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FERTILIZER TRIALS WITH JARRAH

Introduction

Trials to determine the response of jarrah to applications of inorganic fertilizers were started at the Dwellingup Research Station in 1966. Investigations were made initially using jarrah seedlings in pots. The research programme then extended into the field and the responses of poles of between 35 and 45 years old were studied.

At the present time three field studies remain operative and will continue to do so until responses to fertilizer applications in them have ceased. Until this stage is reached no firm conclusions on the economic status of fertilization is possible. However, at least one trial has reached a stage of rapidly declining response and some extrapolation of the results of this trial has yielded data suitable for tentative calculations of profitability. These estimates are detailed at the end of this paper and they are likely to be on the conservative side. They are presented as a guide to the future prospects of forest fertilization in the jarrah forest.

All the investigations described herein were carried out in jarrah stands growing on laterite gravel soils; where pot trials are mentioned, the soil used in the pots was the same. Normal controlled burning operations on a 4-6 year cycle are carried out in the stands used.

Assessment of responses to fertilization has not been confined to the tree crop alone; study of effects on the ground vegetation has been included.

Investigations Using Potted Seedlings

General

Studies using potted seedlings were considered necessary to determine accurately the main responses of jarrah to the three major elements Nitrogen (N), Phosphorus (P), and Potassium (K) and to trace elements as a group. Using small plants grown in a shade-house gives a close control over growing conditions and almost eliminates the vagaries of climate, pathogen and insect attack.

The two experiments described in this section were conducted in the same way. Pots were filled with unsterilized laterite gravel taken from the top 9 inches of soil beneath a healthy jarrah stand. The soil was sieved through quarter inch mesh before use.

Jarrah seed was sown direct into the pots, and plants were reduced to the 3 most vigorous per pot at six weeks. Fertilizers were applied as top dressings to the pots when the plants were 2 months old. Watering was from above to ensure entry of the fertilizer into the soil. Plants were harvested and measured $3\frac{1}{2}$ months after fertilizer application. Measurements were taken of:-

(a). Total height

(b). Oven-dry shoot weight

(c). Oven-dry root weight

(d). The length and width of the largest leaf on each plant (done in the first trial only).

The fertilizers used in this study were ammonium nitrate (34% N), aerophos (52% P_2O_5), and sulphate of potash (48% K_2O). The trace element mixture used in the first trial consisted of

Magnesium sulphate	70%
Manganese sulphate	10%
Zinc sulphate	10%
Copper sulphate	4%
Cobalt chloride	2%
Sodium borate	2%
Sodium molybdate	2%

Seedling trial 1.

Method. Nitrogen, phosphorus, potassium, and trace elements were tested in all combinations by a 2^4 factorial trial with 4 replications. Nitrogen was applied at the rate of 0.75 gm ammonium nitrate per pot, phosphorus as 1.15 gm aerophos, potassium as 0.6 gm sulphate of potash and the trace element mixture at 0.1 gm per pot.

Results.

The results of the trial are summarised in Figure 1. Trace element effects have been excluded for the sake of clarity and the results in this table are presented from an analysis of variance on the basis of a simple randomised block experiment. The complete analysis of the trial as a factorial indicated significant interactions invariably involving N & P; these are summarised briefly in Figure 2.

Four major points emerged from this experiment.

(1). All the treatments with nitrogen resulted in significant increases in plant size.

(2). There was a powerful N x P interaction, causing a very large increase in plant size and in the root/shoot ratio of the plants.

Although no N x K interaction could be detected from the factorial analysis, the weight of plants treated with these two elements was significantly greater than the controls with no fertilizer.

(3). Phosphorus and potassium, either separately or combined showed a tendency to depress growth.

(4). Trace elements were involved in some of the higher order interactions (see table 2). The mean weight of all plants receiving trace elements was 13% higher than those without. Further investigation of this factor may be warranted in the future.

Discussion.

The suspected depressing effect in growth of phosphorus by itself, and the massive increases associated with phosphorus in combination with nitrogen suggest that the latter element may be the more important factor and thus be required in larger quantities than phosphorus. The second pot trial was designed to test this hypothesis.

The high root to shoot ratio in all treatments with N and P could be an undesirable characteristic if it occurred in the field. Over-development of the tree crown in relation to its root system would result in water stresses during the hot, dry summer period. However, the application rates used in this trial were equivalent to many thousands of pounds of fertilizer per acre. Such high application rates would be out of the question on a field scale, hence the problem is unlikely to arise and thus far has not arisen in any trials in the field.

