ALLEVIATION OF OCCURRENCE OF TIPBURN AND INTERNAL ROT IN TROPICAL CHINESE CABBAGE

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ABSTRACT

In summer Chinese cabbage cultivation, both tipburn and internal rot are very serious problems which are generally considered to be caused by calcium deficiency associated with a variety of environmental, physiological or nutritional factors.

Research carried out at AVRDC indicates that ammonia (NH_4-N) toxicity, rather than calcium deficiency is a more direct cause of tipburn in summer-grown Chinese cabbage. Ca deficiency is brought about by water stress due to root damage caused by NH_4-N toxicity. The head formation stage is the most sensitive period to tipburn ; hence, the deleterious effect of NH_4-N should be avoided at this stage.

Effective measures to reduce tipburn include the suppression of the initial plant growth by covering outer leaves with rice straw, use of split nitrogen application, and omission of heavy nitrogen fertilizer application at any growth stage. Attenuation of soil moisture fluctuations by compost application, water management and mulching are also effective measures for alleviating the incidence of tipburn and internal rot.

Internal rot was caused by limited Ca translocation into head leaves, vigorous growth rates and use of round-shaped heading cultivars. Measures to reduce internal rot include foliar spray of citric acid, covering outer leaves before head formation, split application of nitrogen fertilizer, selection of long-headed cultivars and acceleration of rooting by water management.

Introduction

Tipburn in summer-grown Chinese cabbage is a serious problem confronting most growers. The cause of the tipburn is generally attributed to calcium deficiency associated with a variety of environmental, physiological or nutritional factors (Collier, 1982 ; Misaghi and Grogon, 1978 ; Palzkill *et al*., 1976 and 1980 ; Shafer and Sayer, 1946). The calcium deficiency was traced either to a low amount of available soil calcium, or to the inhibition of calcium absorption and translocation in the plant.

The soil science research group at AVRDC has recently confirmed that ammonium toxicity, which causes root damage and subsequent water stress is the direct cause of tipburn in summer Chinese cabbage cultivation (Soil Science, 1985 and 1987 ; Imai, 1987 ; Imai *et al*., 1988).

This project aimed to develop cultural practices for soil as well as water and fertilizer management which could minimize the occurrence of tipburn and internal rot in summer Chinese cabbage.

Materials and methods

Part I : Two sand culture experiments were conducted from the autumn of 1983 to the spring of 1985 at the AVRDC greenhouse, in order to examine the relationship between the incidence of Chinese cabbage tipburn and the time of nitrogen application as well as N form and concentration.

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In experiment 1, sixteen days old seedlings of the Chinese cabbage cultivar Fong-luh were transplanted to sand-filled pots, and allowed to grow until harvest, at 47 days after treatment (DAT). The apparatus and composition of the culture solution used for this experiment were described elsewhere (Soil Science, 1985).

The cultivar ASVEG 1 which had been grown in a smoked rice hull medium for eighteen days, was transplanted on April, 1984 and harvested on May 25, 1984. The duration of cultivation until harvest was 42 days.

Part II : Four greenhouse experiments were conducted to develop integrated cultural practices which would minimize the incidence of tipburn and internal rot in Chinese cabbage. In addition to these experiments, two field experiments were performed to examine the effects of compost application and soil pH on the frequency of tipburn incidence, and also to test four heat-tolerant cultivars on their susceptibility to internal rot and tipburn.

The experiments were carried out from the summer of 1984 to the autumn of 1985. All the seedlings used had reached the fourth foliage stage. The seedlings were, therefore, transplanted at 17 to 20 days after sowing (DAS) in the spring and summer trials, and 28 to 32 DAS in the autumn trial.

Results and discussion

Part I NH_4-N toxicity and tipburn

1 Appearance of tipburn symptoms

In experiment 1, all of the plants grown with NH_4-N showed symptoms of tipburn 7 days after treatment (DAT). Leaves turned dark green and wilted ; the edges of outer leaves curled upward, and the young leaves were wrinkled and poorly developed Symptoms appeared first on the young leaves, and then later on the outer, more fully developed leaves.

When NO_3-N applied until the head formation stage of the plants was replaced by NH_4-N, the symptoms of tipburn suddenly appeared five days after the change in the nitrogen source. Plants grown with NH_4-N before the head formation stage, and with NO_3-N afterwards, however, quickly recovered after the switch in the nitrogen form, and their leaves soon began to grow normally.

The same phenomenon was observed in the roots. Roots of plants grown with NH_4-N were short, dark, lignified, and easily broken while roots of plants grown with NO_3-N were more numerous and were long, slender, and white, with abundant hairs.

In experiment 2, in all the plants which received NH_4-N from the beginning the leaf color became dark green from six DAT. Slight tipburn symptoms appeared at 10 DAT. Although the tipburn symptoms were slightly alleviated by increased applications of calcium in experiment 1, tipburn developed only on plants which received NH_4-N regardless of calcium concentrations.

