THE USE OF ^{32}P TO STUDY ROOT GROWTH OF SOYBEAN AS AFFECTED BY SOIL COMPACTION

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ABSTRACT

THE USE OF ^{32}P TO STUDY ROOT GROWTH OF SOYBEAN AS AFFECTED BY SOIL COMPACTION. Two greenhouse and two field experiments have been conducted to study the effect of soil compaction on root growth and plant growth of soybean. In the greenhouse experiments it was clearly shown that by increasing soil compaction the growth of roots and shoots was inhibited. The growth of roots was expressed in $\sqrt{\%}$ Arcsin converted from the counts per minutes (cpm) of ^{32}P content in the shoots and in cpm of ^{32}P in shoots without conversion. While the plant growth was expressed in plant height, number of leaves, dry weight of pods and shoots. In the field experiment after conducting the second experiment it was shown distinctively that root growth in the 15 cm soil layer was inhibited when soil compaction increased. Like in the greenhouse experiments the growth of roots was expressed in cpm of ^{32}P of roots, shoots, and pods. While the growth of plants was expressed in plant height, number of pods and dry weight of pods, seeds, and stover.

INTRODUCTION

Recently the government of Indonesia through its Yunior Minister of Agriculture has encouraged the use of hand tractors for soil cultivation on farmers' land. This is apparently one of the methods to shorten soil cultivation time and to solve the problem of the decrease of farm labour. It is expected that with the shortening of land cultivation time of planting especially lowland rice could be more accurate in one planting season with less farm labours. So hopefully plant rotation in one planting season could be managed to reach optimal yield.

In connection with the possibility use of hand tractors the influence on the soil physical properties must be taken into

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consideration. It is well known that physical soil properties could direct the use of soil for agricultural purposes. The ability of soil to store water, to retain soil nutrients, to provide good aeration, plasticity, and the ability of roots to penetrate the soil, are all related to physical soil properties. According to DE BOOTH (1) the main factors which could be influenced by the physical properties of soil are, soil humidity, soil aeration, and mechanical properties of the soil. Recently research in agriculture started to pay attention to mechanical soil properties as a factor which could possible inhibit root growth and development and growth of seedlings in the field. And one of the mechanical soil properties is soil compaction. Mc KIBBEN (2) and CANNELL (3) stress that soil compaction is one of the main factors which could cause soil degradation. Soil compaction could occur because of severe soil practices, such as restricted soil cultivation and the use of heavy machinary on agricultural soil. The effects of soil compaction on soil are for example, the increase of bulk density and the decrease of the volume of soil pores which usually are filled with gases. And all these factors could have unfavourable influence on root and plant growth. HENDERSON (4) forwarded that in Australia, soil compaction is mainly caused by agricultural traffic, meaning the use of heavy machinary on agricultural soil. And soil compaction usually happened when soil moisture is high especially in fall and early spring. Further according to him (5) in one of his experiment using a tractor of 4 t weight for only four times back and forth already resulted in a hard pan beneath the plough layer. Rechel *et al.* (6) from his own experiments and coating other research workers such as Russell and Goss (7) and Willat (8) forwarded that soil strength which is an expression of the impact of agricultural traffic could decrease root length. Besides this Meek *et al.* (9) found that soil sites which have not been travelled on by tractor traffic had a lower soil density, higher water up take, and higher growth rates which were able to provide higher biomass of plants compared to soil which had been cultivated by tractors for several times.

This paper reported two greenhouse experiments and two field

experiments to look at the impact of soil compaction on root growth and plant growth, where growth of roots was determined using ^{32}P.

MATERIALS AND METHODS

1. Greenhouse Experiments

1.1. Plant Containers

1st Experiment

Each plant container consists of 5 polyethylene tubes, with each tube having a 11 cm dia. and a 5 cm height and formed a column of 25 cm height. At the bottom of the column a polyethylene petri-dish was attached to prevent soil losses. The top tube was emptied and the four tubes below was each filled with a certain weight of soil according to the treatment applied. At the site of each of the 4 bottom tubes a small glass tube was inserted to be used for injection of the $KH_2{}^{32}PO_4$

2nd Experiment

Plant containers used were pots with a 7 l volume. Like in the first experiment each pot was filled with a certain soil weight according to treatments applied.

