apparently was more and Fe and Al less readily absorbed by Sp. 162 than U. 10B with the -Mg treatment as indicated by relative changes in concentration (Table 14). Although there was a tendency in the blade tissue from U. 10B to accumulate Fe and Al and not Mg and P, the reverse was apparently true in Sp. 162 on the -(Mg and P) treatment, indicating a varietal-treatment interaction, that is, U. 10B and Sp. 162 were not similarly influenced by the same treatment.

Summary

The nutrient-element composition of relatively genetically homogeneous celery varieties was somewhat more variable and related to chlorosis when grown in solution than in soil culture. For example, an absence of both Mg and P in the ambient milieu resulted in the highest concentration of Mg in the blade tissue of Sp. 162 and the lowest Mg and P concentration in blade tissue from U. 10B plants which expressed the initial symptoms of chlorosis. However, the results were consistent with those of the preceding experiments in that the stem plate and specifically the transition region preferentially accumulated nutrient-elements.

A consistent relationship among the relative amounts of the various nutrients with all treatments was somewhat obscure. However, trends were indicated. A treatment-variety interaction was indicated by a

100 percent greater Mg content in the blade tissue of Sp. 162 than U 10B with the -(Mg and P) treatment, indicating no accumulation in other plant tissues and perhaps a greater initial Mg accumulation in Sp. 162 than U. 10B. Also, the relative growth of U. 10B increased 11 percent with the -Mg level, but dry weight growth of Sp. 162 decreased 22 percent, additional evidence for a significant treatment-variatal interaction.

Perhaps more important than the interdependence of Mg and P is the apparent dependency of the Fe and Al concentration and translocation on the Mg and P ratio, absorption, and translocation.

GENERAL DISCUSSION

The nutritional behavior of celery, as influenced by variety, soil, Mg and P, has been evaluated in an attempt to ascertain the nature of the factors influencing the inability of celery varieties of certain genetic constitution to absorb Mg in adequate quantities to prevent the development of chlorosis.

Magnesium and Its Relation to Chlorosis

Magnesium comprises 2.7 percent of the chlorophyll molecule, which is estimated to represent 0.8 percent of the total green leaf dry weight (175). Therefore, it is evident that in order to prevent the breaking down of chlorophyll and the subsequent manifestation of chlorosis, the total Mg content of the leaf must be considerably greater than the quantity present in chlorophyll.

Data on the Mg composition of blade tissue of celery indicated that within a variety, low Mg concentrations or contents are not definitely associated with chlorosis. These data generally support the observation of Longnecker (112) that there is not a close relationship between chlorophyll concentration, or leaf chlorosis and total Mg content. Also, the data support the conjecture by Bukovac et al. (26) that the depletion of the Mg pool by meristematic tissues, chlorophyll turnover, and probable incorporation of Mg into cell wall pectates and oxalates may be more influential in Mg chlorosis than Mg translocation from the leaf. However, there exists an extensive literature indicating that Mg "content" was lower in chlorotic than in non-chlorotic leaves.

The "content" frequently referred to is actually concentration of Mg (dry weight basis) and unless considered with dry weight variation, conclusions based thereon may be erroneous. For example, an increase in dry weight at a greater rate than Mg accumulates, would result in an apparent decrease in Mg concentration, but actually an increase in total leaf Mg might result.

Since the high requirement of meristems for Mg may result in preferential transport of root absorbed Mg to these tissues, the rate of Mg accumulation by older tissues is either reduced or not maintained at the same rate as the increase in total dry weight when levels of this nutrient are critical.

The Mg values observed in this study generally agree with previous findings (87, 176, 178) which indicated that Mg concentration in the blade tissue was 0.3 to 0.4 percent. However, the Mg concentration in the "leaves" and petioles of celery, which was grown on muck soil in New York (132) was much lower than those found in this study.

Influence of Variety on Magnesium and Nutrient Content

The results obtained in the various experiments indicate that inherent variation was associated with differential nutrient absorption and accumulation patterns.

Wallace and Lunt (166) concluded that the most striking single factor related to chlorosis was the variation in susceptibility both among and within plant species. Although inheritance of Fe utilization in the soybean (170) and Mg and B utilization in celery (133) has been shown to be controlled by a single gene, in other cases (63, 93, 94) the genetic complex for efficient utilization or for toxicity resistance has been proved to be complex. Gorsline et al. (63) found that the differential accumulation of Ca, Mg and K in the ear-leaves of single

crosses of maize was highly inherited under an essentially gene additive scheme.

Internal factors of nutrient efficiency have to be considered in relation to a number of integrated processes, such as absorption, translocation, and assimilation, which include in part, one recognized variable (165) namely, differential nutrient uptake, as shown by the concentration or total content of an element in shoots or roots.

Differential Nutrient-Element Interrelationships

The variable interrelationships among nutrient-elements in tissue of the celery plant may be manifestations of inherent variation influencing various bio-chemical and physical functions and differential Mg treatment as indicated by this study. However, general trends were indicated. For example, higher rather than lower Fe and Al concentrations and contents were associated with chlorosis of Sp. 162 and U. 10B varieties and among selections of the Greenlite variety. On the other hand, lower rather than higher Mg and P concentrations were associated with the same inter- and intra-varietal differences of chlorosis. These data indicate that a reciprocal Fe-Al/Mg-P relationship may be independent of the crop even though varietal variations prevail. That is, an increase in the concentration of Mg and P in the plant was associated with a concomitant decrease in Fe and Al content. Cooper et al. (36, 37) reported a close correlation between the relative strength of ions and the relative amount of the nutrients in the plants. Therefore, a possible explanation of the observed phenomena may be the relative strength of ions, as measured by their normal electrode potentials (98) which is a measure of the intensity factor of energy rather than of the capacity or quantity factors.