Seedling trial 2.

Method. Nitrogen and phosphorus were tested in various proportions and various quantities in a 5 x 5 factorial replicated 3 times. Fertilizer rates were such that approximately equal quantities of elemental N and P were applied at similar levels in the factorial arrangement. The actual rates used per pot were:-

Nitrogen -	N_1 - .05gm Amm. nitrate	Phosphorus -	P_1 - .075gm aeropho
	N_2 - .1 " " "		P_2 - .15 " "
	N_4 - .2 " " "		P_4 - .30 " "
	N_8 - .4 " " "		P_8 - .60 " "
	N_{16} - .8 " " "		P_{16} -1.20 " "

Results.

Measurements were made of the oven-dry weights and the heights of the plants; both followed similar trends and only the oven-dry weights are discussed here. The results of the trial, in terms of weight increases in the plants for each unit increase in fertilizer, are shown in ~~Table~~ figures 3A + 3B.

Analysis of variance of the original data revealed a highly significant interaction between the two factors confirming that the response to one element varied with the quantity of the second element.

The conclusions drawn from these results are based on the means in table 3 and are as follows:-

(1). Plant response to either element tends to be greater at the higher levels of the second element. This tendency ceases at level 8 beyond which a marked falloff in response is evident - from 0.37gm to 0.12gm for P and 0.64 to 0.12gm for N.

(2). The response to nitrogen in the presence of phosphorus reaches a peak at level N_8. Phosphorus in the presence of nitrogen peaks at level P_2. This suggests that nitrogen may be more critical, reflecting a greater requirement of this element by jarrah.

(3). The overall means, represented by the figure in the bottom right hand corner of each table, would support this hypothesis. The figures for nitrogen and phosphorus being 0.46gm and 0.30gm respectively. Increasing nitrogen levels increased the root:shoot ratio but to nowhere near the extent observed in the first trial. These ratios are listed in figure 4.

Discussion.

The relatively weak response to phosphorus can be expected in a species of plant that dominates a soil type notoriously low in this element. Nitrogen is likely to fluctuate violently in its availability to jarrah in the forest. Periodic intense fires producing nitrogen fixing legumes in the ground vegetation are a feature of the forest environment. These may be followed by fire-free periods, or a succession of mild fires which fail to germinate the leguminous seed. It is suggested, therefore, that jarrah may be an opportunistic receiver of nitrogen and, as such it has the ability to utilize this element, when available, to its advantage. However, the pot trials have shown that the presence of additional phosphorus is essential for the maximum response to be achieved to additional nitrogen.

Fertilizer Experiments in the Forest

General.

The two experiments using jarrah seedlings in pots gave a basis for extention of the investigation in the field. All the field trials described below were conducted in approximately even-aged jarrah pole stands of 35 to 45 years old with a dominant height of the order of 70 to 80 feet.

Experimental method was carefully controlled to reduce variation between trees and stands due to variation in stand density and in the size of the study trees. Both these factors can influence growth rates to a point where treatment effects can be masked. Extreme care was taken to ensure that where single tree plots were used, the trees were as uniform in size as possible. Where plots were used, areas of uniform stand density were used as a basis of covariance when the results of the trials were analysed. An additional serious source of variation in jarrah growth rate is the stage of the seeding cycle which the tree has reached. Again, a serious attempt was made to reduce this source of variation by choosing trees and stands that showed no signs of recent flowering or capsule development.

Where single-tree plots were used, fertilizers were evenly spread for a radius of 12 feet round each tree at the rate applicable to the prescribed application rate per acre. Single tree plots were sited a minimum of 40 feet apart.

Fertilizer applications in plot trials extended to 0.4 acres (2 ch. x 2 ch.) of which only the central 0.1 acres (1 ch. x 1 ch.) was used for measurement.

Field Trial 1. Field Response to N, P and K fertilizers.

The aim of this investigation was to determine whether responses detected in the first pot trial would be repeated in the field. Experimental layout was a 2^3 factorial replicated 6 times. Single tree plots were used; breast height girth averaged 38 inches (range 22 to 56 inches.) The trial was conducted in two stands. The first, unthinned, had a density of 150 $ft.^2$ basal area/acre and the second, thinned area 60 $ft.^2$/acre. Nitrogen, Phosphate, and Potassium were applied in all combinations at the following rates.