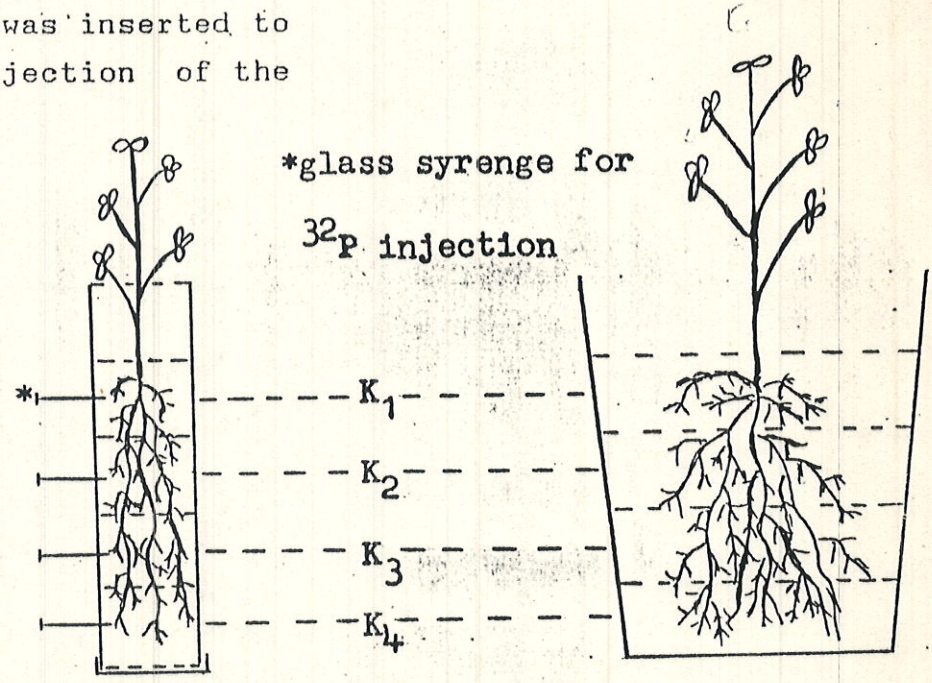

Figure 1. Plant containers used in the green house experiments

1.2. Plant Material

1st Experiment

Plant material used was soybean var. WILIS. Each plant container was planted with 3 seeds. After one week the best growing seedling was left to grow and the two others were incorporated into the soil.

2nd Experiment

The same plant material was used as in the 1st Experiment. And the same cultivation method was applied.

1.3. Soil Compaction

1st Experiment

To obtain different soil compaction each tube was filled with different soil weight as shown below,

P1 : each polyethylene tube was filled with 0.55 kg air dried soil, the total soil weight in the plant container was 4 x 0.5 kg = 2.00 kg

P2 : each polyethylene tube was filled with 0.60 kg air dried soil, the total soil weight in each plant container was 4 x 0.60 = 2.40 kg

P3 : the total air dried soil in the plant container was 2.72 kg, where each polyethylene tube was filled with 0.68 kg soil

2nd Experiment

Like in the 1st experiment each pot was filled with different soil weight to obtain different soil compaction as follows,

follows,

P1 : each pot was filled with 5.5 kg air dried soil.

P2 : pots were filled with 6.05 kg air dried soil each

P3 : each pot was filled with 6.60 kg air dried soil

In both experiments the soil used was a Latosol type from Pasar Jumat, South Jakarta, and the site from where soil was taken had

been planted before with soybean. The physical and chemical soil properties are presented in Table 1.

1.4. Radioisotope employed

The isotope used in both experiments was ^{32}P in the form of $KH_2{}^{32}PO_4$ carrier free solution. The specific activity used was 100 uCi/1ml. The radioisotope solution was injected into the soil by disposable 5 ml syrenges 2 days before the plants were harvested.

1^{st} Experiment

In each soil depth which were, 0 - 5 cm (K1), 5 - 10 cm (K2), 10 - 15 cm (K3), 15 - 20 cm (K4), 1 ml carrier free $KH_2{}^{32}PO_4$ solution as injected through the glass tube attached to the plant containers.

2^{nd} Experiment

Like in the 1^{st} Experiment carrier free $KH_2{}^{32}PO_4$ solution was injected into the soil equal to the soil depth employed in the 1^{st} experiment. The radioisotope was injected in 4 holes surrounding the plants. In each hole 1 ml radoiisotope solution was injected so that each plant received 4 ml of the radioisotope solution.

1.5. Percentage of plant roots

The percentage of roots was calculated based on the cpm of ^{32}P in the shoots.

