THE HYDRAULIC ROUGHNESS OF
VEGETATED CHANNELS
INTERIM REPORT

Report No SR 74
1985

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1. INTRODUCTION

The growth of weeds in rivers and canals is an ever present problem. In many existing waterways, the consequences of the weed growth will have been learned by experience. However, there are a number of situations where a prediction of the effect of weed growth is required. Examples of such situations are

(a) Design of new drainage channels

(b) A change of flow conditions in an existing waterway e.g. increased run-off from bankside developments; use as a feeder from storage ponds or pumped aquifers.

(c) Where an assessment is required of the benefits of weed control programmes.

Intermittent flow over grass has been widely studied in the field and in the laboratory but comparable information on aquatic weeds, which are much more varied in form, is not readily available for general application. The purpose of this Commission is to extend knowledge in this field.

This report, the second of a series, describes field studies carried out between February 1984 and April 1985.

2. PREVIOUS WORK

The first stage of the investigation was a literature survey. This was followed by laboratory work on artificial vegetation to obtain a better understanding of how the ratio of depth of flow to lengths of vegetation affected channel roughness. The first steps were then made to mount the field study that is the subject of the present report.

The earlier work is described in HR Report No SR 36, March 1985.

3. FIELD SITES

3.1 General description

The sites originally chosen were the River Anton near Romsey and the River Wey near Farnham. The R. Anton was a relatively large river with an uneven bed and difficulty was experienced in inspecting and measuring some areas because of the depth of the water. Early in the year, study of the R. Anton was therefore discontinued and an alternative site was adopted at Candover Brook on the east side of Winchester.

All these sites were of the same type; gravel bed streams with a relatively high width to depth ratio and moderate to high flow velocities throughout the year. In these circumstances the principal mainstream weeds were ranunculus and calitriche. Both of these are streaming weeds that have no inherent stiffness in individual plants but, in bulk, form large beds with an elastic consistency that respond to the hydraulic forces by expanding or contracting. The shallows were populated by varieties of weed that have more innate stiffness but do not thrive in the velocities encountered in the mainstream. As silt was deposited in the slow flow through these weeds there was a gradual encroachment of the banks of silt and their weed population into the mainstream until the weeds died off and the banks of silt were eroded away. The advance and retraction of the banks lines took place in a yearly cycle.

An essential requirement for a research site, and a major limitation on availability of suitable sites, is a means of measuring the discharge. Each of these sites was close to a measuring structure.

Other factors looked for in the choice of site were :

1) A history of strong weed growth
2) Unrestricted weed growth i.e. little or no management
3) Absence of pollutants in the flow

3.2 Locations

1. The principal source of data through the year was Candover Brook at Itchen Stoke near Winchester. This stream, running mainly through private property, is spring fed and exceptionally clear. The weed is allowed to grow naturally and is not managed in any way. One bank is lined with substantial tree growth and, while in some reaches the shading appears to inhibit weed growth, in others weed growth is very extensive. This has the advantage that methods of analysis can be checked against sections of uniform weed cover, high and low, and also against combined sections with non-uniform weed cover.

The Brook has an average width of 7m and typical water depth in the centre of the stream was 0.5m. The section chosen for testing was straight for a distance of approximately 120m but, to avoid side streams and cattle drinking places the test length was limited to 40m. It was intended to use this as a single section but under some flow conditions it was possible to measure the water surface slope with sufficient accuracy to allow analysis of subdivisions of the test length.

Flow was measured a short distance downstream of the test section by a high precision Crump Weir. There were no significant flow inputs between the test section and the weir.

During the year, surface weed covers as high as 60 per cent were recorded.

2. The second site was the River Wey at Farnham. The test section was near the centre of the town with houses backing onto one bank and open ground with public access on the other.

The river is 8 - 9m wide and typical water depth in the centre was 0.6m. The total test length was approximately 100m, comprising two 50m lengths of distinctly different slopes.

Flow was measured by a non-standard full width weir immediately upstream of the test section. The weir rating was obtained from the Thames Water Authority but the accuracy of this rating was unknown.

In practice, the results from this site were of poor quality. The weed growth during the year was very low and died off early; one observer took the view that the weed had been killed by water pollution. This could not be confirmed but the outcome was that only limited data was obtained and doubts were raised as to the value of this river as a principal site. As a result a search was begun for an alternative site, which is about to be brought into action, and the R.Wey site now has the status of 'secondary site' to be used to broaden the data base when good weed growth is obtained.

4. TEST PROGRAMME

The most rapid changes in weed volume occurred between April and August and visits were made to each site at least once a month during this period. During the remainder of the year, visits were still made, if weather permitted, in order to establish the natural roughness of the test channels without weed and to observe the movement of the silt beds which are often retained by the weed roots after the top growth has died away.

5. SITE MEASUREMENTS

The only permanent work at the sites was the installation of bench marks to locate sections on the rivers and provide a reference level. The marks consisted of concrete blocks cast into the ground with a rounded bolt head inserted as the reference point. In soft ground the block was cast around a steel angle iron driven into the ground. These were placed at 10m intervals on the Candover Brook and approximately 25m intervals on the R Wey. Straight lines between the markers formed the base line for horizontal measurements.

On reaching the site, the head over the weir was recorded. A river cross-section was then surveyed at each of the markers. Water level at the section was established with the aid of a tripod mounted point gauge stood in the river to give a firm level indicator which was then related to the bench mark with an optical level. Water depths, weed height on the section and silt depths were then measured relative to the water surface. A marked rope stretched across the river located measuring positions relative to the baseline. When the sections had been completed, the weed growth was surveyed. The method used was for an operative to wade the river, marking the outline of large weed beds with a ranging rod at appropriate points or, in the case of small weed clumps, marking the centre and measuring length and width. Each time a position was marked, the position was triangulated to the base line by two theodolites located over the two bench marks that spanned the section being surveyed. For each weed bed, depths from the water surface to the top of the weed, to the silt within the weed bed and to the channel bed was recorded at several points. Type of weed was also recorded. The bank lines were also plotted by the same method of triangulation.

Alternative methods of surveying the weed had been experimented with, particularly the use of aerial photography from a helicopter or a model plane.

