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ABSTRACT

The study measures intensity of attacks by *Sitona lineatus* L. on pea crops in farmers' fields, and the resulting damage. Insect attacks were measured on the aerial parts of the plant at the vegetative stages, and on roots at the start of flowering of the crop. Attack intensity varied between and within plots. Early sown crops were at greater risk of severe damage. There was a good correlation between leaf damage at the beginning of the crop cycle and damage to nodules at the start of flowering in unsprayed crops. Aerial spraying did not completely prevent nodule damage in crops severely injuried by insects at the early vegetative stage. The effects of the attacks on nitrogen nutrition of the pea crop were also assessed; these results are discussed with regard to the consequences for crop management.

Key-words : *Sitona*, *Pisum sativum* L., crop damage, on-farm approach.

INTRODUCTION

The area devoted to spring peas (*Pisum sativum* L.) increased considerably in France during the 80's, going from less than 100,000 hectares in 1980 to almost 700 000 in 1992. This increase has been accompanied by increases in diseases and pests, especially the pea weevil *Sitona lineatus* L.. The effects of *Sitona lineatus* larvae on pea yields is well documented (see for example Bardner *et al.*, 1979). It is considered to be one of the three most dangerous insect species for the crop in France (Bournoville, 1988). The work of Cantot (1986) led to a method for estimating the infestation sizes at both the adult and larval stages. Cantot (1986) also observed a relationship between the infestation size of first generation adults and the infestation size of the following generation larvae under semi-field conditions (artificial infestation under cages in a field). He identified effects of the larvae on certain productivity factors, the number of seeds and the yield per plant, under semi-field or controled conditions (hydroponic cultivation of the peas in an air-conditioned room) (Cantot, 1989). The threshold for these effects is 10 eggs per plant for isolated plants. Experiments comparing the productivity of pea crops with and without insecticide treatments showed that the yield of treated plots could be enhanced, depending on treatment type and infestation size (Bardner & Fletcher, 1979; Bardner *et al.*, 1979; King, 1981; Vulsteke & Seutin, 1985). However, the true scale of weevil damage to peas within France is not really known, because the attacks can vary greatly between fields within an area. This fundamental information is needed in order to develop strategies for controlling *Sitona*. We therefore undertook this study to obtain information about on this variability and on the resulting damage.

MATERIALS AND METHODS

Farm fields in the Seine-et-Marne district of France were studied for three years (34 in 1988, 27 in 1989, and 17 in 1990). All the fields were within an area of about 1000 km^2, and were chosen to represent the variabilty of the cropping systems used in the area. The soils were loamy, and the main features of the climate are shown in table 1. We studied only a small plot of about 250 m² in each field in 1988 and 1989. The variability of the attacks within each field (sizes from less than 5 to over 20 hectares) was also assessed in 1990. The pea cultivars were of the afila type: Solara in 1988 and 1989; and Solara and Ascona in 1990. The sowing period of the pea crops was divided into two parts by rainfall in each year of the study. Some fields were sown early (first sowing period), others were sown about two weeks later (second sowing period; dates are given in table 2).

Measurements

The severity of infestation (*Sitona* first generation adults) was determined when the peas were at the "3-4 leaf" stage. The method used was derived from Cantot (1986) and is based on the number of notches on the first pair of stipules of each plant. Plants were scored on a scale of 0 (no infestation) to 5 (severe infestation) (see figure 1); a score of 5 was used for foliar damage rather more severe than that observed by Cantot (1986). Cantot (1986) showed that a rapid assessment by eye corelated well with the number of notches for grades 0 to 4. We therefore scored 40 to 100 plants per plot by eye. The score for a plot was the median value of the marks per plant (0 to V). The median was used rather when the mean because it is not possible to calculate the mean of qualitative scores. The values for plots were recorded directly by fast visual assessment in 1990, without using the marks on an individual plant basis. We evaluated the variability of the attacks in this third year, by scoring a number of plots equal to the number of hectares of the field rather than a plot about 250 m²/field.

In 1990 we counted notches on leaves 5-8 at the 7-8 leaf stage. These notches in plots which had scored 0 at the 3-4 leaf stage indicated that new weevils were present on this part of the field. If notches were observed on plants which had scored more than 0 at the 3-4 leaf stage, the adult pest had not died or left between the two testing dates.