1.6. Basal dressing and plant management

Basal dressing applied to both experiments at planting time was 20 kg N/ha, 60 kg P/ha, 60 kg K /ha, respectively. To prevent drought plants were watered once in the two days.

In the 1^{st} experiment the seeds were planted on July 9^{th} 1991 and plant harvest was done on August 23^{th} 1991 respectively.

For the 2^{nd} experiment seeds were planted on October 4^{th} 1991 and plant harvest were carried out on December 26^{th} 1991.

1.7. Experimental design

The experimental design applied for both experiments was a factorial experiment involving a randomized block design with 3 replications.

1.8. Parameters applied

1st Experiment

Parameters applied were,

- plant height and number of leaves observed at 3, 4, 5, and 6 weeks after planting (W1, W2, W3, W4) respectively
- pod number observed at W3 and W4
- plant dry weight
- root growth expressed in percentage of roots based on the ^{32}P content of shoots
- cpm of ^{32}P of several plant parts

2nd Experiment

Parameters applied were,

- comparing the cpm of ^{32}P shoots to roots vs dry weight of roots
- dry weight of shoots

2. Field Experiments

Two field experiments were conducted at the Center for the Application of Isotopes and Radiation/PAIR - BATAN. Soil of the experimental site was a Latosol type and its physical and chemical properties are presented in Table 1.

The plant material used was soybean var. TENGGER which was planted directly after soil cultivation. Plant distance used was 15 cm x 40 cm. Two harvest time were applied namely at the R4 (pod formation stage) and R8 (seed maturity stage) stages of soybean growth.

For the first experiment the dates of planting and harvest were June 15th 1992 and September 16th 1992 respectively. While for the second experiment the dates were July 2nd 1992 and October 19th 1992 respectively.

Treatments employed in the two experiments were,

T4 : the experimental site was cultivated by a hand tractor of 2 t of 4 times back and forth

T2 : equal to treatment T4 but the site was tractored only two times

C1 : the experimental site was hoed once

All the treatments were repeated 4 times and each treatment was executed at a block of 3m x 3m. The total experimental blocks used were 12 blocks. The design used was a completely randomized block design.

The second experiment was done at the same site and using the same blocks for the same treatments. So for example the T4 treatment in the second experiment has received 2 times T4 treatment, indicating that the experimental blocks for this treatment has been tractored 8 times.

Parameters applied were,

R4 growth stage (end of pod formation) : - active growing roots expressed by the ^{32}P content of stover and pods
- height of plants and number of pods
- dry weight of stover and pods

R8 growth stage (seed maturity) : - dry weight of stover, seeds, and plants

Radioisotope used was the same as used in the green house experiments. For the first experiment the ^{32}P was injected into 4 holes around the plant at a 10 cm distant from the plant stems and at a 15 cm soil depth.

In the second experiment the ^{32}P was injected at the same distant as in the first experiment but at two different soil depths namely 5 and 15 cm. Here the radioisotope was injected not into 4 holes but into 6 holes around the plants.

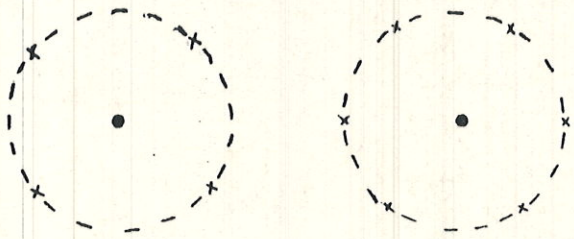

Figure 2. Site for the injection of ^{32}P around the soybean plants.

In the first and second experiment each hole was injected with 5 ml radioisotope solution using a stainless steel syrenge, specially designed for injecting radioisotopes solution in the field.

The specific activity applied was 50 uCi/ml and 25 uCi/ml for the first and second experiment respectively.

The ^{32}P analysis in the plant parts was done using the method as described by L'ANNUNZIATA (10).

RESULTS AND DICUSSIONS

1. Growth of soybean roots

The growth of soybean roots obtained from the greenhouse experiments are presented in Figures 3 and 4.

