Cabbage development and associated lepidopterous pest complex in the southern USA

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Abstract. The cabbage variety 'Greenback' was grown using similar cultural practices at three locations across the southern USA during a 2-year period. Leaf production, plant development and lepidopterous pest populations were monitored and correlated to heat units as degree-days. Results indicate that significant quadratic and linear relations exist between leaf production and degree-days and that a robust linear model can be used to describe leaf production across the southern region of the USA. Pest populations differed in abundance and species composition among locations and between years. Findings indicate that the greatest variability in population abundance may be due to pest immigration from alternate hosts; therefore, pest management strategies may be most reliably based on weekly or twice-weekly scouting of fields, rather than expending efforts on trying to predict populations from models based on heat units and previous population abundance in individual fields.

Keywords: *Trichoplusia ni; Spodoptera exigua; Plutella xylostella; Pieris rapae; Brassica oleracea*; degree-day; heat units; pest complex

Introduction

Cabbage, *Brassica oleracea* L., is a crop of major importance in the United States and Europe in both acreage and value. Like many other cole crops, cabbage is typically grown in the cool-fall-to-spring period in the warm southern tier of states in the USA while summer production (March through October) is concentrated in the more northerly regions. Because productivity periods and varieties grown vary with location, patterns of growth based on heat units and plant phenological stages have been developed for specific locations, including New York (Isenberg *et al.*, 1975), Florida (Strandberg, 1979) and northern Europe (Theunissen and Sins, 1984).

Such quantitative descriptions of plant growth are useful in integrated pest management (IPM) programmes for predicting plant physiological stages which may differ in susceptibility to pests (Hare, 1983). One purpose of the study reported here, therefore, is to develop a generalized growth pattern model for cabbage in southern Texas, California and Louisiana, and to determine how such a pattern might relate to previously published reports.

Development of IPM programmes is dependent on a thorough understanding, not only of plant growth, but also of pest biology and plant–pest interactions. The population dynamics of specialist and generalist herbivores are often influenced by the nutritional and physiological condition of the host plant (Prestidge, 1982; Futumya, 1983; Lin and Trumble, 1987). A second objective of our study was therefore to monitor populations of insect herbivores in relation to plant growth, with the goal of predicting population development and ultimately of improving pest management strategies.

Materials and methods

Studies were initiated in 1984 at three locations in the southern USA to describe cabbage growth, lepidopterous pest population dynamics and pest distribution across a region where cabbage is grown under similar conditions. Studies were conducted at the Texas Agricultural Research and Extension Center, Weslaco; University of California's South Coast Field Station, Santa Ana; and Louisiana Agricultural Experiment Station, Louisiana State University, at the St Gabriel Research Station.

'Greenback' cabbage was grown in a similar manner at the three locations. Cabbage was direct seeded into 0·4 ha plots at the Texas site on 23 August 1984 and 2 February 1985. Cabbage seedlings were transplanted into 0·4 ha plots at the California site on 4 and 15 March, 1984 and 1985 respectively, and into 0·2 ha plots on 5 March 1984 at the Louisiana site. Common cultivation practices were followed at each site. Plants were grown on 1 m bed spacing, two rows per bed and 25 cm between plants. Plots were fertilized with two applications of 30 lb/acre

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($\approx$33·75 kg/ha) NO_3 during the growing season. No insecticides were applied to the plots.

Research plots at each location were divided into six blocks of equal area for sampling purposes. Sampling was initiated at the 5–6-true-leaf stage in Texas (plants direct seeded) and approximately 1 week after transplanting at the California and Louisiana locations. On ten randomly selected plants per block all insects were enumerated at approximately 7-day intervals from the 5–6-true-leaf stage to cupping stage, i.e. when the plants had formed the basic frame for supporting head growth and the first upright leaves that would form the head wrapper leaves were produced (Strandberg, 1979). Sampling was reduced to five plants per block after cupping and continued until the majority of plants in the field were mature and harvestable.

Plant growth was monitored by counting the number of leaves on randomly selected plants on each sampling date and numbering leaves from the outermost frame leaves to the innermost wrapper leaf covering the head of mature plants. Plant stage was noted on the sampling date as seedling or transplant, pre-cupping, cupping, or mature head (Strandberg, 1979). Insect larval presence on each leaf was noted and recorded by species.