2 Plant growth and yield

Plants which received NO_3-N throughout their growth period gave the highest yields, and those grown with NH_4-N the lowest (Table 1). Generally, plants receiving less nitrate before head formation (BHF), i. e. 4 meq or 8 meq, grew more slowly and had reduced head yields. The opposite was observed in plants grown with NH_4-N. In the treatment in which plants were grown with NO_3-N until the head formation stage, and then the nitrogen source was switched from nitrate to ammonia, a sudden reduction of plant growth could be observed and the yields were considerably lower than when the plants received NO_3-N after head formation (AHF). These findings indicate that ammonia applications AHF cause greater loss in yield, and that higher rates of application of ammonia AHF will cause more pronounced yield losses.

In experiment 2, the plants which received NH_4-N before and after the head forma-

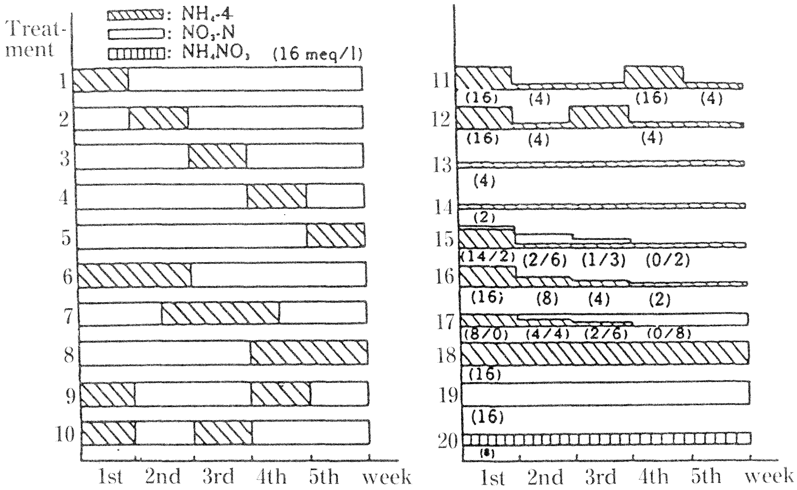

Fig. 1 **Nitrogen treatments** (Experiment 2)
Numerical values in parenthesis indicate the nitrogen concentration in meq/l.

Table 1 Effect of form and concentration of nitrogen and Ca concentration on the head yield of Chinese cabbage (Experiment 1)

N form and concentration (meq/l)		Dry weight of head (g)			Average
BHF[z]	AHF[y]	0	4	8	
		(Ca concentration meq/l)			
NO_3 16	NO_3 16	61.8 a	57.2 a	59.7 a	59.5a[x]
NO_3 8	NO_3 16	54.1 ab	57.7 a	55.0 a	55.6 a
NO_3 8	NH_3 16	17.0 cd	18.0 c	20.2 b	18.4 c
NO_3 8	NH_3 8	21.3 cd	34.1 b	28.9 b	28.1 b
NO_3 4	NO_3 16	35.3 b	35.6 b	27.3 b	32.7 b
NO_3 4	NH_4 16	9.5 cd	10.2 c	7.9 c	9.2 d
NH_4 16	NO_3 8	15.3 c	5.6 cd	5.9 c	8.9 d
NH_4 16	NH_4 8	3.1 d	1.7 cd	1.1 c	2.0 e
NH_4 8	NO_3 8	13.4 cd	14.5 c	3.5 c	10.4 d
NH_4 8	NH_4 8	4.3 d	4.6 cd	2.9 c	3.9 de
Average		23.5 a	23.9a	21.2 a	

[z] Before head formation.
[y] After head formation.
[x] Means within a column followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test.

tion stage (BAHF), gave the lowest yields irrespective of the concentration (Table 2, Treatments 11 to 14, 16, 18). The highest yields were obtained from plants which received NH_4-N for the first week only and from then on NO_3-N (Treatment 1) and the second highest yields with NO_3-N BAHF (Treatment 19). Hence, the application of NH_4-N only in the early growth period is recommended.

The addition of 4 meq Ca increased yields slightly, but not to a statistically significant degree (Experiment 1). The addition of 8 meq Ca, however, retarded the plant growth due to the increase in the salt concentration in the nutrient solution. Although 4 meq of

Table 2 CaO contents in the leaves and frequency of the incidence of tipburn and internal rot in ASVEG 1

