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Response of spring barley to changes of compaction and aeration of sandy soil under model conditions

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A b s t r a c t. The response of grain yield and root growth of spring barley to changes of compaction and aeration of a sandy soil was studied under model conditions. The experiment was done using plots of 1 m x 1 m. The results show that ODR was significantly negatively correlated with bulk density. However, bulk density affects both the mechanical impedance to root growth and the ODR. In our experiments it was not possible to separate these different effects of bulk density. The optimum bulk density for both root growth and grain yield was found to be 1.43 Mg m^{-3}. Grain yield was linearly related to root mass.

K e y w o r d s: soil bulk density, oxygen diffusion rate (ODR), root growth, yield, spring barley

INTRODUCTION

Soil compaction caused by increased agricultural mechanization is a problem for production and also for ecology [4,8,9,12-15,17]. The availability of soil oxygen to plant roots as measured by oxygen diffusion rate (ODR) is characteristic of aeration conditions in compacted soils. The aeration conditions are one of the most important factors governing crop yields [3,5-7,11,16]. The availability of soil oxygen to plants depends not only on its concentration in soil air but also on soil physical properties and conditions around the roots. A measure called the oxygen diffusion rate (ODR) was proposed by Lemon and Erickson [10]. Soil aeration is a problem for crop growth only in wet soils [16]. High values for soil water content provide conditions both for restriction of soil aeration and for disruption of soil structure by compaction. Restricted aeration impairs plant growth by several mechanisms and ultimately reduces crop yields [7].

The purpose of the study was to produce different levels of bulk density in a sandy soil and to investigate the effects on aeration conditions, root mass growth and yield of spring barley.

MATERIALS AND METHODS

The experimental site, soil and climate

The microplot experiment was run at the Institute of Soil Science and Plant Cultivation (IUNG) in the experimental station in Puławy at 51°24´ N, 21°57´ E, in the years 1987-1997 with different crops in rotation. The results from three years (1992, 1994, and 1996) with spring barley are presented in this paper.

The soil used in the experiment had 63% sand, 21% silt and 16 % clay, and is classified as a heavy loamy sand. Over the vegetation period (months IV-IX) at Pu³awy the mean cumulative rainfall is 376 mm and the mean air temperature is 14.4°C.

The plot experiment

The experiment was conducted on plots 1 m x 1 m with three replications, using the independent series method. There were 4 treatments with different levels of soil compaction. The soil on the plots was compacted uniformly by hand with a metal ram of 20 cm x 20 cm. The bulk densities produced in the arable layer (0-40 cm) were as follows: 0 - very-loose soil (bulk density: 1.20-1.25 Mg m^{-3}), I - medium-loose soil (bulk density: 1.30-1.35 Mg m^{-3}), II - weak soil compaction (bulk density: 1.40-1.45 Mg m^{-3}), III - strong soil compaction (bulk density: 1.65-1.70 Mg m^{-3}). In the

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following, we shall assume that the mean bulk densities in these treatments were: 1.225, 1.325, 1.425 and 1.675 Mg m^{-3}, respectively. Each year, the 0-40 cm layer was removed and re-compacted.

ODR and root mass measurements

Soil aeration was determined by measuring the oxygen diffusion rate (ODR), with the use of the universal meter for recording soil electrochemical properties, (manufactured by the Institute of Agrophysics, Polish Academy of Sciences, Lublin). This equipment uses three electrodes (platinum, metallic and calomel) simultaneously. Measurements were made at 20 cm depth with five replications in each plot at around mid-day at crop emergence. The results presented are the means of these values.

The root mass of spring barley was measured as follows. Samples of 630 cm^3 were taken at the heading stage from each 10 cm sub-layer of the 0-40 cm soil layer with an Eijkelkamp root sampler of 80 mm diameter. Soil was removed by washing the samples on sieves with holes of 0.8 mm diameter. The roots were then oven-dried at 60°C for 20 h and weighed.

RESULTS AND DISCUSSION

The average results from the three years of experiment are presented in Tables 1 and 2.

Analysis of variance showed that both the mean values of ODR and of grain yield in the experiment were significantly affected by bulk density in this heavy loamy sand.