Figure 3 clearly shows that the highest root growth for the three different soil compaction are all concentrated at the upper soil depth (K1, 0 - 5 cm soil depth). But the highest root growth for this particular depth is for the most severe soil compaction (P3). This was shown by root growth expressed in Arcsin I (Arcsin $\sqrt{\%}$ dry weight of root) and Arcsin II ($\sqrt{\%}$ cpm of shoots). For the lightest soil compaction (P1) the root growth for the lower soil layers (K2, K3, K4) decreased gradually, meaning that the roots are in a sense more equally distributed among these soil layers. While for the more severe compaction (P2 and P3), the decrease is more distinguish especially for the most severe compaction (P3). This suggest that with the increase of soil compaction, roots would mostly concentrated at the top soil. This is in line with data obtained by GOSS and DREW (11), showing that soil compaction could inhibit the penetration of root into the deeper soil layers. According to RUSSELL (12), this is due to the decrease of soil pores and O_2 contration and the increase of CO_2 concentration.The fact that roots concentrated in the top soils when soil compaction occurs could endanger plant growth. This was suggested by ALSTON and LUNGLEY (13) who stated that when a change of environment towards the worst occurrs for example the occurring of drougth, the first root which will suffer are the roots in the top soil layers. So there would be only a small amount of roots left in the deeper

soil layers to support plant growth.

Fig. 3 also shows that for the lightest (P1) and moderate soil compaction (P2), Arcsin I is lower than Arcsin II. Indicating that active growing roots are less than the total roots. While for the severe soil compaction (P3) nearly all roots are still active growing but the total roots are quite low. This shows that the plants were restricted in their total root growth.

The second greenhouse experiment showed that the cpm of roots were much higher than the cpm of shoots. On the other hand the cpm of the roots are more or less related to the dry weight of the root. This might be due to the equilibrium between shoots and roots of ^{32}P which has not been achieved. As mentioned before the time between ^{32}P application and plant harvest was only two days. Apprently 2 days is too short for ^{32}P to reach an equilibrium between roots and shoots.

In the field experiments the root growth is expressed in cpm of stover and pods as presented in Table 2. Data obtained from the first experiment showed that the cpm of the roots of all the three different experiment was nearly equal. It might be that this was due to the equilibrium of ^{32}P which has been reached after two weeks. As mentioned in Materials and Method the time relapse between ^{32}P application and plant harvest was two weeks and it seems that this period of time was enough for ^{32}P to establish its equilibrium between roots and shoots. Further it was shown that the most active growing roots judged by the cpm of stover and pods is for treatment T4 and the lowest is for treatment T2 respectively (Table 2). In the second experiment there was not much difference between the cpm of all three treatments for roots in the 5 cm soil depth expressed in cpm of stover but when expressed in cpm of pods the difference was quite high and the highest cpm is for treatment C1 (Table 2).
Basing root growth on plant parts with the highest cpm should be considered for further root growth studies.
The data of the first and second experiments suggested that the application of the treatments after two experiments especially for the heavy used of the hand tractor showed, that there is already an effect of soil compaction on root growth.

Comparing the field experiment to the green house experiment apparently in the field, more used of hand tractor for soil cultivation is needed to show an effect of soil compaction on root growth, while for green house studies this purpose was easily achieved.

2. Plant growth of soybean

In both greenhouse experiments the plant growth was inhibited by the increasing soil compaction (Figures 3 and 4). This strongly indicated that there must be a correlation between root growth and plant growth, showing that less plant growth was a result of less root growth.

Interesting data is shown by the field experiments. For the first experiment the best plant growth was shown by the plants receiving the T2 treatments for both harvest (Tables 3 and 4). While in the second experiment this was achieved by plants receiving the C1 treatment (Tables 3 and 4). The lowest growth in the first experiment was for the plants receiving the T4 treatment at the R4 harvest but for the second harvest (R8) it was for plants receiving the C1 treatment (Tables 3 and 4). This shows that plants receiving the T4 treatment when given time could recover. Plant growth was expressed in several parameters as presented in Tables 3 and 4. In the second experiment the highest plant growth was shown by plants applied with the C1 treatment and the lowest growth was achieved by plants apllied with the T4 treatment. When connecting the plant growth and root growth apparently it could be assumed that there was a distinguished correlation between root growth and upper plant growth as obtained too by data from the greenhouse experiments. In the field experiment at the second experiment the soil cultivated by hand tractor was already quite compact to have an effect on root and this would have an effect on plant growth.