Daily maximum and minimum temperatures were recorded at each site. Heat units were calculated using the method of Arnold (1960) to determine daily degree-days based on the daily maximum and minimum temperatures and were cumulated from transplant date at Louisiana and California and from the sampling date at which plants were in the 5–6-true-leaf stage at the Texas site. The lower threshold of plant development for degree-day calculations was 10°C as suggested by Isenberg *et al.* (1975). Degree-days were calculated for each time period between surveys and were noted along with number of leaves per plant to indicate leaf production to correlate with plant development each year.

Regression analysis was used to develop models describing plant growth in terms of number of leaves regressed on degree-days. Analysis of variance was used to determine whether slope coefficient values differed among locations.

Results and discussion

Surveys to determine plant growth and insect populations were initiated on 5 October 1984 and 1 March 1985 at the Texas site. Plants were at the 7·0 and 6·9-true-leaf stage in 1984 and 1985 respectively. The majority of plants were in the cupping stage at the 13·8-leaf stage which corresponded to 552 cumulative degree-days in 1984 and at the 12·2-leaf stage corresponding to 665 degree-days in 1985. Plants reached the heading stage at 18·4 leaves corresponding to 796 degree-days in 1984 and at 18·0 leaves corresponding to 877 degree-days in 1985. The majority of plants in plots had reached maturity by 1021 degree-days in 1984 and 1164 degree-days in 1985 and surveys were terminated. Results indicate that Greenback variety plants are mature at the 18–20-leaf stage which corresponds to 796–1164 degree-days after the transplant stage in south Texas. In terms of number of days after transplant stage, it took 48–74 days for plants to reach maturity (*Table 1*).

Surveys to determine plant growth and insect populations were initiated on 1 March 1984 and 1985 at the California site. Plants were transplanted into the field at the 4·7 and 10·0-leaf stage and surveys initiated in 1984 and 1985 respectively. Degree-days were calculated as at the Texas site and are noted in *Table 1*. Plants reached cupping stage at 14·8 leaves and 14·7 leaves in 1984 and 1985, respectively. Cumulated degree-days for cupping-stage plants varied between 160 and 269. The low value, 160 degree-days, was for 1985 when plants were transplanted at a much later growth stage, 10·0 leaves versus 4·7 leaves for 1984. Plants had mature heads at the 15·9-leaf stage in 1984 and 16·3-leaf stage in 1985 corresponding to 543 and 342 degree-days respectively. Results indicate that Greenback variety plants are mature at the 15·9–16·3-leaf stage, which corresponds to 543 and 342 degree-days. The low value of 342 days was reached in a year in which plants were transplanted late (i.e. the 10·0-leaf stage). Total number of calendar days to maturity varied between 58 and 78 days after transplant in 1985 and 1984 respectively.

Plant growth and insect populations were monitored, starting on 23 March 1984 at the Louisiana site. Degree-days were cumulated from date of transplanting and surveys were inititated when plants were at the 6·1-leaf stage (*Table 1*). Plants reached the cupping stage at the 14-leaf stage, which corresponded to approximately 419 degree-days. Maturity of the majority of plants was reached on 24 May at approximately 14 leaves and corresponding to 834 degree-days.

Regression analysis of the mean number of leaves on degree-days was used to develop predictive models for plant leaf production (*Table 2*). Significant linear and quadratic relations were indicated from analysis of data from all locations and years (*Table 2*). Correlation coefficients were greater for curvilinear responses relative to linear responses. ANOVA was used to test for equality of slopes among locations and years and results indicated no significant difference in slopes for the linear models (*Table 3*). Consequently, leaf development can be reliably predicted using linear models based on degree-days accumulated from the transplant stage of plant growth. Significant differences were indicated among locations and years for quadratic equations, indicating that separate models are necessary for each location if models are based on a quadratic equation.