This method was very weather dependant. In very bad weather the planes could not fly and reflections or wind-ripples on the water surface led to very poor resolution. Lack of contrast was also a problem particularly if algae was present on parts of the river bed. In view of the organisational problems of setting up an aerial reconnaisance and the need for someone to be on or in the river to identify weed types and obtain depth information, there was no saving in survey time and this method was abandoned. the triangulation method used was immune to all but the worst weather and tests made during the plotting showed that errors in positioning even at large included angles were negligible relative to the errors implicit in tracing the edge of moving weed beds.

When the survey was complete, the water level at the gauging weir was again recorded.

From time to time, when weed growth was high, velocity measurements were made in the open water channels and in the lee of the weed beds. The measurements were made with a Braystoke 5 inch diameter propellor meter mounted on a rod standing on the river bed. The purpose of the metering was to obtain some indication of the relative flows around and through the weed beds.

6. OUTLINE OF ANALYSIS

The surface outline of the weed was manually plotted from the triangulation data to be large scale, typically 1:40. Areas were then calculated with a computer-linked digitiser and combined with the depth measurements to calculate volume of weed, volume of silt, average thickness of weed and the ratio of weed surface area to water surface area.

There were two approaches to the analysis of the data. The first was to attempt to obtain a detailed picture of the influence on the flow of the weed bulk and the weed frictional characteristics and to define the principal parameters controlling both.

However, it would be impractical, if not impossible, to obtain the data required to make use of such an analysis in the context of a whole river system.

The second approach was therefore to attempt to relate the flow pattern to those dimensions that could readily be obtained in practise. These were considered to be :

a) Cross sections of the clear channel
b) Discharge or water depth (one to calculate the other)
c) Surface area of weed

Item c) was considered to be the only measure of the weed that could be easily obtained for long sections of river, either by estimation on the ground or by aerial photography. This approach was considered first.

For each of the sections surveyed, Mannings n was calculated using the channel bed as the boundary to obtain the cross-sectional area and wetted perimeter (i.e. as if no weed was present). This was done because the weed cross-section at any point will not bear any relationship to the total weed in the reach upstream of the section, except by chance.

Mannings n value for the weed-free channel. For clarity, not all the points are plotted in Fig 3 but the line is fitted through all data points.

Since the intercept on the Y-axis would vary from river to river, this graph may be said to be specific to the test sites. However, the natural channel roughness is unlikely to vary widely on rivers prone to this type of weed growth and affects only the lower part of the curve since the weed roughness and bulk will predominate at higher values of K. Nonetheless, an attempt was made to separate weed and channel roughnesses by using the formula for composite roughness devised by Pavlovski and others, which equates total force resisting the flow to the sums of the forces resisting the flow in the subdivided areas. The equation is

Overall Mannings n =

$$\frac{(P_w N_w^2 + P_c N_c^2)^{1/2}}{P^{1/2}} \qquad (2)$$

where, in this case :

P_w = length of wetted perimeter occupied by weed

P_c = length of wetted perimeter that is clear channel bed

N_c = Mannings n for channel bed

N_w = Mannings n for weed

P = total wetted perimeter

The ratio of P_w to P was taken as equal to K and equation 1 was substituted for 'overall Mannings n'. The value of N_w was calculated and plotted against K/Froude No in Fig 4. This is a similar curve to that in Fig 3 but with a smaller range of n values since the effect of the low clear channel value on the overall value is more pronounced when weed cover is low.

The n value of the weed was also plotted against Froude Number in the form of 1/F since Fig 1 shows it to be broadly an inverse relationship. The result is shown in Fig 5 and it can be seen that the correlation is excellent. It would appear that the scatter occurring in Fig 1 when various lengths of reach with varying K values were linked with a particular measured cross-section has been suppressed in the transitional use of equation 2. The correlation coefficient of the line drawn through the points is 0.98

To take the analysis a little further, Mannings n was calculated using as the cross-sectional area of each section, the total area to water level minus the mean cross-sectional area of weed in the reach. The latter is not a dimension that could be easily obtained in a survey of an extensive length of river but in the context of a research study would show if this was necessary for precise results.

The Froude No for each section was also calculated from this corrected area.

Fig 6 shows the resulting plot of Mannings n against K/Froude No. There is extensive scatter. A plot of the relationship of Mannings n to Froude No (Fig 7) shows no better correlation. This line of analysis was therefore discontinued.

A number of analyses exist for flow over vegetated surfaces. These relate mainly to intermittent flow over grass and the vegetation therefore always has 100 per cent cover. They are therefore not directly compatible with the type of vegetation being studied here. However, it was considered of interest to see if similarities existed.

Kouwen, Unny and Hill (Ref 1) proposed an equation of the form :

$$V/V_* = C_1 + C_2 \log \text{(CSA of water/CSA of weed)} \qquad (3)$$

where V = velocity
$V_* \quad \sqrt{gRS}$

where R = hydraulic mean depth

S = slope

and C_1 and C_2 are coefficients related to vegetation density and stiffness respectively.

Substituting surface areas for cross-sectional areas in this case gives the equation.

$$V/V_* = C_1 + C_2 \text{ Log } (^1/K) \qquad (4)$$

Fig 8 shows the plot of V/V_* against log $(^1/K)$.

Although the trend is linear, the scatter is considerable. In the context of streaming aquatic weeds it would appear that this form of relationship is not applicable.

A second analysis of flow over vegetation, and the one most widely used, is that carried out over several years by the U S Soil Conservation Service (Ref 2). By empirical means they deduced that Mannings n was a function of the vegetation (grass) height and the hydraulic parameter VR where V is velocity and R is the hydraulic mean depth. In the present tests the range of values of VR is very small compared with those tested by the USSCS but a plot of Mannings n against VR has been prepared and is shown in Fig 9.

7. DISCUSSION OF RESULTS

The behaviour of plants in an aquatic environment is extremely complex and complex measurements would be needed to describe it fully; far too complex for practical application. The main aim of this work, therefore, is to find descriptions of this behaviour that are accurate enough to be of real value but simple enough to be practical.

In the analysis of the results so far, a promisingly close relationship has been found to relate the hydraulic performance of a channel to a measure of the weed growth that can readily be obtained (Fig 3). This relationship is based almost entirely on data from one site and an alternative that may be of more general application has been suggested (Fig 4 and 5).

A more detailed examination has not yet given any more insight into the problem than the purely empirical analysis made above but is being followed up as more data is acquired.

Previous analytical work which mainly concerns flow over grass surfaces appears to have no relevance to purely aquatic vegetation of the type now under examination.