In the first field experiment it was shown that the highest root growth in the 15 cm soil depth was for plant treated with the T4 treatment (Table 2). But from plant growth data presented in Tables 3 and 4 it was shown that the highest plant growth was achieved by plants applied by the T2 treatment. It

could be suggested based on this data that roots in the 15 cm soil depth alone was not enough to sustain plants for good growth. Apparently root in the soil depth deeper than 15 cm are still needed to support plant growth. Obviously for the T4 treatment beneath the 15 cm soil depth there was already a forming of a hard pan which could not be penetrated by plant roots resulting in less plant root and causing less plant growth.

For the second experiment the root growth condition was visualized well by the plant growth. Low or high root growth expressed in cpm of several plant parts resulted in low or high plant growth too. From the second experiment it was clearly shown that soil compaction inhibited root growth in the field and will further affected plant growth. The data obtained from all the experiment reported here is in line with data obtained by other reseach workers (6, 9, 14, 15).

Other interesting data from the field experiments showed that plant growth expressed in several parameters were higher in the second experiment compared to the first experiment for both harvest (Table 3). It might be that this was due to the season, which was different for both experiments. The first experiment was done at the beginning of the dry season while the second experiment was executed in the beginning of the wet season.

CONCLUSIONS

Soil compaction treatments executed in the green house and field experiments were able to decrease root and plant growth. In the field experiment the decrease of growth both for root and plant was more significantly shown in the second experiment.

High root growth in certain soil depth apparently was not enough to sustain high plant growth.

Further experiments have to be conducted to obtain the best cultivation method to be applied when using agricultural machinary for optimal plant growth by reseach workers who might be interested in using ^{32}P for root studies.

AKNOWLEDGEMENT

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Table 1. Soil properties from Pasar Jumat (Lat. sol type)

Sand	0.7 %
Silt	30.3 %
Clay	69.0 %
pH (H2O)	5.4
(KCl)	4.3
Cation Exchange Capacity (per 100 g)	14.2 me
K	0.3 me
Ca	10.1 me
Mg	3.4 me
Na	0.4 me
Adsorption capacity (per 100 g)	27 me
P_2O_5 (Olsen)	9 me
K_2O	11 me
Organic matter	
C	1.25 %
N	0.14 %
C/N	9

Table 2. Count per minutes (cpm) of several plant parts in the first and second field experiment

		First Experiment			Second Experiment			
		roots	stover	pods		roots	stover	pods
T4	15 cm	43029	62871	83676	5 cm	7784	10590	27270
					15 cm	5361	7866	15492
T2	15 cm	43001	49210	63074	5 cm	7067	11507	27563
					15 cm	8361	15306	30873
C1	15 cm	43649	60394	72795	5 cm	8506	14563	36334
					15 cm	9828	18721	32113

Each number is an average of 4 replicates

Table 3 Plant growth of soybean expressed in several parameters as affected by soil compaction at R4 growth stage

	1st Experiment				2nd Experiment			
	PH	NP	DwP	DwS	PH	NP	DwP	DwS
	(cm)		(g)	(g)	(cm)		(g)	(g)
T4	67.75	31.75	5.80	13.40	64.2	52.4	12.1	23.1
T2	71.25	41.40	7.25	16.00	61.8	54.9	12.4	23.1
C1	76.00	38.55	6.90	15.80	71.3	59.5	14.5	29.4
Calc.- F	ns	ns	ns	ns	**	ns	*	**
LSD (5%)	--	--	--	--	3.22	--	1.72	3.68
(1%)	--	--	--	--	4.28	--	--	4.91
CV (%)	6.65	17.81	17.57	12.36	10.98	23.54	23.39	25.18

Notes : PH = Plant Height, NP = Number of Pods, DwP = Dry weight of Pods, DwS = Dry weight of Stover
Calc.- F = Calculated - F, LSD = Least Significant Difference, CV = Coefficient of Variation
ns = not significant, * = significant at $P < 0.05$, ** = significant at $P < 0.01$

Table 4. Plant growth of soybean expressed in several parameters as affected by soil compaction at R8 growth stage

	1st Experiment			2nd Experiment		
	DwSds	DwS	DwPlt	DwSds	DwS	DwPlt
	(g)	(g)	(g)	(g)	(g)	(g)
T1	220.75	249.75	470.50	275.8	346.8	830.0
T2	316.75	317.25	634.00	329.3	394.5	965.0
C1	213.5	228.00	441.50	363.8	436.5	1067.0
Calc.- F	ns	ns	ns	*	**	**
LSD 5%	--	--	--	51.39	35.21	80.05
1%	--	--	--	---	69.69	102.81
CV (%)	30.87	27.93	29.74	9.20	5.18	6.47