The increased coefficients of determination achieved using a quadratic model to determine leaf

TABLE 1. Cabbage development in terms of days post-transplant stage (Day), date, cumulative degree-days (DD) and mean number of leaves per survey period (LVS)

	1984					1985				
Location	Day	Date		DD	LVS	Day	Date		DD	LVS
Texas	1	October	5	163	7·0	1	April	1	191	6·9
	8	October	12	281	8·0	15	April	15	376	10·6
	18	October	22	460	11·4	24	April	24	517	10·9
	25	October	29	552	13·8	33	May	3	665	12·2
	32	November	5	615	16·6	40	May	10	773	16·0
	39	November	12	700	17·6	46	May	16	877	18·0
	48	November	21	796	18·4	53	May	23	987	22·0
	54	November	27	840	20·1	63	June	2	1164	22·7
	69	December	12	940	16·4					
	74	December	17	1021	19·4					
California	1	March	19	30	4·7	1	March	29	56	10·0
	8	March	26	74	4·5	8	April	5	112	12·2
	15	April	2	104	6·1	15	April	12	160	14·7
	22	April	9	137	8·3	23	April	19	205	12·9
	29	April	16	195	10·8	30	April	26	247	14·9
	36	April	23	241	13·3	37	May	3	299	16·3
	43	April	30	269	14·8	44	May	10	342	16·3
	50	May	7	322	14·5	51	May	17	398	15·3
	57	May	14	394	15·3	58	May	24	459	14·7
	64	May	21	451	15·9					
	72	May	29	543	15·9					
	78	June	4	603	15·9					
Louisiana	1	March	23	118·3	6·1					
	8	March	30	160·6	8·2					
	14	April	5	205·0	9·3					
	19	April	10	250·6	10·2					
	28	April	19	336·9	12·0					
	35	April	26	418·6	15·9					
	40	May	8	576·3	16·5					
	47	May	15	663·1	14·9					
	54	May	22	743·1	15·2					
	61	May	29	834·2	14·1					

TABLE 2. Regression analysis of mean number of leaves on degree-days at three sites during 1984 and 1985 (y, mean number of leaves; x, cumulative degree-days from date of transplant)

Location	Year	Linear and quadratic relations	Correlation coefficients
Texas	1984	$y = 5{\cdot}0 + 0{\cdot}01x$	$r^2 = 0{\cdot}86$, $P < 0{\cdot}05$
		$y = 0{\cdot}8 + 0{\cdot}03x - 0{\cdot}00004x^2$	$r^2 = 0{\cdot}96$, $P < 0{\cdot}05$
	1985	$y = 3{\cdot}0 + 0{\cdot}02x$	$r^2 = 0{\cdot}95$, $P < 0{\cdot}05$
		$y = 5{\cdot}0 + 0{\cdot}01x + 0{\cdot}000005x^2$	$r^2 = 0{\cdot}96$, $P < 0{\cdot}05$
California	1984	$y = 5{\cdot}5 + 0{\cdot}02x$	$r^2 = 0{\cdot}80$, $P < 0{\cdot}05$
		$y = 1{\cdot}5 + 0{\cdot}06x - 0{\cdot}00006x^2$	$r^2 = 0{\cdot}97$, $P < 0{\cdot}05$
	1985	$y = 11{\cdot}2 + 0{\cdot}01x$	$r^2 = 0{\cdot}57$, $P < 0{\cdot}05$
		$y = 7{\cdot}6 + 0{\cdot}04x - 0{\cdot}00007x^2$	$r^2 = 0{\cdot}86$, $P < 0{\cdot}05$
Louisiana	1984	$y = 7{\cdot}3 + 0{\cdot}01x$	$r^2 = 0{\cdot}68$, $P < 0{\cdot}05$
		$y = 0{\cdot}7 + 0{\cdot}05x - 0{\cdot}00004x^2$	$r^2 = 0{\cdot}96$, $P < 0{\cdot}05$

TABLE 3. Results of analysis of variance of data among locations to test for equality of slopes resulting from regression analysis

Source	d.f.	F	Significance probability $> F$
Model	9	23·9	0·0001
Error	39		
Total	48		
Degree-days (DD)	1	162·5	0·0001
Location (LOC)	4	11·0	0·0001
Interaction (LOC × DD)	4	2·0	0·11

production based on degree-days appears to be due to the growth habit of cabbage. That is, as plants reach maturity, growth is restricted to production of leaves in the main plant stem axil which becomes the cabbage 'head'. However, in the surveys of plant growth these leaves were not counted and therefore once a plant began formation of a head, numbers of leaves remained the same or actually decreased due to loss to senescence or destruction of the oldest leaves by insect feeding or disease. Thus, the curvilinear response indicated by the quadratic model becomes apparent at plant maturity. If the main focus of a pest management programme is to be the period of active outer leaf production, then a robust linear model that describes plant growth across locations can be used (*Table 3*). The period of time when outer leaves are actively being produced is probably the most flexible time for management of pests. Once head formation begins, the threshold for tolerance of pest damage is reduced nearly to zero because the head is the marketable portion and no damage can be tolerated to heads in the marketplace in the USA. Therefore, a linear model that describes leaf production and is developed from data pooled across locations and years may be the most appropriate to use for developing pest management programmes.