Experience in the field has led to a modification of some earlier views of the problem. A number of laboratory studies of flow in the presence of vegetation have examined, in detail, the flow through the vegetation. In the case of streaming, buoyant plants, the plant clusters are so dense that flow through them is sufficiently slow to allow extensive deposition of silt. Furthermore, since the flow forces a passage around the plants, the head loss across a weed bed is generally very small. The nett result is that flow through the weed beds is negligible to the point of being unmeasurable under most normal circumstances. In the case of upright plants in the shallows by the bank, the major resistance to flow is not usually the plant stems or leaves but plant debris caught by the upright stems.

A study of individual plant characteristics is therefore largely irrelevant in real situations and field observations should be the principal source of data.

It is, perhaps, because of the tendency of aquatic plants to behave as bulk colonies rather than as individuals that it has been possible to draw consistent relationships from what are, of necessity, relatively simple bulk measurements.

8. CONCLUSIONS

1. The principal interim conclusion is that for streams infested with buoyant trailing weeds such as ranunculus and calitriche, there is a relationship between the equivalent value of Mannings n applied to the whole flow section and the Froude Number of the flow and the surface area ratio of weed to water. Where weed growth is low, the form of the relationship may be influenced by the roughness of the clear channel bed but for higher weed growths the nature of the channel bed will be unlikely to affect the relationship.

2. Confirmation or development of the current analysis requires a greater range of data and data from a wider range of sites. This is in hand.

3. The sites currently being studied have constantly flowing water which determines the type of weed that will become established within the mainstream. A second category is sites where the water is at times stagnant or very slow moving; drainage ditches are the main example. In these sites the erect weeds and others with relatively stiff supporting stems will colonise the whole waterway whereas they are found only along the banks of the present sites. This very important category of sites requires investigation. The practical problems of researching such sites are immense because the flows and water surface slopes are extremely small for most of the time and higher flows are intermittent. Periodic visits to a site with portable equipment are therefore likely to miss significant events and the precision of measurements, which needs to be near laboratory stndards, is difficult to achieve. An intractable problem is to devise a measure of this type of weed that can readily be made in practical applications and is sufficiently precise for general results to be widely applicable. The simple measures so far used for streaming weed cannot be used in these situations. These problems are being urgently studied and prospective sites have been noted. This aspect of weed research is not yet, however, in full swing.

9. REFERENCES

1. Kouwen N., Unny T.E. and Hill H.M. Flow retardance in vegetated channels Proc A S C E, June 1969, Vol 95, IR2.

2. Ree W.O. and Palmer V.J. Flow of water in channels protected by vegetative linings.

   U S Soil Conservation Service, Technical Bulletin 967, February 1949.

FIGURES

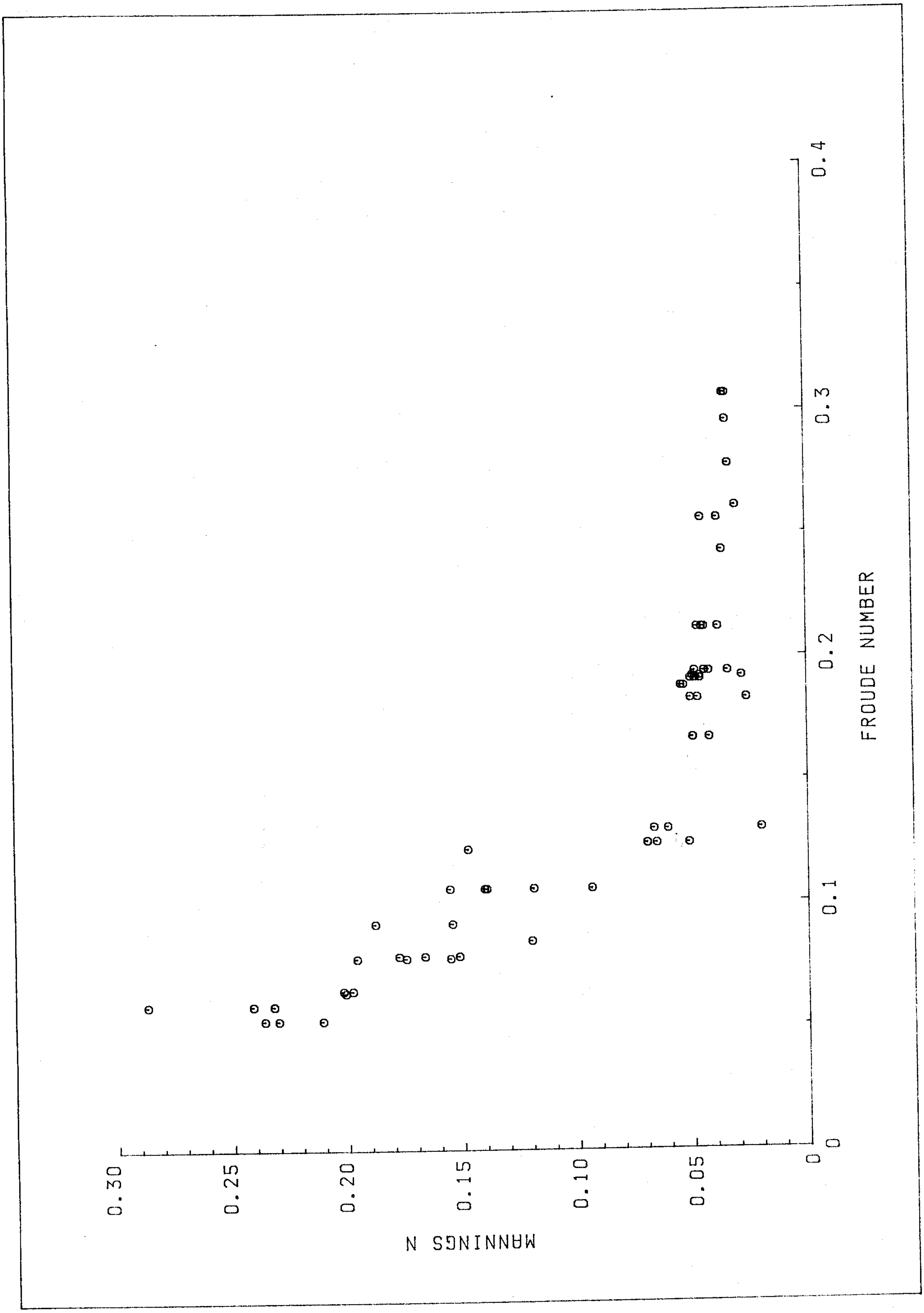

FIG 1   WEED DATA ANALYSIS (EMPIRICAL)