Treatment[z]	Head	CaO % (dry wt basis)				Internal	Tipburn[x]
	dry weight	Head blade	Head midrib	Outer blade	Outer midrib	rot[x]	
1	42.10 a	0.27 ab[y]	1.20 a	7.07 ab	3.03 ab	* *	
2	36.25 abc	0.18 cdef	1.18 a	6.66 abc	3.27 abc	* * * *	
3	34.55 bcd	0.18 cdef	1.17 a	6.56 abc	3.01 bcd	* * *	* *
4	28.30 de	0.23 bc	1.05 abc	7.23 a	3.60 a	* * * *	
5	34.55 bcd	0.19 cde	0.87 d	6.25 cdef	2.94 bcd	* * * *	
6	30.70 cde	0.32 a	1.16 a	6.39 bcde	3.03 bcd	*	
7	18.55 gh	0.26 b	0.96 bcd	5.12 g	1.87 g		* * * *
8	31.15 cde	0.14 ef	0.66 e	5.75 efg	2.71 de	* * * *	
9	29.80 cde	0.17 cdef	0.88 d	5.57 fg	2.39 ef	* * * *	
10	34.75 bcd	0.18 cdef	1.08 ab	5.89 def	2.42 ef		* * * *
11	9.25 ij	0.16 def	0.47 f	1.79 j	0.79 h	* *	* * * *
12	11.15 ij	0.16 def	0.47 f	2.38 ij	0.78 h	* *	* * * *
13	8.90 ij	0.14 ef	0.55 ef	2.94 hi	1.02 h	* *	* * * *
14	12.40 i	0.12 f	0.62 ef	3.41 h	2.16 fg	* *	* * * *
15	25.25 ef	0.13 ef	0.68 e	5.60 fg	3.50 a	* *	* * * *
16	12.90 hi	0.14 ef	0.50 f	2.87 hi	0.98 h	* * *	* * * *
17	34.95 bc	0.16 def	0.91 cd	6.26 cdef	3.25 abc		* * * *
18	5.80 j	0.17 cdef	0.47 f	2.22 ij	0.69 h	* *	* * *
19	39.90 ab	0.22 bcd	1.07 ab	7.11 ab	3.56 a	* * *	
20	21.25 fg	0.21 bcd	0.98 abcd	6.26 cdef	2.90 cd	* * * *	

[z] Refer to Fig. 1.

[y] Means within a column followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test.

[x] Symbols indicate the relative extent of internal rot and tipburn damage : * slight : * * medium : * * * severe : * * * * very severe.

Ca was supplied to all the treatments in experiment 2, tipburn developed only in plants treated with NH_4-N. These facts indicated that tipburn was caused by ammonia toxicity rather than by Ca deficiency.

3 Effect of timing and concentration of nitrogen application on the occurrence of tipburn

Only the plants which received ammonia in the third week developed tipburn symptoms on the young leaves (Table 2). Since head formation started during the second week of the treatments, Chinese cabbage was most susceptible to tipburn during the head formation stage. Tipburn symptoms were detected in Treatments 3, 7 and 10 through 18. In Treatments 3, 7 and 10, NH_4-N was applied during the head initiation period, while in Treatments 11-18, NH_4-N was applied from the initial growth stage either until the head formation stage or harvest. Tipburn also occurred though the concentration of NH_4-N was as low as 2 meq, suggesting that the nitrogen source is more important than the total application rate as a cause of tipburn.

4 Effect of nitrogen treatment on Ca and N uptake

The distribution of Ca in the leaf blades and midribs of treated plants together with the frequency of tipburn and internal rot occurrence is presented in Table 2. Regardless of the NH_4-N concentration, the Ca content of the plants which received NH_4-N BAHF was lower (Treatments 11-14, 16 and 18) as NH_4-N application inhibited Ca uptake by Chinese cabbage due to severe root damage and/or competitive inhibition of Ca uptake. Ca content in the outer leaves was 10 to 30 times higher than that in the head leaves. Since Chinese cabbage transpires chiefly from the outer leaves after head formation, and Ca is mainly transported through the transpiration stream, Ca tends to accumulate in the outer leaves, especially in the leaf blade.

In experiment 1, the Ca concentration in leaves was also markedly affected by the nitrogen source. Plants which received NO_3-N BHF and NH_4-N AHF showed a much lower Ca content in the inner leaf blade than plants which received NO_3-N BAHF (data not shown).

Total nitrogen content in the leaf blades of the head leaves was always found to be higher than in the midribs (Table 3). In Treatments 4, 7, 8, and 18 where yield losses were large due to NH_4-N application 4 weeks after the treatment, a large amount of nitrogen accumulated in the head leaves. In addition, the ratio of N content in the leaf blade to that in the midrib was well correlated with the frequency of tipburn occurrence (Table 2). The ratio was less than 1 or, at most, higher than 1 in plants without tipburn symptoms and considerably higher than 1 in plants with symptoms. These facts indicate that further metabolic transformation of NH_4-N to protein by way of amino acids and amides in the active assimilation sites was retarded due to the high NH_4-N supply.

There was a close correlation between the nitrogen and Ca contents in leaves and head dry weight (Table 4). Nitrogen content in the head leaf was negatively correlated with the head weight. This also indicated that NH_4-N accumulated in the leaf blade of the head leaves with tipburn symptoms. Both the Ca/N ratio and Ca content were closely correlated with the weight.

5 Effect of nitrogen treatment on internal rot incidence

It is difficult to analyse the relationship between the incidence of internal rot and the factors involved in the treatment of experiment 2, as internal rot occurred in all the treatments except for Treatments 7, 10 and 17. Although internal rot was aggravated by later application of NH_4-N, it occurred even when plants received NO_3-N and no correlation could be established between the Ca content of the head and internal rot frequency.