Larvae are generally present on the nodules from the first nodules formation until nodules senesce during pod filling in most areas of the world where the weevil and peas coexist. The start of flowering is the "best" point during crop development for sampling the larvae of *Sitona lineatus* L., because it is generally considered to be the time when most, if not all, larvae that will complete development are present. We assessed the damages to nodules due to larvae at this stage by counting the number of plants in samples of 40 to 80 plants per plot in which the nodules were destroyed by the larvae on the uppermost 10 cm of the primary root (dig to remove the plants and wash with water). According to Tricot *et al.* (1990), this corresponds to the zone where most of the nodules of the primary root are located at this stage of development. Every plot was measured in this way in 1989, and 11 plots in 1990. The mean dry weight of nodules per plant on the same part of the root was determined. Roots were washed in water, the nodules were removed from the roots, dried for 24 hours at 80°C and weighed.

We also measured the nitrogen content of the aerial parts of the pea crops at the same time. Dry matter was measured in 6 samples of about 0.5 m^2 per plot, and the nitrogen content was determined by the Kjeldhal method.

RESULTS

Abundances of adults at the 3-4 leaf stage

Table 3 shows the results of counts at the stage 3-4 leaf for each of the three years. The attacks were minor in all fields in 1988, and were more serious in many fields in 1989 and 1990. Attack variability was assessed in 1990. The patterns within fields were very variable: in some cases the infestation was evenly spread and in others it varied across the field. We used numeric frequency distributions, and set up two classes. The fields which had at least 3 different scores among the tested plots were classified as heterogeneous (H), the others were classified as homogeneous (h). Table 4 shows the distributions in 1990 (h or H), for the two sowing periods (first or second sowing period) and the size of the field (3 classes). Field size had no effect on pest distribution type (χ^2 test, $P>0.05$), but the sowing period had a highly significant effect (χ^2 test, $P<0.01$). Distribution was heterogeneous in 8 of the 9 cases when sowing was early, whereas the 8 fields in which the sowing was late had a homogeneous distribution of mild attacks (never higher than I). The pattern of infestation was not assessed in 1988 and 1989 but the early sown fields had more high marks than the late sown peas in 1989 (table 5). This is consistent with the observations for 1990. The number of early-sown fields was too small in 1988 for conclusions to be drawn.

Changes in the attacks between the 3-4 leaf and 7-8 leaf stages in 1990

Twenty-three of the 81 early-sown were sprayed with insecticide (lindane, 400g/ha, or cypermethrin, 25g/ha, or lambda-cyhalotrine, 8g/ha) by the farmers at crop emergence or around the 3-4 leaf stage. The damage at the 7-8 leaf stage was scored, and classified according to the damage at the 3-4 leaf stage and insecticide treatment (table 6). All unsprayed plots scoring II or more at the 3-4 leaf stage, and many scoring I, suffered further attack. Many of the sprayed crops also suffered further attack, especially on the plots scoring IV or V at the 3-4 leaf stage. No crop sown in the second period was sprayed. About half of the 78 plot were damaged on the upper leaves, but the damage was always scored as less than 5 notches per leaf.

Damage at the start of flowering

We compared the seriousness of attacks by *Sitona* adults at the 3-4 leaf stage to larval damage of the following generation at the flowering onset stage in 1989 and 1990 (table 7). Only one of the fields was sprayed with insecticide before the start of flowering. When the score was low at the 3-4 leaf stage, the fraction of plants with destroyed nodules was generally low. When the score was high, the fraction of damaged nodules was higher. Figure 2 shows the relationship between the fraction of plants in which nodules were destroyed and the dry matter of nodules per m^2. The greatest fractions of plants affected in 1989 were in plots of plants with low nodule dry matter. The nodule dry matter was very variable in the plots in which few plants were damaged by *Sitona*. This is presumably due to variability in nodulation between plots for reasons other than *Sitona* infestation (see for example the review by Sprent *et al.*, 1988). For this reason, the correlation coefficient of a linear regression between fraction of plants with nodules destroyed and nodule dry weight is only r = 0.55. Some of the plots observed in 1990 were in the same field, and are identified by the same letter. The fraction of plants within a field having destroyed nodules is a good measure crop damage. As in 1989, differences between fields lead to a low correlation coefficient (r = 0.77).

The relationship between the nodule dry matter per m^2 and the amount of N accumulated in the aerial parts per m^2 at the start of flowering is shown in figure 3. The general distribution of the points for each year shows that low nodule weights correspond to low amounts of accumulated nitrogen. Points corresponding for plots with high nodule damage are identified. They show the great effect of *Sitona* feeding on pea crop N nutrition. The correlation coefficients were respectively 0.63 in 1989 and 0.64 in 1990.