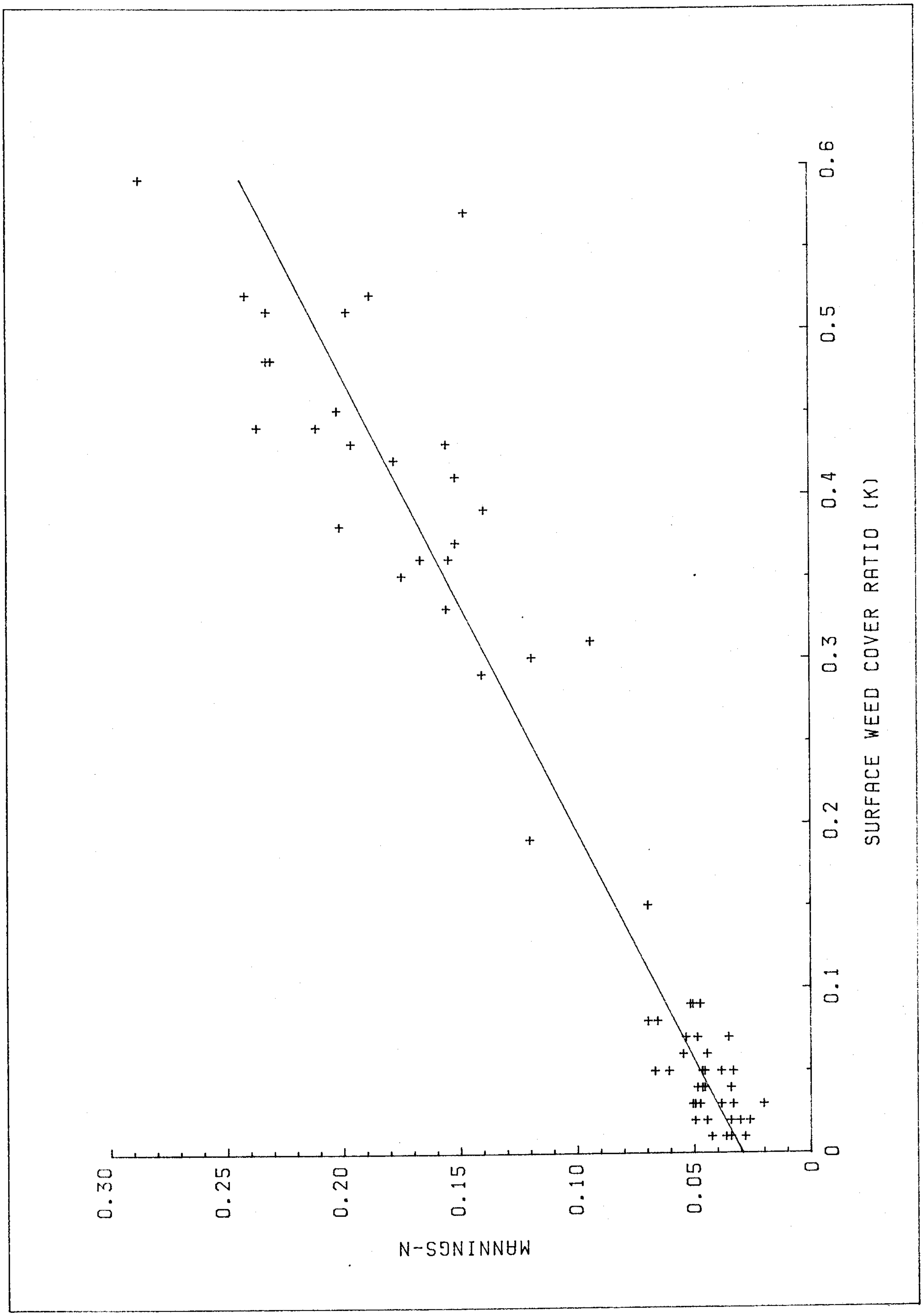

FIG 2 WEED DATA ANALYSIS (EMPIRICAL)