Increasing bulk density (ρ) reduced the mean oxygen diffusion rate (ODR) according to the following regression equation:

$$\mathrm{ODR} = 338 - 179\rho, \quad r^2 = 0.97 \tag{1}$$

as shown in Fig. 1.

The range of critical values of ODR for the emergence of spring barley was found to be 25-42 μg m^{-2} s^{-1} by Bertrand and Kohnke [2] and Letey *et al.* [11] . The mean value of ODR at the time of emergence obtained by us for the most compacted treatment was smaller than the 40-50 μg m^{-2} s^{-1} reported as being restrictive for plant growth by Gliński and Stępniewski [7]. Therefore we conclude that soil aeration at the time of crop emergence in our experiments was a limiting factor only in the strongly - compacted treatment.

The results in Table 2 show that root mass was greatest in Treatment II at all depths. The results show that very loose as well as strongly-compacted soil limited root growth. Figures 2 and 3 show the effects of bulk density, ρ, on root mass, M_r, and on grain yield, Y, respectively.

In both cases, the response exhibited a maximum value at some optimum bulk density, ρ_{opt}. It was found that these data can be well described by second-order equations of the type:

$$M_r \text{ or } Y = a + b\rho + c\rho^2. \tag{2}$$

These equations were fitted by regression and gave the parameters shown in Table 3.

T a b l e 1. Spring barley yields under different soil compaction and aeration conditions

Treatment	Bulk density (ρ) (Mg m^{-3})	Oxygen diffusion rate (ODR) (μg m^{-2} s^{-1})	Grain yield (Y) (dry mass g m^{-2})
0	1.225	119.5	438
I	1.325	95.1	457
II	1.425	92.0	478
III	1.675	36.5	406
LSD(α= 0.05)	-	18.46	17.61

T a b l e 2. Effect of soil compaction on spring barley root mass (g dry mass in 630 cm^3 of soil)

Treatment	Soil layer (cm)				Mass of root (M_r)
	0-10	10-20	20-30	30-40	Total: 0-40 cm
0	0.156	0.085	0.033	0.041	0.314
I	0.160	0.110	0.039	0.021	0.329
II	0.227	0.125	0.039	0.072	0.462
III	0.159	0.046	0.012	0.035	0.252
LSD (α= 0.05)					0.015

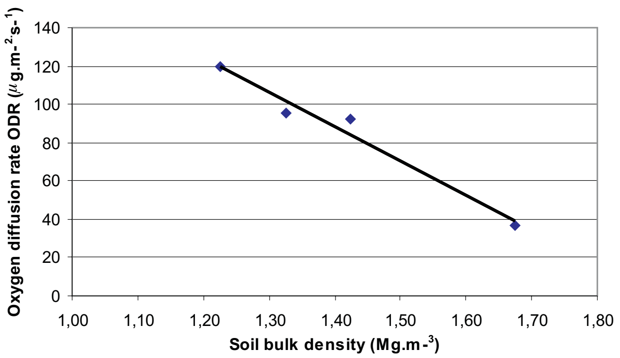

Fig. 1. Effect of soil bulk density (ρ) on the mean oxygen diffusion rate (ODR).

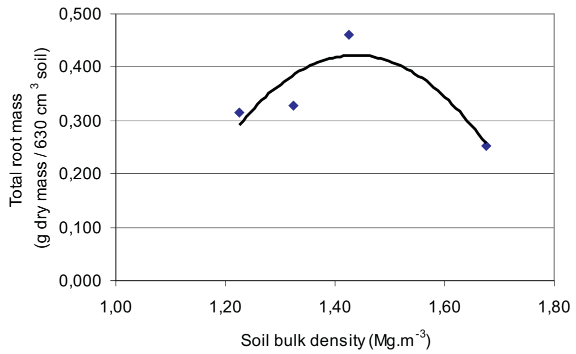

Fig. 2. Effect of soil density on total root mass of spring barley in the 0-40 cm layer**.**

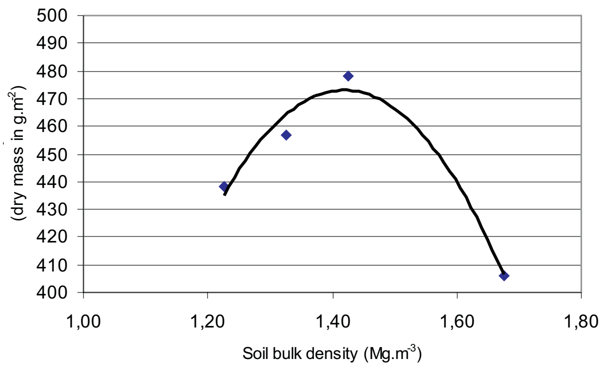

Fig. 3. Effect of soil bulk density on grain yield of spring barley.