Notes : DwSds = Dry weight of Seeds, DwS = Dry weight of Stover
DwPlt = Dry weight of Plants
Calc. - F = Calculated F, LSD = Least Significant Difference, CV = Coefficient of Variation, * = significant at $P < 0.05$, ** = significant at $P < 0.01$

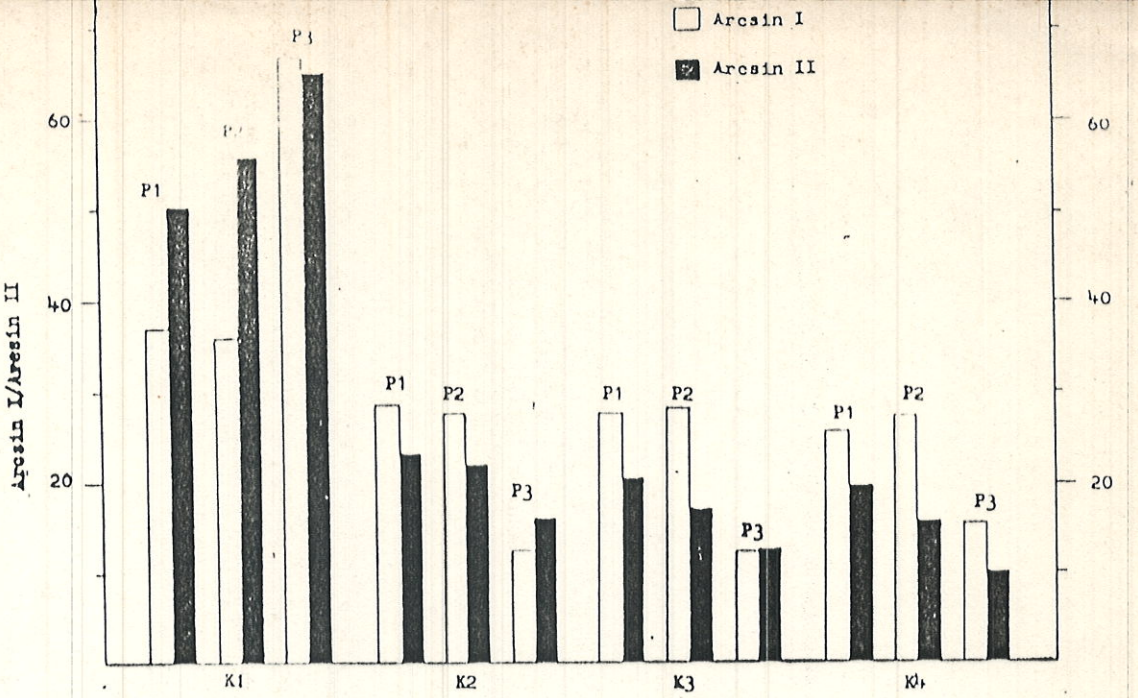

Figure 3. Influence of different soil compaction (P1, P2, P3) on root growth in different soil depths, K1 (0 - 5 cm), K2 (5 - 10 cm), K3 (10 - 15 cm), K4 (15 - 20 cm)