Nitrogen:- N_0 - None

N_1 - {500 lb/acre sulphate of ammonia (100 lb N/acre) in Year 1.
{220 lb/acre urea (100 lb N/acre) in Year 2.

Phosphorus:- P_0 - None

P_1 - 1000 lb/acre superphosphate (100 lb P/acre)

Potassium:- K_0 - None

K_1 - 167 lb/acre sulphate of potash (70 lb K/acre)

Fertilizers were applied in August 1967 and annual measurements of girth at breast height have been made to the present. An assessment of crown density was made in September 1970.

Results.

The growth results are expressed as basal area increments in square feet per tree. In all cases adjustment for tree size was made by covariance analysis. The data are shown in ~~table 4~~ Figure 5.

A portion of the unthinned section of the experiment was accidentally scorched by controlled burning in spring 1970. This could account for the discrepancies in response to some of the treatments between thinned and unthinned stands, particularly in the response to N, P & K together.

These results verify those found in the first pot trial. All treatments including nitrogen showed marked increases in growth rate compared with the control. An N x P interaction is again evident. The N x K interaction suggested in the pot trial has shown strongly in this field trial.

If a tree is growing rapidly, its general vigour should be detectable in the condition of the crown. As a further guide to the responses of the poles to fertilizers in this trial, a visual assessment of crown density was made in September 1970. Five independent observers, one with no forestry experience, were asked to rate crown density on each tree with no fore-knowledge of the fertilizer treatment to which it had been subjected. Crowns were assessed as thin, (awarded 3 marks) medium (2 marks) and dense (1 mark.) All marks awarded by each observer for each treatment were then summed; the lowest sum indicating the densest crowns. There was an acceptable agreement between observers, the coefficient of concordance in the thinned stand being 0.51 and in the unthinned stand 0.43, both figures significant at the 5% probability level. The overall ratings for both thinned and unthinned stands combined were also significant at the 5% probability level. No attempt was made to differentiate significance between individual treatments.

The summary of density ratings is shown in figure 6; the lower the figure the denser the crown.

Combinations of NP, and NK again ~~there~~ showed superiority reflected in dense crowns.

The Period of Response.

At the last measurement of this trial, responses to some treatments were still evident; this represents a period of 4 years but, as figure 7 illustrates, the magnitude of the response is declining rapidly in some treatments. It will be at least 1 year ahead before a firm statement on the effective period of response to fertilizers can be made. At this stage it seems unlikely to last beyond five or six years.

The data illustrated in figure 7 demonstrate a very small response to fertilizers during the first year after application. A peak is reached during years 2 and 3 after which the rapid decline commences.

The Effect of Stand Density.

The trees in the two parts of the trial were standing at 60 ft.^{2}/acre basal area in the thinned area and at 150 ft.^{2}/acre in the unthinned. When the degree of response to the more successful fertilizer applications (N, NP, & NK) are considered, there appears a relationship between magnitude of response and stand density, the trees in the denser stand showing the greater response. Growth increases attributable to fertilizers were 40% in the thinned trees and 49% in the unthinned.

Comparison of Fertilizer Combinations.

Figure 8 shows the combined results for thinned and unthinned trees to applications of N, NP, and NK, the three outstanding treatments.

The addition of Phosphorus to Nitrogen resulted in a growth increase attributable to fertilizer of 2%; the addition of potassium resulted in an 18% increase. These results should be treated with caution. Reference to figure 1 shows that the decline in response to nitrogen ~~alone~~ & phosphorus has been very rapid and could possibly be accounted for by factors such as the crown scorch mentioned previously in this report.

If the responses to these three treatments are considered for the first three years of the experiment, when no obvious extraneous factors operated, the respective increases attributable to N, NP, & NK are 39%, 54%, and 60%. This gives a more reliable comparison. In terms of absolute figures, the application of 100 lb/acre nitrogen has increased tree growth rate by 39% over 3 years. An additional application of 100 lb/acre P gave a further increase of 15%. The addition of 67 lb/acre K to the 100 lb/acre N application gave a further 21% increase in growth rate. The implications of these data will be discussed in a later section on the economics of fertilizing.

The Effect of Tree Size.