DISCUSSION

The intensity of attacks by *sitona* on legumes is known to vary from year to year (see for example Vulsteke & Seutin, 1985). The increase between 1988 and 1990 in the area we studied is consistent with previous observations in other areas of northern France. It has sometimes been suggested that this increase could be due to the increase in pea crop areas. We disagree with this assumption for three reasons. First, according to Hamon *et al.* (1987), the fraction of legumes in the total cultivated area has no effect on the seriousness of *Sitona* attacks. Second, the area devoted to spring pea crops increased between 1988 and 1990 in France, but not in the area of our study. And third, the area under peas decreased slightly in 1991, yet the intensity of *Sitona* attacks continued to increase. There were very few attacks in 1992 and 1993, although the pea crop area again increased. Thus, frther studies are necessary to dissociate the effect of the pea crop area from the effect of climatic pattern on attack intensity. In one such study, Schotzko & O'Keefe (1988) showed that the climate during the winter influenced the ability of adults to move in spring.

Between-fields and within-field differences in attack intensity were described by Hamon *et al.* (1987). Like these authors, we do not have complete information on the cropping histories of the fields or on the geographic position of legumes in the neighbouring fields during the previous year. Nevertheless, the data available suggest that these factors are not the only ones responsible for the observed differences between and within fields (not shown). There seems to be less risk of a severe attack on late-sown fields than on early-sown fields. This is consistent with the flight periodicity of *Sitona* observed by Hamon *et al.* (1987). They describe little trivial flight; once individuals have located a crop, they move through it by walking. Such a pattern of infestation could also be responsible for the differences within a field, making it difficult for a farmer to get a rapid, accurate assesment of the attack intensity within a field. Our results on the effect of the sowing period are consistent with those of Hamon *et al.* (1987) for beans. They compared two sowing dates over several years in Rothamsted, and found that the latest sowing dates gave the highest yields. Vulsteke & Seutin (1985) and Decoin (1991) also showed differences in attacks on early- and late-sowing peas in experimental situations. These differences are also seenin farmers fields sown at different periods in the same area. It concerns both only the mean attack intensity and its distribution, regardless of the field size. This effect of the sowing period was attributed by Proctor (1963) to differences in the sowing bed structure: late sowings result in the finest seedbed soil structures, which are worse conditions for *Sitona*. We have shown elsewhere (Doré, 1992-a) that this is not valid for our model area. About the half the plots sown during the second period in 1989 had rough structured seedbeds, but did not suffer from heavy attacks.

We have confirmed relationship between adult attacks at the 3-4 leaf stage and damage to nodules at the start of flowering seen by Cantot (1986) for farmers' fields, at least when no insecticide is used. Three plots had little nodule damage though the mark at the 3-4 leaf was high (score IV) (table 6). We saw no evidence that this was due to low adult fertility, starving, feeding on crops other than pea, or variable winter quiescence (Schotzko & O'Keefe, 1988). Where adults were not killed by treatment, adult movement by walking seems to be plausible explanation in few cases. Treatment did not kill all the adults under farm conditions when the infestation was heavy, confirming previous studies by McEwen *et al.* (1979), King (1981), and Bardner *et al.* (1983).

It is difficult to compare the levels of attacks we detected to those observed by others, because the pea varieties (afila or not) and the methods used to estimate damage vary from one study to another. The numbers of notches per plant have been reported: Vulsteke & Seutin (1985) give figures from 1.35 to 35 notches per plant, but the number of leaves involved is not given; McEwen *et al.* (1979) give 17.2 to 71.5 notches on the stipules of afila plants, but there is no information on the stage of the plants when scored; Bardner *et al.* (1983) give 4.18 to 8.29 notches on the last leaf developed on non-afila types; the highest values given by Cantot (1986) were 20 notches per plant on the first leaf and 12 notches per plant on the stipules of the first leaf, on non-afila types. We scored plants on some plots as 5; it was impossible to count the notches on the stipules of the first leaf at the 3-4 leaf stage on these plants because they were too numerous. These plots, therefore, suffered heavier attacks than those described by McEwen *et al.* (1979), which had been sprayed with insecticide against *Sitona* and had a significantly higher yield than non-treated plot. We cannot directly compare the yields obtained between fields because they depend on factors other than *Sitona* attacks. Nevertheless, heavy attacks decreased nodule weight in farmers' fields, with some effect on plant nitrogen accumulation. We have shown (Doré, 1992-a) that poor nitrogen nutrition due to heavy *Sitona* attacks or other factors is directly responsible for low numbers of peas, and for poor pea crop yields. We also showed that the amount of nitrogen accumulated in the pea crop greatly influenced the N supply in the soil for a subsequent wheat crop (Doré, 1992-b).