In experiment 1, among the treatments, internal rot was noted only in plants which

Table 3 Distribution of total nitrogen content in leaves of ASVEG 1

Treatment[z]	Total nitrogen (%)				
	Head leaf		Outer leaf		
	blade	midrib	blade	midrib	blade/midrib ratio
1	3.86 efgh[y]	3.22 cdef	4.01 bcd	4.61 a	0.87
2	4.03 efgh	3.38 cd	4.24 bcd	4.19 abc	1.01
3	4.35 def	3.51 bc	4.47 b	3.91 bc	1.14
4	5.23 ab	3.95 a	4.33 bc	4.13 bc	1.05
5	4.23 defg	4.00 a	4.14 bcd	4.33 ab	0.96
6	4.03 efgh	3.16 cdef	4.14 bcd	4.30 ab	0.96
7	4.82 bcd	3.98 a	4.62 b	3.39 de	1.36
8	4.82 bcd	4.18 a	3.98 bcd	3.81 cd	1.04
9	4.30 def	3.83 ab	4.57 b	3.81 cd	1.20
10	4.37 def	3.55 bc	4.53 b	3.80 cd	1.19
11	4.44 cde	2.85 fg	3.26 ef	2.28 f	1.43
12	4.34 def	2.74 g	3.62 de	2.13 fg	1.70
13	4.15 efg	2.99 defg	2.32 fg	2.01 fg	1.15
14	3.43 h	1.53 j	2.17 h	0.99 g	2.19
15	3.77 fgh	1.97 i	2.15 h	1.10 h	1.95
16	3.65 gh	2.36 h	2.81 fg	1.81 h	1.55
17	4.10 efg	2.95 efg	3.67 cde	3.03 e	1.21
18	5.04 bc	3.97 a	5.59 a	4.02 bc	1.39
19	4.15 efg	3.30 cde	3.70 cde	4.31 ab	0.86
20	5.74 a	4.15 a	3.07 ef	3.30 e	0.88

[z] Refer to Fig. 1.

[y] Means within a column followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test.

Table 4 Correlation coefficients between leaf nutrient content and head dry weight[z]

Nutrient content		Head dry weight	
		Fong-luh	ASVEG 1
T-N in	Head leaf blade	−0.445 **	−0.127 ns
	Head leaf midrib	−0.246 ns	0.293 ns
	Outer leaf blade	−0.137 ns	0.290 ns
	Outer leaf midrib	0.494 **	0.648 **
CaO in	Head leaf blade	0.049 ns	0.385 *
	Head leaf midrib	0.469 **	0.821 **
	Outer leaf blade	0.575 **	0.904 **
	Outer leaf midrib	0.418 **	0.859 **
Ca/N in	Head leaf blade	0.149 ns	0.462 **
	Head leaf midrib	0.472 **	0.561 **
	Outer leaf blade	0.533 **	0.571 **
	Outer leaf midrib	0.209 ns	0.080 ns

[z] ns : not significant ; *significant at the 5% level ; **significant at the 1% level.

received high concentrations of NO_3-N BAHF, in which cases the Ca content was well correlated with the rate of Ca application. Thus, it appears that there was no correlation between the Ca content and the incidence of internal rot. However, it was confirmed that compact heads associated with excessive growth following a high rate of basal nitrogen application, promoted the incidence of internal rot.

Part II Integrated cultural practices to alleviate tipburn and internal rot

1 Effect of foliar spray of Ca salts and organic acids

In experiment 3, foliar spray of Ca salts could not cure tipburn in Fong-luh and internal rot in ASVEG 1 (Table 5). Citric acid, however, increased the yield and significantly decreased the frequency of tipburn incidence. Thus, there was a sizeable difference in the frequencies of tipburn and internal rot incidence between the two cultivars : Fong-luh was more susceptible to tipburn than to internal rot and the opposite was true for ASVEG 1.

In experiment 4, foliar citrate spray reduced the incidence of internal rot unlike malic acid and Ca citrate (Table 6a). Citric acid is a strong ligand which forms chelate compounds with Ca after penetrating into plant tissues to convert insoluble Ca compounds to water soluble forms. As a result, translocation of Ca to the head leaves is facilitated. Since malate, on the other hand, is a weak chelator, it cannot dissolve a sufficient amount of insoluble Ca.

As mentioned previously, ASVEG 1 was very susceptible to internal rot, unlike Fong-luh which had a long head composed of many leaves with equal weight and similar upward growth rate. On the other hand, ASVEG 1 is composed of few, rather heavy, thick leaves. As the inner leaves close in upon themselves in the shape of a balloon, they apply a pressure that is not easily released upward as in the case of Fong-luh. Therefore, the increase in nitrogen and compost rates, temperature, and water supply results in a rapid growth rate that applies a strong physical pressure inside the head, creating a condition conducive to internal rot.