Population trends of lepidopterous pest larvae on the untreated cabbage were monitored at each location during both years (*Table 4*). Generalist herbivores including cabbage looper, *Trichoplusia ni* (Hübner); beet armyworm, *Spodoptera exigua* (Hübner); and the diamondback moth, *Plutella xylostella* (L.), were found at the California and Texas sites. A specialist herbivore, the imported cabbageworm, *Pieris rapae* (L.), was found at the California location but not in south Texas or Louisiana. Larval population numbers varied greatly within and among years and locations as indicated in *Table 4*. Cabbage looper larvae were the most abundant pests at the Texas and California sites while diamondback moth and cabbage looper were equally abundant in Louisiana.

Looper population abundance at the Texas site varied from a low of 0·20 (5 October) to a peak of 1·61 (22 October) larvae per plant in 1984 (*Table 4*). Larvae were less abundant in the spring of 1985 with a low of 0·02 on 1 April and a peak abundance of 0·54 larvae per plant on 17 May. Population abundance in 1984 was quite variable and remained high throughout the season. Larval numbers increased steadily throughout the spring 1985 season, corresponding to increasing cumulative degree-days and number of leaves per plant. Cabbage looper population trends at the California site in 1984 and 1985 were similar to those during the spring of 1985 in Texas. Numbers in 1984 varied from a low of 0·0 to a peak on 4 June of 5·06 larvae per plant. Populations in 1985 varied from 0·0 on 29 March to a peak of 7·76 on 3 May. Trends were similar to those found in Texas with numbers of larvae steadily

TABLE 4. Mean number of cabbage looper (LP), beet armyworm (BAW), diamondback moth (DBM), imported cabbageworm (ICW) and total (TOT) larvae per plant on untreated cabbage by survey date at three locations during 1984 and 1985

		1984					1985					
Location	Date	LP	BAW	DBM	ICW	TOT	Date	LP	BAW	DBM	ICW	TOT
Texas	October 5	0·20	0·03	0·00	—	0·23	April 1	0·02	0·03	0·10	—	0·15
	October 12	0·30	0·02	0·00	—	0·32	April 15	0·07	0·00	0·00	—	0·07
	October 22	1·61	0·05	0·00	—	1·67	April 24	0·13	0·08	0·15	—	0·36
	October 29	0·90	0·02	0·00	—	0·92	May 3	0·18	0·03	0·21	—	0·43
	November 5	0·38	0·02	0·00	—	0·40	May 10	0·35	0·15	0·35	—	0·85
	November 12	0·50	0·03	0·03	—	0·57	May 16	0·54	0·03	0·12	—	0·69
	November 21	1·35	0·00	0·03	—	1·38	May 23	0·30	0·02	0·07	—	0·38
	November 27	1·45	0·00	0·00	—	1·45	June 2	0·53	0·00	0·37	—	0·90
	December 12	1·33	0·00	0·00	—	1·33						
	December 17	0·80	0·00	0·00	—	0·80						
California	March 19	0·00	0·00	0·00	0·00	0·00	March 29	0·02	0·00	0·00	0·00	0·02
	March 26	0·02	0·00	0·00	0·03	0·05	April 5	0·38	0·02	1·05	0·00	1·45
	April 2	0·03	0·02	0·03	0·07	0·15	April 12	1·43	0·03	1·94	0·05	3·45
	April 9	0·12	0·00	0·07	0·15	0·34	April 19	3·39	0·06	2·24	0·04	5·73
	April 16	0·62	0·28	0·12	0·12	1·14	April 26	6·42	0·05	4·07	0·01	10·55
	April 23	0·19	0·33	0·20	0·19	0·91	May 3	7·76	0·37	3·70	0·16	11·99
	April 30	0·37	0·10	0·15	0·21	0·83	May 10	7·50	0·36	3·53	0·20	11·59
	May 7	0·50	0·19	0·25	0·19	1·13	May 17	6·68	0·15	2·36	0·46	9·65
	May 14	1·60	0·14	0·17	0·47	2·38	May 24	6·67	0·18	2·48	0·40	9·73
	May 21	2·68	0·11	0·38	0·33	3·50						
	May 29	4·57	0·15	0·28	1·43	6·33						
	June 4	5·06	0·00	0·17	2·71	7·94						
Louisiana	March 23	0·00		0·00	—	0·00						
	March 30	0·00	—	0·00	—	0·00						
	April 5	0·00	—	0·03	—	0·03						
	April 10	0·00	—	0·11	—	0·11						
	April 19	0·10		0·58	—	0·68						
	April 26	0·46		1·66	—	2·12						
	May 9	1·24		4·24	—	5·48						
	May 16	2·26		1·67	—	3·93						
	May 22	2·26		0·38	—	2·17						
	May 28	0·20		0·07	—	0·27						