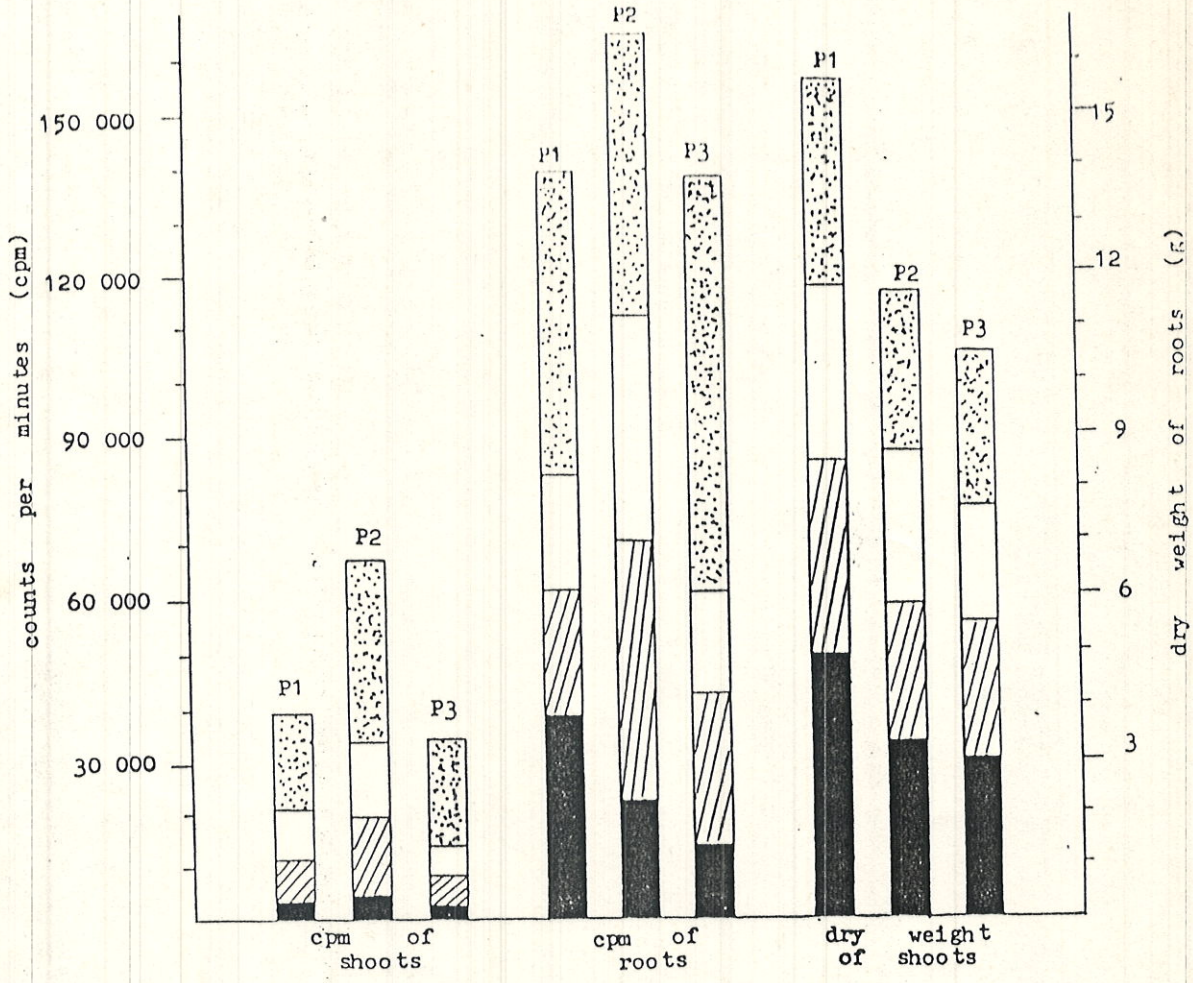

Figure 4. Influence of different soil compaction (P1, P2, P3) on cpm of shoots and roots, and dry weight of roots in different soil depths K1 (▒), K2 (▭), K3 (▨), and K4 (■)