Since the Ca foliar spray affected the N/Ca ratio of the heading leaves and delayed heading time the head shape switched from round to long, and the inner pressure was released upward.

Table 5 Effect of fertilizer application, cover materials and foliar spray on the incidence of tipburn and internal rot in Chinese cabbage (Experiment 3, Autumn, 1984)

	Treatments	Fong-Luh			ASVEG 1	
		Head weight (g/plant)	Tipburn	Internal rot	Head weight (g/plant)	Internal rot
1	Liquid NH_4-N[x]	939 ab	0	0	864 a[z]	0[y]
2	Liquid NO_3-N[w]	1049 a	0	0	912 a	0
3	Solid NH_4-N[v]	657 bc	3	0	675 ab	3
4	Covering BHF[u]	631 bc	1	1	719 ab	2
5	Covering AHF[t]	359 c	4	0	565 b	2
6	Covering BAHF[s]	528 bc	3	1	573 b	2
7	Covering AHF+Ca-cit FS[r]	449 bc	5	0	533 b	3
8	Covering+Ca-cit FS, AHF[q]	469 bc	4	0	476 b	3
9	Ca-cit FS	647 bc	5	0	801 ab	2
10	$CaCl_2$ FS[p]	687 b	5	0	551 b	4
11	CA FS[o]	802 ab	0	2	810 ab	2
12	Water FS	573 bc	1	0	776 ab	2

[z] The same letters are not significantly different at 5% level by Duncan's Multiple Range Test.
[y] Each score was obtained by rounding the average value of four samples. Numerals indicate the relative extent of tipburn and internal rot damage : 1=Very slight ; 2=Slight ; 3=Medium ; 4=Severe ; 5=Very severe.
[x] 0.25 g N dissolved in water was applied twice a week by $(NH_4)_2SO_4$.
[w] Same as in Treatment 1 except N source ($NaNO_3$).
[v] 2-2-2.5 g/pot (N-P_2O_5-K_2O) as basal and 1 g N at the head initiation time.
[u] Outer leaves were covered with a black vinyl sheet before head formation.
[t] After head formation.
[s] Before and after head formation.
[r] 50 ml/pot of Ca citrate at a concentration of 0.0005 *M* was sprayed twice a week throughout the cultivation period
[q] Both foliar spray and covering were commenced after head formation.
[p] $CaCl_2$ foliar spray.
[o] Citric acid foliar spray.

2 Effect of N split application on the incidence of tipburn and internal rot

In experiment 3, split application of liquid nitrogen induced the formation of the heaviest head without any symptoms of tipburn and internal rot (Treatments 1 to 3, Table 5) because the nitrogen concentration did not increase steeply. As a result, NH_4-N toxicity was avoided, and the initial vigorous growth was suppressed.

High application rate of basal nitrogen stimulated the initial growth and resulted in large total and head weights (Table 6b). However, the plants experienced severe internal rot. Although the incidence of internal rot was slightly reduced by N split application, it could not be eliminated completely, as in the autumn trial. In the spring both temperature and light intensity increased markedly from the head initiation time onward. Therefore, as high temperature accompanied by high light intensity accelerated the inner leaf growth rate after head formation, tipburn and internal rot could not be completely controlled by N split application alone.

3 Regulation of plant growth rate by the use of cover materials

In experiment 3, the outer leaves were covered with a black vinyl sheet from the time of transplanting to the head formation stage. This treatment resulted in higher yield than in any other treatments, and decreased the frequency of tipburn incidence, but not that of internal rot. Covering after the head formation stage caused a marked decrease in head

Table 6a Experimental design for the evaluation of the effect of N fertilization, foliar spray and IGETAGEL application on the incidence of internal rot in Chinese cabbage (Experiment 4, Spring, 1985)

Fertilization				Other treatments
Basal (N-P_2O_5-K_2O, g/plant)		10 DAT[z]	20 DAT	
1	Liquid NO_3-N[y]			None
2	2-1.5-2.5	1-0-0	None	None
3	3-1.5-2.5	1-0-0	1-0-0	None
4	3-7.5-2.5	1-2.5-0	1-2.5-0[x]	None
5	2-1.5-2.5	1-0-0	None	Ca-cit, FS, BHF[w]
6	2-1.5-2.5	1-0-0	None	CA FS, BHF
7	2-1.5-2.5	1-0-0	None	Malate FS, BHF
8	2-1.5-2.5	1-0-0	None	Covering, BHF
9	2-1.5-2.5	1-0-0	None	Leaf tying, BHF
10	2-1.5-2.5	1-0-0	None	IGETAGEL (5%)[v]
11	2-1.5-2.5	1-0-0	None	IGETAGEL (2%)
12	3-7.5-2.5	1-2.5-0	1-2.5-0[x]	IGETAGEL (5%)

[z] Days after transplanting.

[y] 0.25 g N dissolved in water was applied twice a week.

[x] N and P were applied together in the form of $(NH_4)_2HPO_4$.

[w] Ca-citrate foliar spray before head formation.

[v] IGETAGEL was mixed with the soil surrounding plants (15 cm in diameter and 10 cm in depth).