increasing with cumulating degree-days, and number of leaves per plant. Population abundance of cabbage looper varied from a low of zero on four dates in Louisiana to a peak of 2·26 larvae on 16 and 22 May. Total number of larvae increased steadily along with increasing degree-days, and number of leaves per plant.

T. ni developmental periods are in the range of 20–30 days (Jackson, Butler and Bryan, 1969) at the temperatures recorded in this study. Population increases at the locations were gradual and probably due to steady oviposition pressure from immigrants rather than from new generations of adults developing within our plots. Harding (1976b) found cabbage looper larvae feeding on 24 species of plants in south Texas, including 16 wild hosts, indicating that the species may be considered a generalist in terms of host feeding specificity. Predicting population increases of this species would be difficult due to immigration from wild or other crop hosts and emigration to other hosts from within a field. However, pheromone traps to monitor moth flights may be useful in short-term predictions of egg-laying periods in fields.

Presence of beet armyworm larvae was sporadic at the Texas site and population abundance was low during 1984 (*Table 4*). The peak abundance was 0·05 larvae on 22 October and no larvae were noted on 21 and 27 November or 12 and 17 December. Populations were more abundant in 1985 with a peak of 0·15 larvae per plant on 10 May. No larvae were noted on 15 April or 2 June. Beet armyworm larval numbers were also low during both years at the California site in spite of the plantings occurring during the peak spring flight periods (Trumble and Baker, 1986). Peak abundance in 1984 was 0·33 larvae on 23 April and in 1985 was 0·37 larvae on 3 May. No trends of increasing beet armyworm larvae with the progression of plant growth or degree-days was noted at either site. Beet armyworm larvae were not found feeding on cabbage at the Louisiana site. However, this species is known to occur in Louisiana and is considered to be a pest of various agronomic crops during the summer months. Cabbage plantings in Louisiana in spring may escape infestations of this species.

Development of beet armyworm takes approximately 20–30 days at 20–30°C. It is therefore unlikely that populations could build significantly within a field to large numbers without the influence of immigration. Larvae of this species have been recorded feeding on 11 host species in south Texas (Harding, 1976a) including five wild species, indicating that it also is a generalist in its feeding behaviour and that it would be difficult to predict population fluctuations based on single field surveys. However, pheromone trapping could be used to monitor adult flights and possibly to predict egg-laying periods in fields.

Few diamondback moth larvae were found on plants at the Texas site during 1984 (*Table 4*). Population abundance in 1985 varied between a low of 0·0 larvae on 15 April and a peak of 0·37 larvae per plant on 2 June. No trends were apparent in terms of increasing populations with seasonal progression in terms of plant growth, or cumulated degree-days. Diamondback moth larvae were more abundant in 1985 than in 1984 at the California site with a peak abundance of 0·38 larvae per plant in 1984 and 4·07 in 1985. There were no noticeable trends in population increases with seasonal progression; peak populations occurred on 21 May 1984 and 26 April 1985. Diamondback moth larvae were first noted on plants in Louisiana on 5 April (0·03/plant) and population abundance peaked on 9 May (4·24/plant) (*Table 4*). Populations increased gradually over the time span of late March to mid-May and then declined.

The diamondback moth has a short development period relative to the time it takes for cabbage to develop. Populations may increase in fields as a result of reproduction by a population in a single field within a season, without necessarily being influenced by outside population immigration. However, larvae of this species have been found feeding on 14 species of plants in south Texas (Harding, 1976a), of which nine were wild species, and therefore populations may immigrate into cabbage fields from other hosts making it difficult to predict population fluctuations on the basis of in-field surveys.