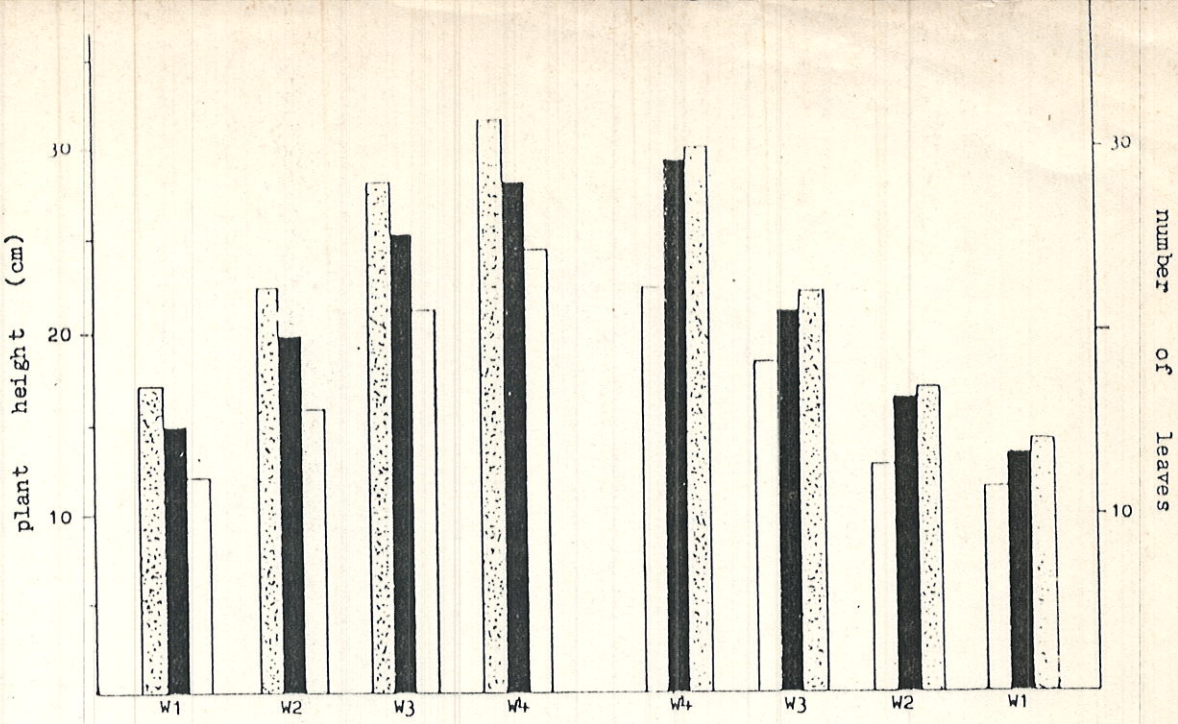

Figure 5. Influence of different soil compaction (▨ P1, ■ P2, □ P3) on plant height and number of leaves at different observation dates (W1 = 3 weeks after planting/w.a.p., W2 = 4 w.a.p., W3 = 5 w.a.p., W4 = 6 w.a.p.)

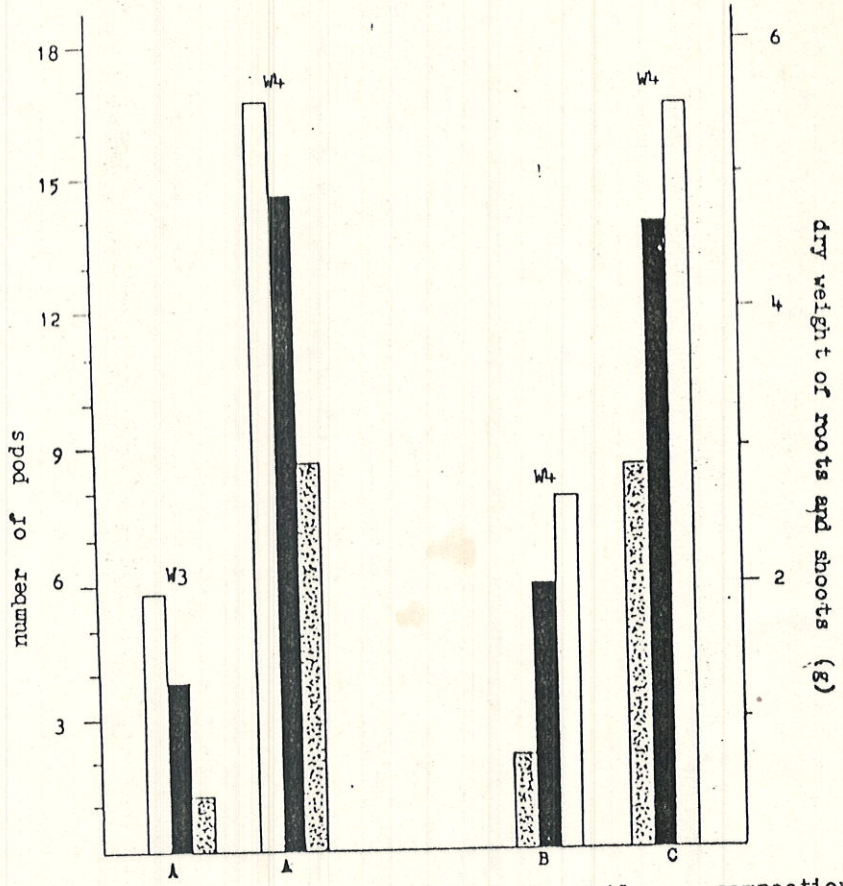

Figure 6. Influence of different soil compaction (□ P1, ■ P2, ▨ P3) on number of pods (A), dry weight of roots (B), and dry weight of shoots (C) at different observation dates (W3 = 5 weeks after planting and W4 = 6 weeks after planting)