Table 6b Effect of N fertilization, foliar spray and IGETAGEL application on the incidence of internal rot in Chinese cabbage (Experiment 4, Spring, 1985)

Treatment No.[z]	Total weight (g/plant)	Head weight (g/plant)	Internal rot
1	1375 c[y]	850 bcd	2[x]
2	1430 abc	905 bcd	4
3	1680 ab	1048 ab	3
4	1525 abc	1043 ab	3
5	1410 abc	898 bcd	3
6	1500 abc	953 abcd	2
7	1690 a	1005 abc	3
8	1395 bc	770 de	0
9	1095 d	588 e	0
10	1420 abc	803 cd	3
11	1440 abc	900 abcd	3
12	1645 abc	1085 a	2

[z] Refer to Table 3.

[y] Means followed by the same letter in the same column are not significantly different at the 5% level based on Duncan's Multiple Range Test.

[x] Refer to Table 1.

weight and enhanced the incidence of both tipburn and internal rot.

In experiment 4, covering or leaf tying before the head formation stage completely eliminated internal rot, but both the total and head weights decreased.

In experiment 5, the blue film cover resulted in a considerable yield loss, aggravated tipburn, but completely eliminated internal rot. Red film and rice straw covers markedly decreased the incidence of both disorders (Table 7a). Covers should thus applied one week after transplanting up to the head formation stage.

4 Effect of water management on tipburn and internal rot

Irrigation through pipes buried at a 10 cm or 20 cm depth effectively decreased the incidence of tipburn and internal rot (Table 7b). Initial growth was slightly retarded before the water reached the plant roots ; but thereafter, this irrigation method accelerated root development and minimized the incidence of both tipburn and internal rot.

In experiment 6, the combination of red or yellow film covers with buried pipe irrigation completely controlled internal rot (Table 8a, 8b). It is considered that the growth rate can be suppressed by covering or enhanced by N and water application at the desired time to eliminate tipburn and internal rot without a concomitant decrease in yield. Application of fertilizers through a pipe together with irrigation water is the best technique as nitrogen can be distributed more evenly in the soil. As a result, N localization is avoided and the incidence of internal rot decreases.

5 Field experiment

In experiment 1, compost application enhanced the incidence of internal rot in ASVEG 1 (Table 9) while the soil pH, except at 4.5, did not affect the frequency of internal rot incidence.

In experiment 2, Hybrid 82-157 was not affected by internal rot (Table 10). Since this cultivar has a slightly smaller and less compact head than ASVEG 1, N split application decreased the incidence of internal rot. The results of the field experiments were in agreement with those obtained in the greenhouse experiments.

A summary of the countermeasures to alleviate the incidence of tipburn and internal rot is given in Table 11.

Table 7a Experimental design for evaluation of the effect of cover materials and irrigation methods (Experiment 5, Summer, 1985)

Treatment No.	Material[z] added	Cover meterials	Irrigation[x] Pipe	Fertilizer[w]	Boric[v] acid
1	GG	—	—	Solid	—
2	GG	〃	〃	〃	+
3	QS	Red film 2	〃	〃	〃
4	QS	Blue film 2	〃	〃	〃
5	QS	Rice straw 2	〃	〃	〃
6	GS	No	〃	〃	—
7	〃	〃	〃	〃	+
8	〃	Red film 2	〃	〃	〃
9	〃	Blue film 2	〃	〃	〃
10	〃	Rice straw 2	〃	〃	〃
11	—	Red film 1	+	〃	〃
12	〃	〃 2	〃	〃	〃
13	〃	Blue film 1	〃	〃	〃
14	〃	〃 2	〃	〃	〃
15	〃	Rice straw 1	〃	〃	〃
16	〃	〃 2	〃	〃	〃
17	〃	—	2 pipes at 10,20cm	〃	—
18	〃	〃	2 pipes at 10,20 cm	〃	〃
19	〃	〃	1 pipe at 10 cm	〃	〃
20	〃	〃	1 pipe at 20 cm	〃	〃
21	〃	〃	+	Liquid	〃
22	GG	〃	〃	〃	〃
23	QS	〃	〃	〃	〃
24	—	—	—	Solid	〃

[z] Material added : GG, Gypsum granule ; QS, Quartz sand. These materials are mixed with soil in the ratio of 2 to 50 on weight basis. — : No addition.

[y] Cover : Red film 1 ; Plant is covered with red plastic film for 2 weeks from 1 week after transplanting (Aug 28-Sep 11)
Red film 2 ; Covered for 2 weeks from 2 weeks after transplanting (Sep 4-Sep 19)
Blue film, covered with blue plastic film
Rice straw, outer leaves of plant are covered with rice straw.
Numerals following cover materials have the same meaning as those for the red film treatment

[x] Irrigation pipe : Water is applied. + ; through an irrigation pipe buried at the depth of either 10 cm or 20 cm
— : ordinary watering.