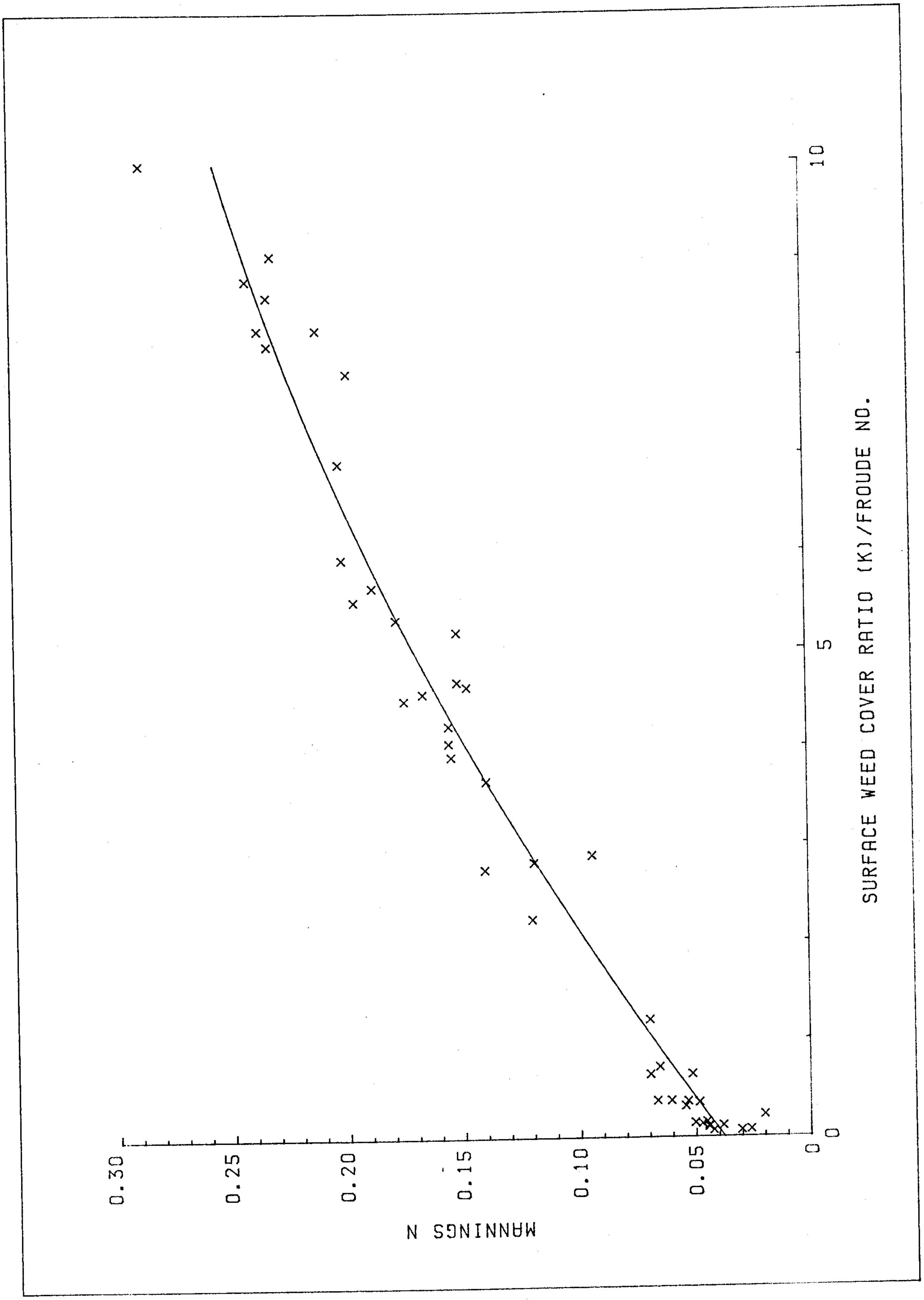

FIG 3 WEED DATA ANALYSIS (EMPIRICAL)

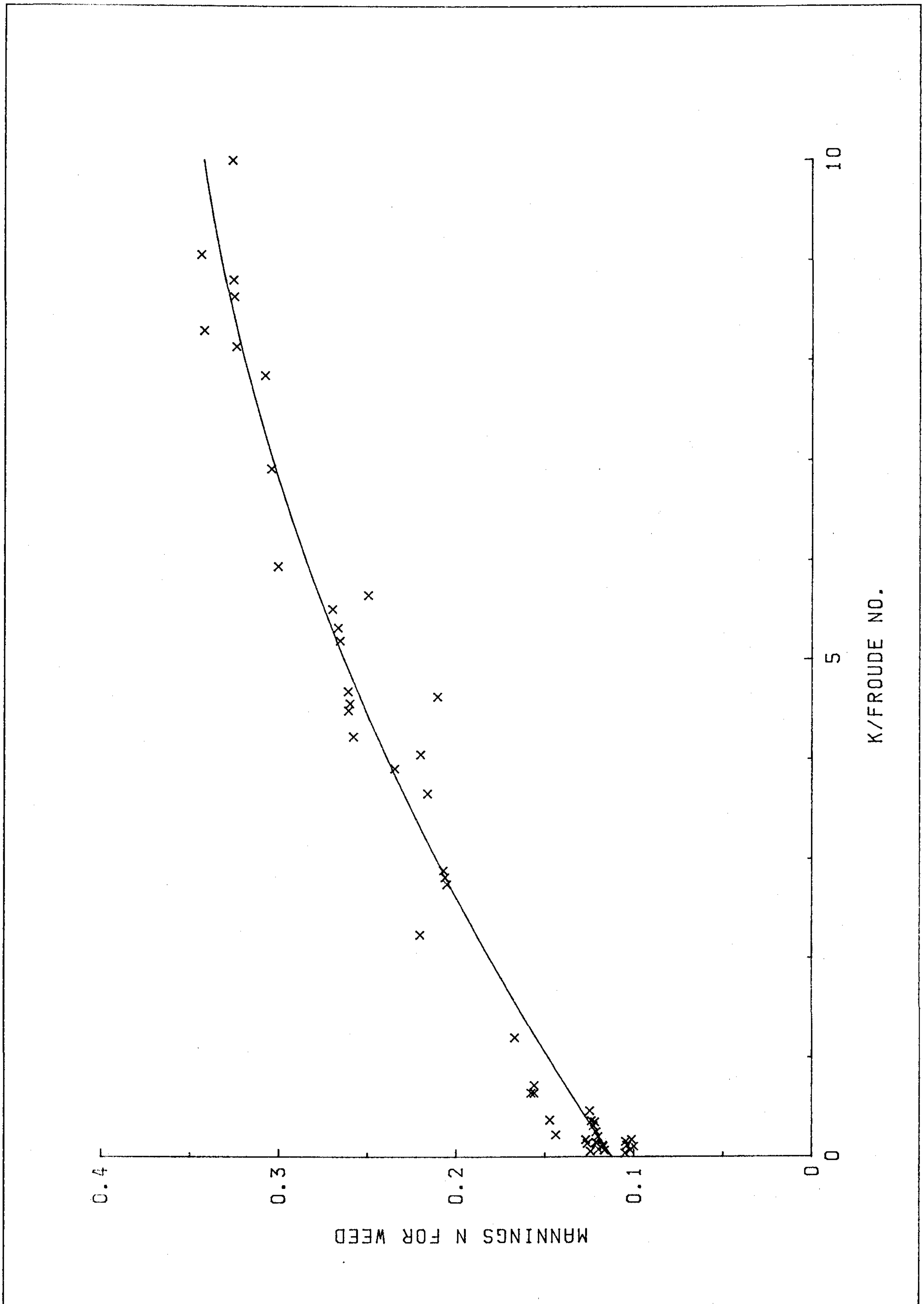

FIG 4 WEED DATA ANALYSIS (EMPIRICAL)