T a b l e 3. Parameters of Eq. (2) for total root mass, M_r, and grain yield, Y, as functions of soil bulk density, ρ. The coefficient of determination is given as r^2

Parameter	a	b	c	r^2
M_r	-2.924	8.402	-5.612	0.77
Y	-1009	2863	-1558	0.97

The maxima of these curves occur at

$$\frac{dM_r}{d\rho} = 0 \text{ and } \frac{dY}{d\rho} = 0\text{, respectively.} \tag{3}$$

Differentiation of Eq. (2), and the application of Eq. (3), shows that maximum root mass or maximum grain yield occurs at an optimum soil bulk density, ρ_{opt}, given by:

$$\rho_{opt} = -\frac{b}{2c}. \tag{4}$$

Substitution of the values from Table 3 shows that for root mass,

$$\rho_{opt} = 1.44 \text{ Mg m}^{-3} \tag{5}$$

and for grain yield,

$$\rho_{opt} = 1.42 \text{ Mg m}^{-3}. \tag{6}$$

These values are not significantly different, and we shall consider that the mean value of ρ_{opt} = 1.43 Mg m^{-3} is the optimum density for the growth of spring barley on this soil.

At densities greater that those given by Eqs (5) and (6), plant growth and yield are reduced by increasing bulk density partly because of increased mechanical resistance to root penetration and partly because of the reduced availability of oxygen as shown by the ODR values. Our experiments do not allow us to separate these two effects.

The reduction in plant growth and yield found with soil bulk densities smaller than those in Eqs (5) and (6) is more difficult to interpret. It may be partly a consequence of poor soil - root contact affecting water and nutrient uptake. A similar response of plants to low soil densities has been reported by Hakansson [9] and Arvidsson, Hakansson [1]. Grain yield, Y, was linearly related to total root mass, M_r, as shown in Fig. 4.

The regression equation obtained is:

$$Y = 320\, M_r + 336 \text{ (g m}^{-2}\text{)}, \quad r^2 = 0.86. \tag{7}$$

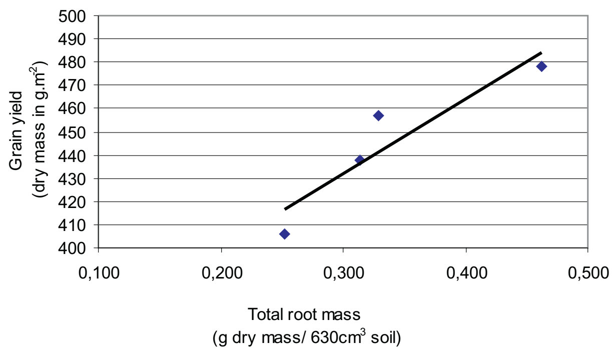

Fig. 4. Correlation between root mass in the 0-40 cm layer and grain yield.

This shows the importance of having good soil physical conditions for root growth if it is desired to achieve optimum yields.

CONCLUSIONS

1. In treatment III - with strong soil compaction, the ODR value was decreased by 69.5 % in comparison with treatment 0.

2. The results show that very loose as well as strongly-compacted soil limited root growth. Aeration was a limiting factor at the time of emergence of spring barley only in the strongly-compacted soil. This would have contributed to the observed decreases in the grain yield.

3. The optimum density of the heavy loamy sand soil for root growth and yield of spring barley was in the treatment II with weak soil compaction, and occurred at a density of ρ_{opt} = 1.43 Mg m^{-3}.

4. In comparison with the yield at the optimum soil density, grain yield was decreased by 8.4 % in treatment 0 - with very-loose soil, and by 15.1 % in treatment III - with strong soil compaction.

5. Grain yield was significantly positively correlated with total root mass. This illustrates the importance of having good soil physical conditions for root growth if it is desired to achieve optimum yields.

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