[w] Fertilizer : Solid ; Solid fertilizer is applied in the following ratio ;
Fertilization (N-P_2O_5-K_2O, g/pot) : Basal, 1.0-1.5-1.0 ; Top 1 (10 DAT), 1.0-0-1.0 ; Top 2 (20 DAT), 1.0-0-0.
Liquid ; 0.25 g N dissolved in distilled water is applied 3 times a week. All the P, K is added as basal fertilizer.

[v] Boric : + ; 500 mg of boric acid is added to each plant. — ; No.

Table 7b Effect of cover materials, irrigation methods and boron application on the incidence of tipburn and internal rot in Chinese cabbage (Experiment 5, Summer, 1985)

Treatment No.	Total weight (g/plant)	Head weight (g/plant)	Tipburn	Internal rot[z]
1	1020 hi	435 f	1	0
2	1015 hi	460 ef	4	0
3	1060 ghi	520 def	0	1
4	1165 fgh	555 def	0	0
5	630 k	205 g	4	0
6	720 jk	230 g	4	0
7	685 jk	225 g	4	0
8	870 ij	215 g	0	0
9	1220 fgh	550 def	1	0
10	1215 fgh	545 def	0	0
11	1285 efg	690 bcd	0	1
12	1210 fgh	560 def	0	0
13	1355 cdef	740 bcd	0	1
14	1495 abcde	700 bcd	1	3
15	1230 fgh	615 def	0	3
16	1290 efg	665 cde	3	3
17	1525 abcd	855 abc	0	1
18	1575 abc	855 abc	0	1
19	1605 a	965 a	0	1
20	1590 ab	905 ab	0	1
21	1600 a	955 a	0	1
22	1480 abcde	730 bcd	0	3
23	1365 bcdef	670 cde	0	1
24	1310 def	610 def	0	4

[z] Refer to Table 1.

[y] Means followed by the same letter in the same column are not significantly different at the 5% level based on Duncan's Multiple Range Test.

Table 8a Experimental design for evaluation of the effect of cover materials and irrigation methods (Experiment 6, Autumn, 1985)

Treatment No.	Cover materials	Irrigation[y] pipe	Fertilizer[x]
1	Red film	No	Solid
2	〃	2 pipes at 10 and 20 cm	〃
3	〃	〃	Liquid,0.25 g $NaNO_3$
4	Yellow	No	Solid
5	〃	2 pipes at 10 and 20 cm	〃
6	〃	〃	Liquid,0.25 g $NaNO_3$
7	—	1 pipe at 10 cm	〃 0.25 g$(NH_4)_2SO_4$
8	〃	〃	〃 0.25 g$(NH_4)_2HPO_4$
9	〃	〃	〃 0.25 g $NaNO_3$
10	〃	〃	〃 0.75 g$(NH_4)_2HPO_4$
11	〃	〃	〃 〃 g$(NH_4)_2HPO_4$
12	〃	〃	Solid

[z] Cover : Red film, plant is covered with red plastic film for 2 weeks from 1 week after transplanting. Yellow film similarly, covered with yellow plastic film.

[y] Irrigation pipe : Water is applied. 2 pipes at 10 and 20 cm ; through an irrigation pipe buried at the depth of 10 cm from transplanting to the head formation stage and 20 cm after the head formation, 1 pipe at 10 cm ; through the pipe buried at the depth of 10 cm throughout the growth period stage — : ordinary watering.

[x] Fertilizer : Solid ; solid fertilizer is applied in the following ratio ; (N-P_2O_5-K_2O, g/pot) Basal 2.0-1.5-2.0, Top (10 DAT) 1.0-0-0. Liquid 0.25 g $NaNO_3$; $NaNO_3$ (0.25 g as N) dissolved in water is applied 3 times a week through the irrigation pipe. P_2O_5 and K_2O are applied all as basal fertilizer in the ratio of 1.5 g and 2.0 g/pot, respectively.
Liquid 0.25 $(NH_4)_2SO_4$; Same as above except for the nitrogen form.
Liquid 0.25 $(NH_4)_2HPO_4$; Same as above, but only K_2O is applied as basal fertilizer.
Liquid 0.75 $NaNO_3$; $NaNO_3$ (0.75 g as N) dissolved in water is applied once a week through the irrigation pipe.

Table 8b Effect of cover materials, irrigation methods and N fertilization on the incidence of internal rot in Chinese cabbage cultivar, ASVEG 1 and Hybrid 82-157 (Experiment 6, Autumn, 1985)

Treatment No.	ASVEG 1		Hybrid 82-157	
	Head weight (g/plant)	Internal rot	Head weight (g/plant)	Internal rot
1	873 ef[z]	4[y]	749 bc	1
2	914 def	0	697 c	0
3	1102 abc	0	765 abc	0
4	801 f	4	850 ab	0
5	989 cde	0	733 bc	1
6	1006 bcde	0	867 ab	0
7	1034 bcd	0	770 abc	1
8	970 cde[z]	0	817 abc	1
9	1147 ab	0	874 ab	0
10	1206 a	0	904 a	0
11	1063 abcd	0	850 ab	0
12	1155 ab	0	816 abc	5

[z] Means followed by the same letter in the same column are not significantly different at the 5% level based on Duncan's Multipe Range Test.