Imported cabbageworm larvae were not found at the Texas or Louisiana sites but were present in California in both years (*Table 4*). Population abundance peaked on 4 June at 2·71 larvae per plant and on 17 May 1985 at 0·46 larvae per plant. Population abundance tended to increase as the number of leaves, and degree-days increased during both years (*Tables 1* and *4*).

Results of surveys at all sites over 2 years indicate that the lepidopterous pest complex differs in terms of species composition. Imported cabbageworm was present only in California while beet armyworm larvae were found in California and Texas. It is not clear why some species were absent in Louisiana and Texas. However, the south Texas production area is geographically isolated by the Gulf of Mexico to the east, and semi-arid range lands to the south, north and west, and migration of the imported cabbageworm into this area may be reduced. This species has been reported as an important pest of cabbage in north Texas (Kirby and Slosser, 1984).

In terms of abundance the cabbage looper is the pest of primary importance in Texas and California. Diamondback moth larvae were the most numerous species encountered in Louisiana. However, diamondback moth larvae are much smaller than cabbage looper larvae and consume less plant tissue per larva (Prasad, 1956). The beet armyworm appears to be of sporadic importance in Texas and California and numbers are low in comparison to those of the cabbage looper. Little is known concerning the feeding behaviour of this species in terms of type of damage or tissue mass destruction in cole crops.

Control action guidelines in California and Texas are based on scouting for and counting lepidopterous larvae as a composite pest complex (Flint, 1985; Cartwright, Edelson and Chambers; 1987). Texas guidelines suggest spraying with insecticides to control lepidopterous larvae when the mean number of larvae (all species counted as a complex) reach a threshold of 0·3 larvae per plant. California guidelines suggest action (1) if larvae are stressing the plant in the seedling stage, (2) if nine or more small to medium-size larvae are present at the seedling to heading stage or (3) if larvae are present after heading is initiated. On the basis of the Texas guidelines, spray applications would have been suggested on all but one date in 1984 in Texas because populations were >0·3 larvae per plant (*Table 4*). Populations of larvae were >0·3 per plant on all dates except 1 and 15 April during 1985 in Texas, indicating heavy pest pressure and a need for control action.

Population abundance in California in terms of total larvae is indicated in *Table 4*. Plants reached the heading stage by 7 May in 1984 and 19 April in 1985. Larval abundance on plants between the transplant (seedling) stage and heading stage did not approach nine per plant in either year and no action to control larvae would have been suggested. However, populations increased to a peak of 7·94 per plant in 1984 after plants began heading and applications of insecticides would have been necessary for control on each survey date after heading was initiated.

No guidelines for control action are currently recommended for producers in Louisiana. Using the more stringent thresholds as recommended for Texas (0·3 larvae/plant), control programmes would have been initiated on 19 April (0·68 larvae/plant) and continued throughout the remainder of the season at the Louisiana site.

Results of this research have been used to describe cabbage plant growth in terms of leaf production and indicate that the models of growth based on quadratic relationships from data taken at specific locations account for the greatest amount of variability for the data sets. However, a robust linear model based on pooled data from three locations and over a 2-year period is also described and may be most appropriate for developing regional pest management programmes that integrate plant growth and pest biology.

Prediction of lepidopterous larval pest populations is more difficult and cannot be done on the basis of degree-days or plant phenology. Cabbage looper, beet armyworm and diamondback moth feed on numerous species of plants, including wild and commonly cultivated species, and immigration from and emigration to these other hosts can have an impact on population fluctuations that is not accounted for by surveys conducted within individual cabbage fields. Use of traps to indicate moth flights may allow the prediction of egg-laying periods. However, trapping moths involves time for trap maintenance and expense for materials and the ability to predict oviposition in an individual field is not reliable. Therefore, the best method for use in IPM programmes for cabbage larval pest management appears to be scouting individual fields once or twice weekly and basing control decisions on larval abundance using thresholds already provided by previous research.

Plant development can be predicted and will be useful in IPM programmes, allowing scouts and growers to predict time periods of maximum concern in which to concentrate scouting efforts (i.e. the cupping to mature head stage). A plant growth model will be useful to growers, enabling them to predict plant maturity and thus the impact on management of marketing and harvesting activities.

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