CONCLUSION

This survey provides a fairly detailed assessment of the effect of *Sitona* on the pea crop in the French Paris Basin. Comparisons between our data and the abundances noted by other authors indicate that the attacks can be sufficiently heavy and cause enough damage to justify action against these insects. However, designing strategies to kill *Sitona* will not be easy. The first problem will be to determine the real intensity of an attack on a field. Attacks in farmers' fields are very heterogeneous. The second problem will be to kill, if necessary, the adults. Aerial treatment will not always be satisfactory if the attack is serious. Seed treatment should help to solve this problem (Blondel, 1991; Decoin, 1991). Finally, the strategy for fighting *Sitona* should include management of the whole crop, as shown by the effect of sowing date on the risk of heavy attack. Hamon *et al.* (1987) discussed sowing crops later to avoid attack, and concluded that it had little chance of being accepted by the farmers, because late sowing exposes the crop to attack by other pests, and delays the sowing date of the succeeding wheat crop. This latter argument is not valid in our study, as the pea crop is harvested in July or August, and wheat is sown in October. In any case, we have shown elsewhere (Doré, 1992-a), that the sowing date should also be considered to reduce the risk of packing the soil structure in th same area.

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Table 1: Main climatic features at the area during the 3 years of the study

P = Rainfall (mm); ETP - P = Evapotranspiration minus Rainfall (mm); T = mean temperature (°C)

	1988			1989			1990		
	P	ETP-P	T	P	ETP-P	T	P	ETP-P	T
01/03–10/03	15.2	12.9	3.5	31.9	−20.9	8.8	1.2	9.8	6.8
11/03 20/03	33.6	−25.6	7.9	15.5	−2.9	7.8	1.2	14.8	10.5
21/03–31/03	53.8	−19.3	8.6	4.0	17.3	11.3	8.2	8.8	7.0
01/04–10/04	0	19.6	8.1	36.5	15.4	8.3	5.8	19.2	7.2
11/04–20/04	16.2	7.9	11.7	17.7	21.1	8.3	35.9	−16.9	7.9
21/04–30/04	0	35.1	9.7	40.4	20.8	6.1	12.9	15.1	10.7
01/05–10/05	98.3	−69.4	14.2	16.5	26.0	13.7	11.1	34.5	16.7
11/05–20/05	8.9	19.0	14.6	4.3	38.0	14.6	1.1	37.2	14.4
21/05–31/05	36.8	−1.5	13.7	0	52.9	15.7	1.8	41.4	13.3
01/06–10/06	1.8	32.7	13.9	71.9	−39.9	11.9	27.9	3.3	13.7
11/06–20/06	6.0	41.3	16.2	0	37.0	18.5	4.1	27.4	14.4
21/06–30/06	18.1	17.5	16.5	21.9	23.1	14.6	34.6	4.1	17.6
01/07–10/07	51.2	−11.7	16.0	10.6	25.4	18.6	20.3	16.0	14.0
11/07–20/07	2.3	16.1	15.9	0	54.1	17.9	0	65.5	19.2
21/07–31/07	31.7	6.1	18.0	12.7	41.5	18.3	12.7	55.9	20.1

Table 2: Sowing dates for the 3 years

Sowing periods	Sowing dates
1988:	
1st period	08/03–11/03
2nd period	04/04–10/04
1989:	
1st period	13/03 and 14/03
2nd period	21/03–28/03
1990:	
1st period	24/02 and 25/02
2nd period	09/03–13/03

Table 3: Percentage of total observations for each score and each year at the 3-4 leaf stage (N = number of fields observed)

	0	1	2	3	4	5
1988 (N = 34)	26	68	6	0	0	0
1989 (N = 27)	56	22	4	0	11	7
1990 (N = 17)	41	35	0	12	0	12

Table 4: Effects of the sowing period and the size of the field on the distribution type of the attacks at the 3-4 leaf stage" in 1990 (h = homogeneous, H = Heterogeneous; each letter corresponds to one field)

Size of the plots (ha)	1st sowing period	2nd sowing period
3–7	h, H, H	h, h, h
8–10	H, H, H, H, H	h
11–23	H	h, h, h, h, h