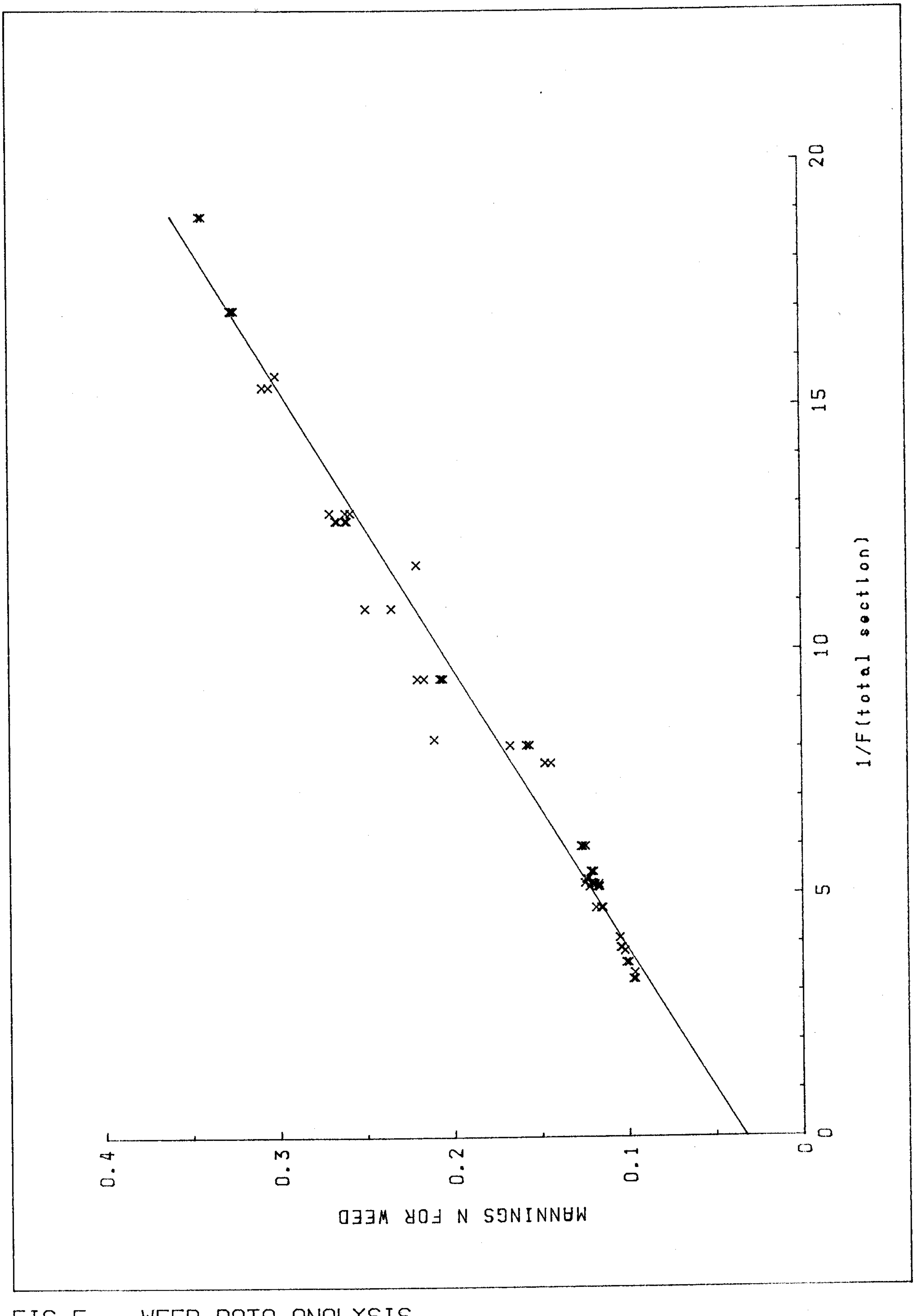

FIG 5 WEED DATA ANALYSIS

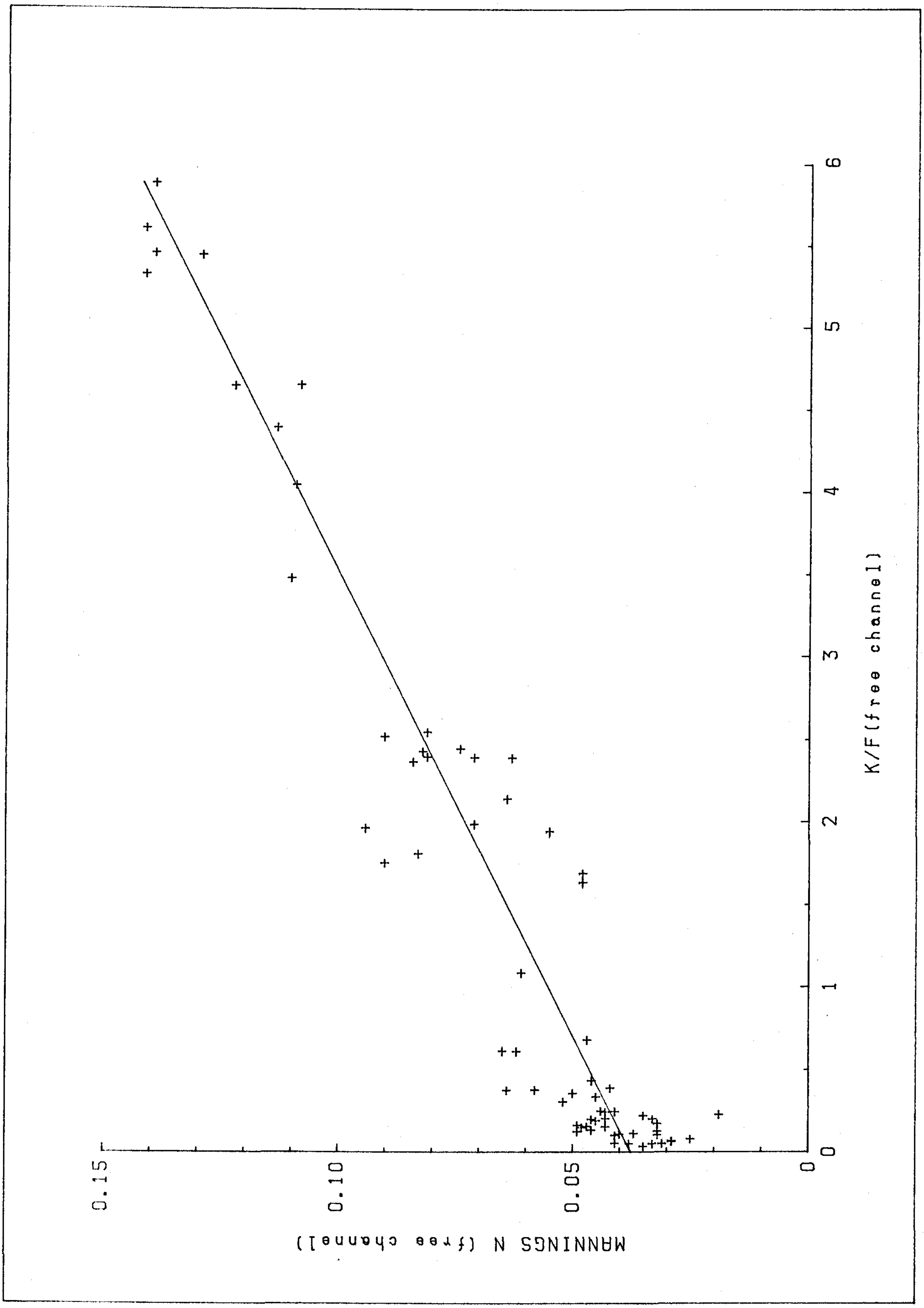