However, Hoffer (78) found that the absorption abilities of selfed lines and crosses of maize varied widely with respect to Fe and Al, and that hybrid vigor was associated with a tendency to absorb less Fe and Al. Also, the susceptibility of lines to develop a heritable type of leaf injury was associated with higher amounts than normal of Al and Fe.

Tissues intermediate between the source of the nutrient supply and the site of ultimate utilization, may during the ontogeny of the plant, differentially accumulate nutrients. Even though the meristems probably have primary consideration in nutrient distribution and may induce deficiencies, which were characterized by the withdrawal of some nutrients, intermediate tissues with apparent zones of accumulation may preclude acropetal translocation. For example, the data from this investigation indicated that the stem plate and specifically the transition region was a zone in which accumulation of Fe and Al occurred and reduced the translocation of other nutrients especially in the U.10B variety.

The data support the findings of various investigators, who found that varietal differences do influence the absorption and accumulation of nutrients. Rabideau et al. (134) found that P^{32} was differentially accumulated by two inbred maize lines and their hybrids. Maume et al. (121, 122) were able to demonstrate varietal differences in the absorption and accumulation of N, P, K, S, Ca, and Mg by wheat grown under the same conditions. Also, certain indicator plants have the capacity to accumulate large quantities of certain nutrients and Al (83).

It appears that the capacity of plants to differentially accumulate nutrients was associated with the formation of insoluble oxalates and pectates (37). Although Brown (22) achieved an apparent Fe-P precipitation, which reduced their mutual translocation in soybeans, Biddulph (12) reported that the ferric ion reduced P translocation which may

explain the mechanism of Fe accumulation in the nodes of maize as reported by Sayre (129). Since Fe and Al values were higher in stem plate tissue of chlorotic than normal selections, and differences in P values between tissues of chlorotic plants did not generally show increases from root to top to the same extent as observed in normal plants, it is possible that Fe and Al interfere with P mobility and activity by complexing with phosphate (91, 135). This might result in immobilizing the P or precipitating and incorporating it into cellular tissues which ultimately decrease permeability (142).

SUMMARY AND CONCLUSIONS

Chlorosis of celery varieties was generally not related to Mg composition but more closely associated with the Al and Fe composition of the blade and stem plate tissues.

The Fe and Al composition decreased with applications of Mg ranging from 25 to 125 lbs. per acre, but growth was not closely associated with increased Mg levels.

Chlorosis of leaf tissue occurred when Fe, Al and less frequently P, accumulated in the stem plate and specifically the transition region. These differences in nutrient-element content were consistently attributable to inherent variation irrespective of the imposed Mg regimen. Utah 52-10B, a chlorosis susceptible variety, contained relatively more Fe and Al than Spartan 162, a chlorosis resistant variety.

It was found that an increase in the concentration of Mg and P in the plant was associated with a concomitant decrease in the Fe and Al content and occurred independent of selection or variety of celery but was differentially influenced by variable Mg levels.

Variety and Mg treatment occasionally did not exert their influences independently on the nutrient-element composition as was shown by the significant interaction between various treatments on varietal response. Therefore, the significant interactive effect of treatment and variety ascertains the interdependence of the nutrient-element content and precludes the unqualified use of overall varietal and treatment means.

Future improvements in crop performances must consider the differential effects of very small changes in the genetic constitution

of the plant on nutrient uptake and assimilation as influenced by various environmental conditions.

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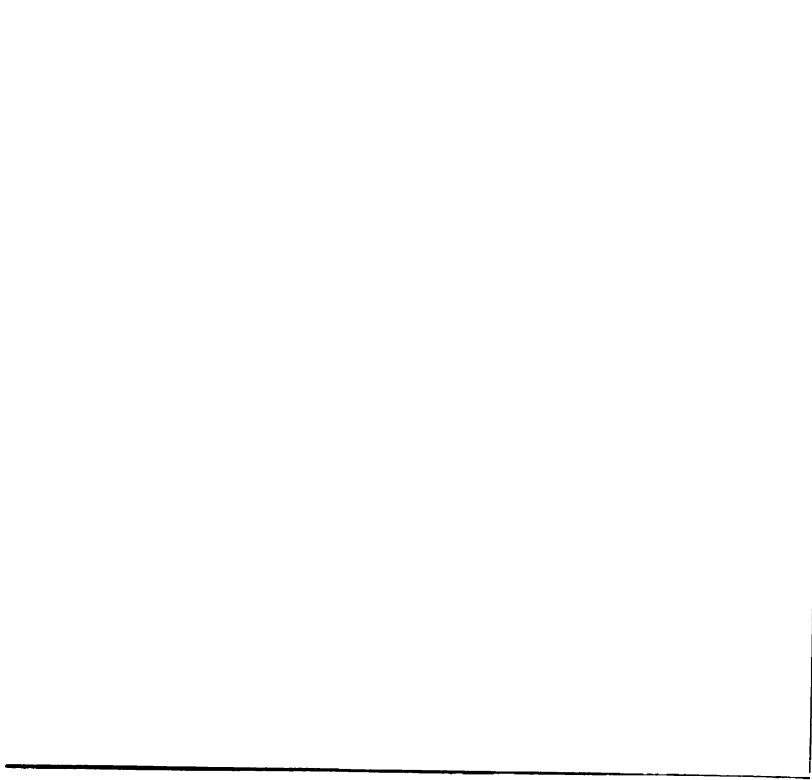
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