Table 5: Effect of the sowing period on the infestation intensity at the 3-4 leaf stage in 1988 and 1989. Scores as a percentage of total observations for a sowing period (N = number of plots)

Sowing periods	0	1	2	3	4	5	N
1988:							
1st period	0	67	33	0	0	0	3
2nd period	29	68	3	0	0	0	31
1989:							
1st period	8	46	8	0	23	15	13
2nd period	100	0	0	0	0	0	14

Table 6: Effects of insecticide treatment and score at the 3-4 leaf stage on the subsequent severity of the attacks at 7-8 leaf stage in 1990 (first sowing period only). The figures are the number of plots corresponding to each case

Score at the 3–4 leaf stage	with insecticide		without insecticide	
	no notches	notches	no notches	notches
0	8	1	2	0
1	10	1	3	4
2	7	2	0	2
3	8	4	0	7
4	4	5	0	3
5	2	6	0	2

Table 7: Relationship between the score at the 3-4 leaf stage and the damage to nodules at the start of flowering. The figures are the numbers of plots in each case (27 plots in 1989, 11 plots in 1990). Nodules destroyed in: A - less than 20% of plants; B - more than 20 %

Scores at the 3–4 leaf stage	A	B
0	16	1
1	10	0
2	1	1
3	0	0
4	3	2
5	0	4

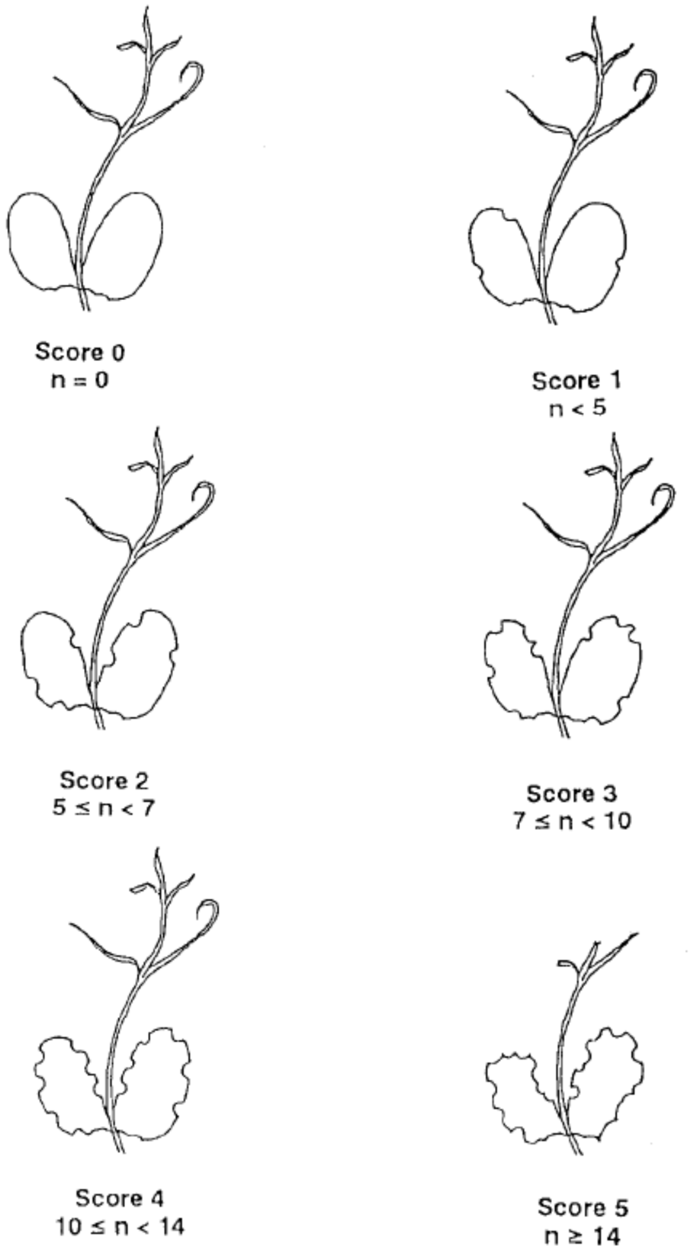

Figure 1: Damage assesment on leaves by counting the notches on one plant (n = number of notches on the stipules of the first leaf)