FIG 6 WEED DATA ANALYSIS

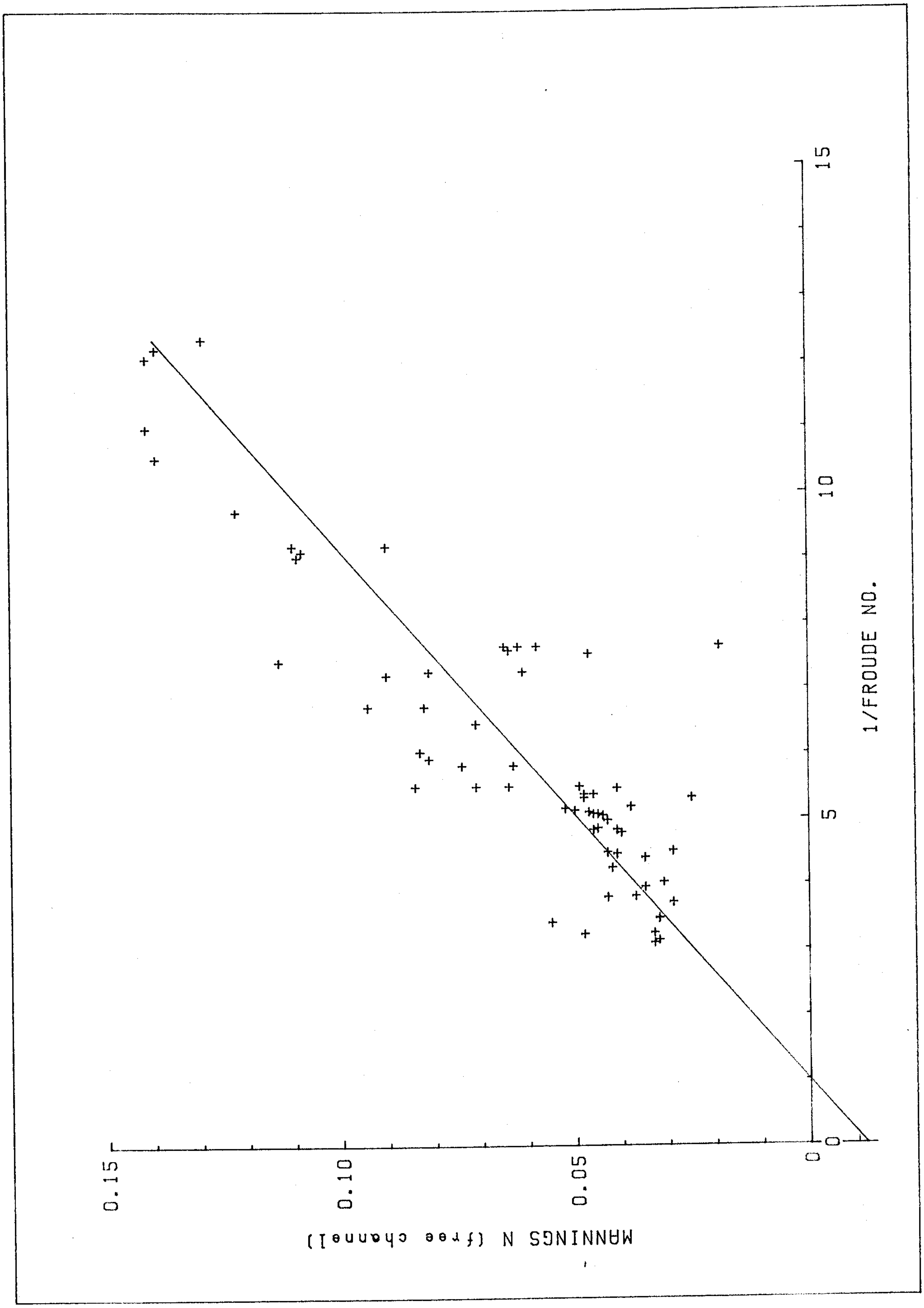

FIG 7 WEED DATA ANALYSIS

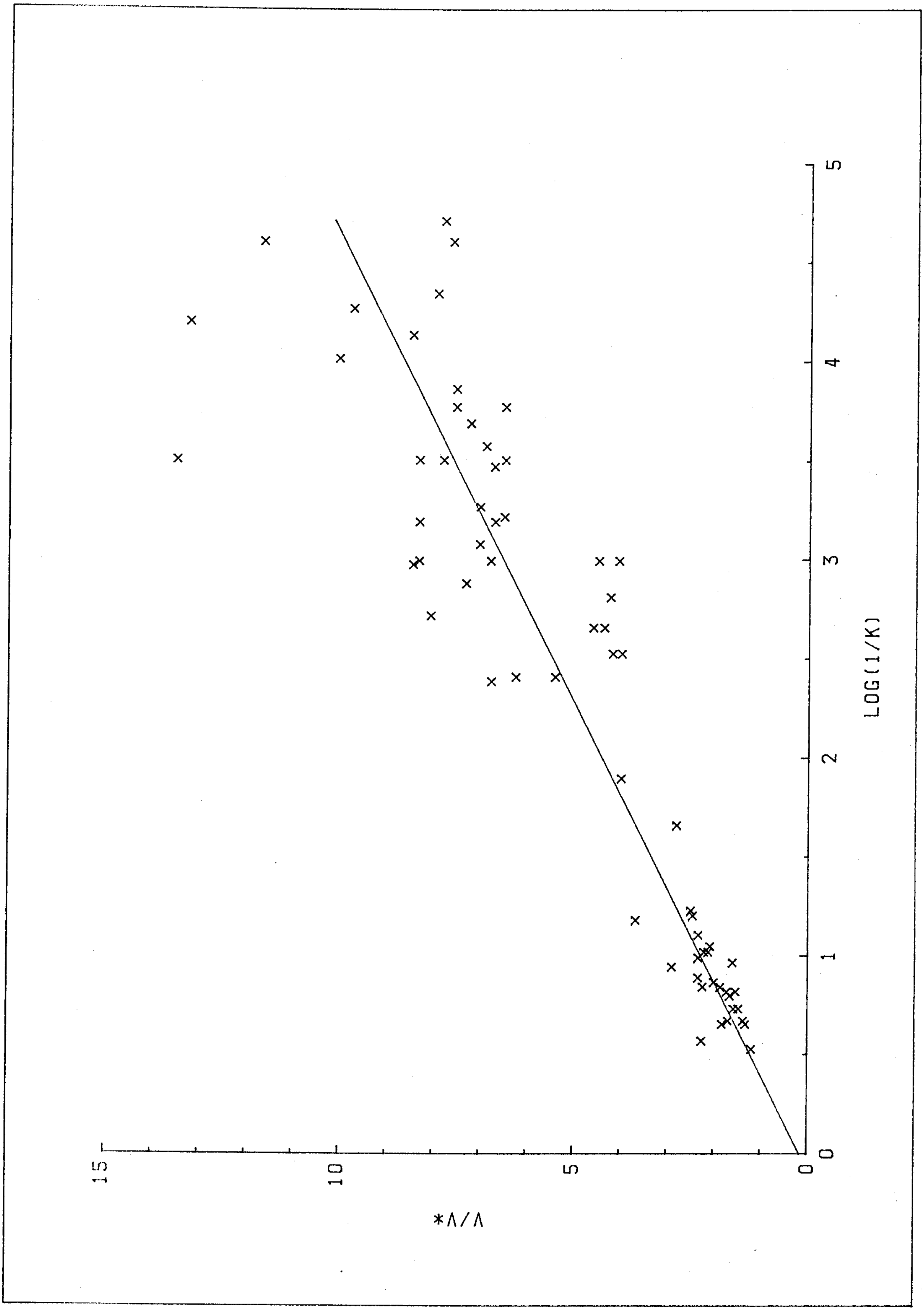