[y] Refer to Table 1.

Table 9 **Effect of compost application and soil pH on the yield and frequency of incidence of tipburn and internal rot in Chinese cabbage (Field experiment 1, Summer 1985)**

Treatment	Head yield	Total yield	Frequency of incidence of tipburn and internal rot (%)[z]		
	(ton/ha)		Int (+)	Int (−)	Tipburn
Main plot					
1 Compost 50[x]	21.9 a	39.3a	25.0a	51.9a	0.2 a[w]
2 Compost 25	20.9 a	36.9a	33.0a	45.8a	0.0 a
3 Compost 0	22.2 a	39.8a	27,7a	38.0a	0.0 a
Sub-plot					
1 pH 6.0	24.6 ab	42.4a	34.1a	44.4a	0.3 a
2 pH 5.5	25.3 a	42.8a	35.9a	47.1a	0.0 a
3 pH 5.0	21.5 b	40.3a	37.0a	46.2a	0.0 a
4 pH 4.5	13.3 c	26.9b	8.3b	41.1a	0.0 a
5 Check	23.5 ab	40.9a	27.5a	47.3a	0.0 a

[z] % of total plants harvested.

[y] Int (+) ; internal rot damage was medium to severe, Int (−) ; slight damage.

[x] Compost was applied at the rate of 50 ton/ha.

[w] The same letters are not significantly different at the 5% level by Duncan's Multiple Range Test.

Table 10 **Effect of cultivar, high seedling pot and fertilization on the yield and frequency of tipburn and internal rot in Chinese cabbage (Field experiment 2, Summer, 1985)**

Treatment	Head yield (t/ha)	Total yield (t/ha)	Frequency of tipburn and internal rot (%)		
			Int (+)	Int (−)[z]	Tipburn
Main plot					
Cultivar.					
1 ASVEG 1	29.5 a	50.4 a	24.1b	43.2 a	0.0 a
2 82-157	22.2 a	44.6 a	0.4 c	9.8 b	0.0 a
3 77M(3)-27	26.4 a	47.1 a	51.7 a	26.6 ab	0.7 a
4 77M(2)-35	26.6 a	49.7 a	29.1 b	30.5 a	0.0 a
Sub-plot					
Seedling pot :					
1 High pot	24.9 b	48.8 a	25.3 a	31.9 a	0.5 a
2 PE pot[y]	27.5 a	47.1 a	27.3 a	23.1 a	0.0 a
Sub-sub-plot					
Fertilization :					
1 F1[x]	26.0 a	48.4 a	20.2 b	25.4 a	0.5 a
2 F2	26.4 a	47.5 a	32.5 a	29.6 a	0.0 a

[z] Int (+) ; internal rot damage was graded medium to severe : Int (−) ; slight damage.

[y] High pot ; Made of a hard PE pipe, 12 cm in diameter 12 cm in height : PE pot ; ordinary seedling pot, 10 cm in diameter 8 cm in height.

[x] Fertilization

	Basal (kg/ha)	Top (kg/ha)	Remark
F1	60-60-60-16	60-60-60-16	$N-P_2O_5-K_2O-MgO$
F2	120-80-100	None	$N-P_2O_5-K_2O$

Table 11 Summary of countermeasures to minimize the incidence of tipburn and internal rot

Hazard	Factors involved	Countermeasures
Internal rot	Limited Ca translocation	Foliar spray of citric acid
	Rapid growth rate	Covering outer leaf BHF N split application Sub-surface drip irrigation
	Balloon head type	Ca foliar spray Select adequate cultivar
	Decreased outer leaf activity	Split N fertilizer application
Tipburn	NH_4-N toxicity	Avoid applying NH_4-N at head initiation time
	Root damage	Increase soil CEC Keep soil moisture constant Avoid heavy fertilization
	Limited root mass	Increase soil mass Enhance rooting by water management
	Rapid initial growth	Split nitrogen fertilizer application Covering outer leaf with rice straw Underground pipe irrigation

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Discussion

Yang Rui (People's Republic of China) : 1. In China, tipburn occurs over wide areas, especially along the coast when a large amount of nitrogen is applied. Could you comment on this aspect ? 2. Are there any differences in the incidence of tipburn and internal rot among chinese cabbage varieties ?

Answer : 1). Soils in coastal areas may be sandy. If heavy application of nitrogen is performed, nitrogen concentration in soil increases, resulting in rapid growth of the plant and root damage, hence the occurrence of tipburn. Heavy application of nitrogen, especially in sandy soils, should be avoided. 2). Long-headed type is associated with tipburn and the balloon type head cultivars are susceptible to internal rot. Therefore, foliar spray of Ca salts and covering of outer leaves before head formation at the early growth stage are effective measures to convert the head shape from round to long type, hence preventing the occurrence of internal rot.