There appears to be no difference in response to fertilization associated with tree size (and therefore age) over the ~~25"~~ ~~to 55" gbh~~ girth range used in this trial. 4 year basal area increments, expressed as a percentage of the individual tree basal area at fertilization, were calculated for all trees in the treatments yielding the main responses, (N, NP, and NK). The mean increment was 13.4% within the gbh range 25" to 40", and 12.9% in the 40"-55" range. These figures do not differ significantly.

It is concluded that the results of this trial are applicable to trees and stands of up to at least $4\frac{1}{2}$ feet gbh.

Field Trial 2. The Development of a Response Curve.

To determine the economics of using fertilizers it is essential that the unit increase in timber production for each unit increase in fertilizer be known over a wide range of application rates. The relationship between fertilizer application and response of the crop invokes the law of diminishing returns at some level. Represented graphically such data forms a response curve and this particular trial was established for this purpose.

An extensive trial comprising 21 plots of 0.4 acres each was laid down in August 1969 in a simple randomised block layout. Each of the 7 treatments ~~were~~ was replicated 3 times. The crop under test was jarrah poles approximately 45 years old and thinned in 1965 to a residual density of 72 ft.^{2}/acre basal area. Fertilizer application rates were such that approximately equal quantities of elemental N and P were applied at each treatments. Nitrogen was used in the form of urea (46% N) and phosphorus as double superphosphate (approx. 17% P). A summary of the treatments follows.

1. Control, no fertilizer
2. Urea 60 lb/acre and double superphosphate 160 lb/acre
3. " 120 " " " " " 310 " "
4. " 240 " " " " " 620 " "
5. " 480 " " " " " 1260 " "
6. " 960 " " " " " 2500 " "
7. "1920 " " " " " 5020 " "

The fertilizers were broadcast in late August 1969. Individual tree girths in the central one-tenth acre of each plot were measured at breast-height with a steel tape. Diameters were measured with a pentaprism caliper at $\frac{1}{4}$, $\frac{1}{2}$, and $\frac{3}{4}$ of bole height. Breast height girths are remeasured annually and upper diameters at 5 year intervals.

An assessment of the ground vegetation by species composition and percentage ground cover was made at the start of the trial. 16 systematically located points were permanently marked in each plot. These points formed the centre of a metre-square quadrat used for ground vegetation assessment.

Two remeasurements have been made of girth at breast height since the inception of the experiment and a second ground vegetation assessment was made in September 1971, two years after fertilizer application.

Results - Basal Area Increment.

A summary of the measurements of basal area increment appears in ~~Table 6~~ Figure 9. The data have been treated by covariance to allow for differences in stand density between plots.

The general pattern of a relatively small response in the first year followed by a much greater response in the second year is very similar to that found for single trees in the previously described trial. The NP fertilizer rates applied in the first trial correspond closely with the 240 lb urea/620 lb double superphosphate treatment of the second and the increases in growth rate in both trials are similar. This comparability is the basis of the extrapolation of results exercised in a later section of this paper.

From the data shown in figure 3 it is apparent that a point of saturation is reached somewhere in the region of the 960:2500 treatment. Additional fertilizer beyond this level elicits no further response.

Crown Density.

No measure of crown density was made in this trial. However, it was observed that trees in the two treatments of heaviest fertilizer application developed crowns so heavy in leaf that an unusual degree of branch shedding occurred in the winter of 1971.

The Effect of Fertilizers on the Ground Vegetation.

The percentage ground cover and the species composition of the ground flora was assessed at fertilizer application and again two years later.

Changes in the percentage ground cover are shown in figure 10. A 28% reduction in ground cover occurred in the unfertilized plots over 2 years. Increases in cover in the fertilized plots were 3.8% and 14.9% in the plots receiving light and heavy fertilizer applications respectively. The outstanding feature of the changes in ground cover percentage was the increase in bracken (*Pteridium aquilinum*) associated with fertilization. In plots receiving heavy fertilizer treatments the ground cover of bracken was almost doubled. All other species together were reduced by 30% in both unfertilized and heavily fertilized plots, but remained at a constant level in the light fertilizer treatments suggesting that these were generally beneficial to the ground vegetation.

It is concluded that fertilizer levels within the light fertilizer class will slightly increase the proportion of bracken in the ground flora, and may result in an overall slightly denser ground vegetation in the long term. The long term effects of heavy fertilizer applications seem likely to be the domination of the ground vegetation by dense bracken.

The Response Curve.