FIG 8   WEED DATA ANALYSIS

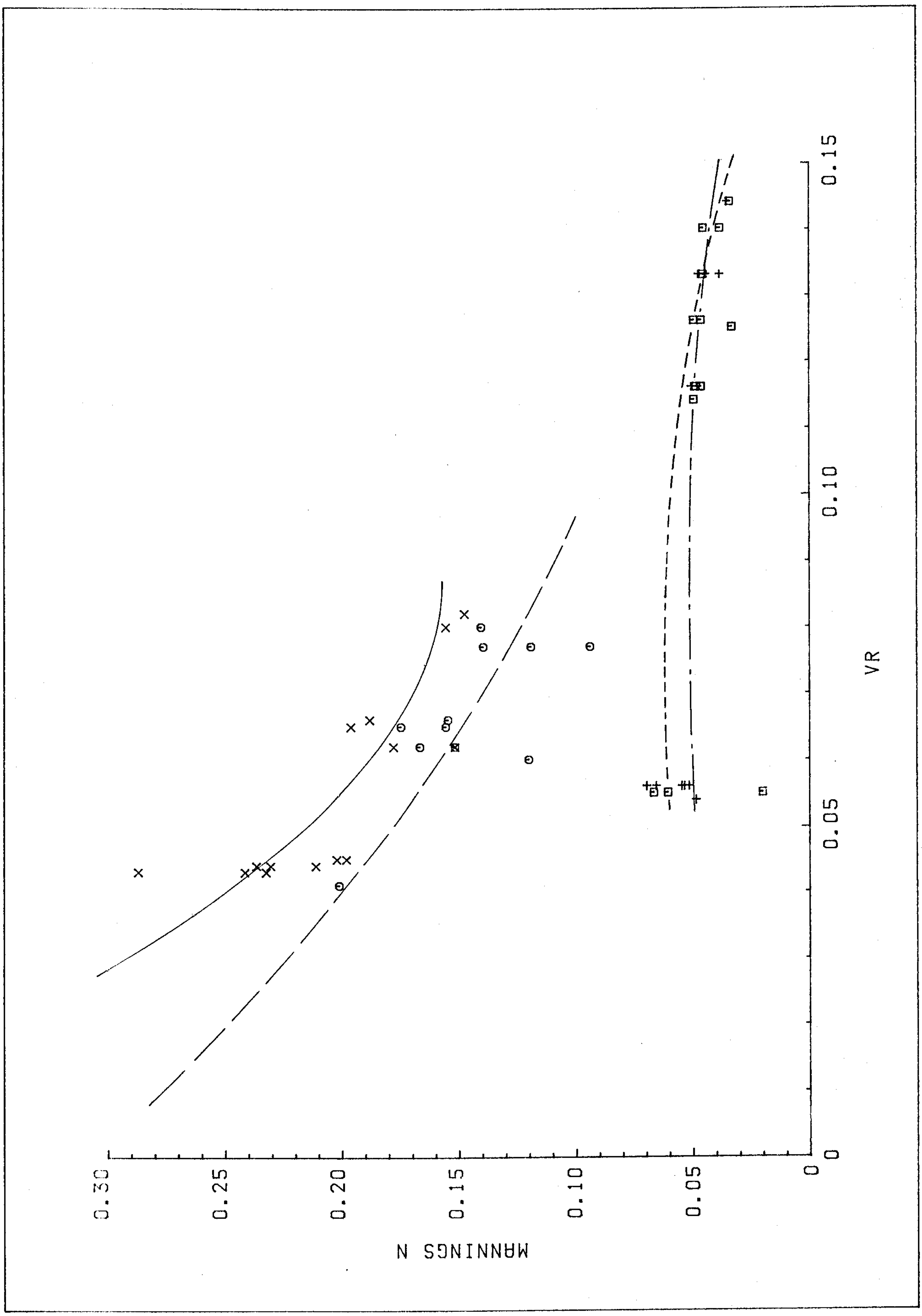

FIG 9 WEED DATA ANALYSIS