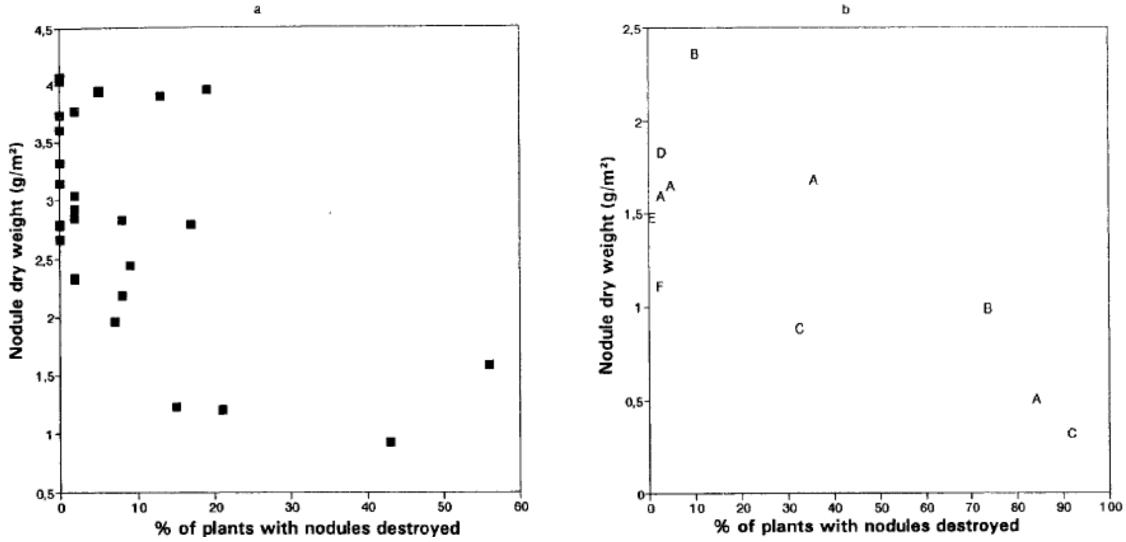

Figure 2: Relationship between the fraction of plants in which nodules have been destroyed (X-axis) and the nodule dry matter per m²(g.m^{-2}, Y-axis)- a- 27 plots in 1989 and b - 11 plots in 1990 (a same letter corresponds to different parts of the same field)

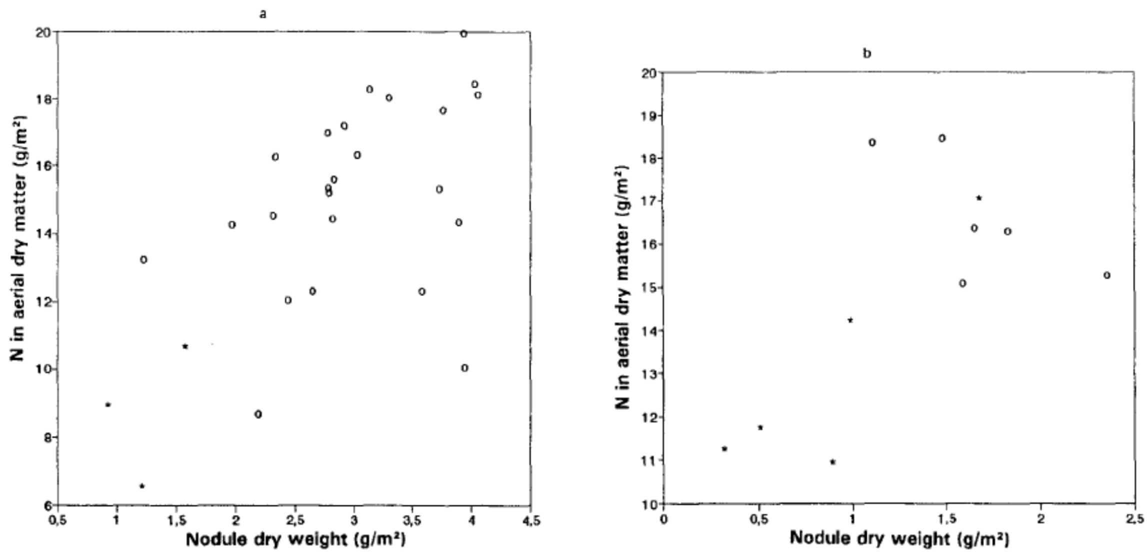

Figure 3: Relationship between the nodule dry matter per m² (g.m^{-2} ,X-axis) and the amount of N accumulated in aerial dry matter (g.m^{-2}, Y-axis) - a - 27 plots in 1989 and b - 11 plots in 1990