A response curve has been developed in Figure ~~7~~ 11. Three curves have been constructed. The first represents the measured increase in growth rate on plots over a two year period. The second is an extrapolation of this data to a four-year period based on the results of the initial field trial using individual trees. Both these lines represent increased growth rates to various applications of N and P together. A third line represents an estimate of the response to nitrogen alone over a four year period; this is also based on the initial trial using individual trees. Estimates of the volume increases relating to the measured basal area increase are shown on the right hand vertical axis of the graph. The volume figures were derived from the basal area multiplied by a bole length of 40 feet and a form factor of 0.7.

The point of maximum response, represented by the steepest rise in the curves, is difficult to determine from figure 1~~3~~. Data representing additional growth responses to increasing quantities of fertilizer are shown in figure ~~4~~ 12. It is evident that the maximum response occurred where 120 lb urea and 320 lb double superphosphate were applied (2 units of fertilizer). The upper limit of fertilizer application, beyond which no further increase in growth rate occurs is somewhere between 16 and 32 units (960-1920 lb urea and 2500-5020 lb double superphosphate per acre). It is not necessary to determine the exact point as fertilizer rates of this order are quite uneconomic.

The Profitability of Fertilization

It is evident from data produced from the two field trials that N, NP, and NK all produce large responses in increased growth rates. N alone produces the least response followed by NP with NK giving the best growth rates. Major considerations in the economics of fertilization are (a) the cost of fertilizer and (b) the cost of applying it. There can be no doubt that in the jarrah forest the only feasible method of application is from the air. This in turn demands high analysis fertilizers to keep the quantities required, and hence application costs, within reasonable limits.

The difference in the response of jarrah to N alone and to N & P together is too small to warrant further consideration of the use of phosphatic fertilizers. High analysis phosphatics are fairly expensive while the very cheap superphosphate containing less than 10% P is too bulky. Potassium compounds are generally rich in elemental K and their use combined with N holds distinct possibilities. Further investigations of NK mixtures are required to produce adequate data for economic analysis.

At this point there remains N in the form of urea which is concentrated (46% N) and reasonably priced. Calculations of profitability are therefore confined to the use of urea.

Reference to figure 4 suggests the optimum application rate at 2 cwt urea/acre (approximately 100 lb N/acre). The estimated increase in timber production at this level is read off figure 3 as 96 cubic feet per acre accrued over a 4 year period. The estimated cost of applying 2 cwt urea/acre from the air is $9.50 per acre. This figure compounded at a 7% interest rate over 4 years becomes $12.97, and the cost of the extra timber produced is then 13 cents per cubic foot, or $6.50 per load.

At current royalty rates for mill logs, fertilizing to produce timber at $6.50 a load is not an attractive proposition. However, two other factors must be taken into account. Firstly the extra timber produced by fertilizing should be harvested very soon after the stand has ceased responding or extra interest costs will reduce the profitability. Secondly far higher royalty rates are received for transmission poles and peeler logs than for mill logs. Hence the extra increment accruing from fertilization can be harvested as a selective thinning to yield this high value produce. To the present investigations have been confined to pole sized trees; produce from the forest at this stage is limited to transmission poles worth, at a conservative estimate, \$10 per load measured over bark.

On this basis, a single fertilization giving a timber yield of 96 cubic feet per acre harvested four years after fertilization will yield a return of 14% compound interest on the capital spent on the operation. Alternatively a 7% or better compound interest yield will accrue provided the extra timber produced is harvested between 4 and 10 years after fertilization.

The subject of fertilization of stands containing trees approaching peeler-log size needs further investigation. However, it seems likely that the high royalty value of this produce, in the region of \$14 or more per load will make fertilization an attractive economic proposition.

It is emphasized that the foregoing estimates are tentative. They are included in this paper to indicate that large scale trials of fertilization are warranted at this stage, and that further investigation of fertilization techniques can yield valuable information leading to increased forest productivity.

Future Work

Further investigation is planned along the following lines.

(1). To re-test the N x K interaction in the field and to compare the profitability of using this mixture with the use of N alone.

(2). To investigate the responses of older stands, particularly those in the 5 to 7 foot gbh range.

(3). To determine the optimum source of nitrogen, particularly to compare nitrate and ammonium forms of N. All the trials described above were with the ammonium form.

(4). To determine the optimum time of application of the fertilizer.

(5). Costing trials for aerial application of fertilizers.

(6). To re-test the response of jarrah to trace elements.