

Growth and Nutrient Uptake of Grain Legumes as Affected by Induced Compaction in Andisols

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ABSTRACT

A greenhouse experiment was conducted to evaluate the effect of different levels of compaction on grain legumes viz. soybean, chickpea and lentil in different Andisols. Plants were grown in different levels of surface compaction as (i) no compaction, (ii) medium compaction and (iii) high compaction. In this experiment, the effects of compaction on the shoot and root development and uptake of N, P, K, Ca, Mg, Fe, Mn, Zn and Cu were investigated. The plant dry weights differed among the crops for various compaction treatments. The yields of plants decreased with increase in soil compaction. The results obtained in the study revealed that compaction causes detrimental effects on uptake of nutrients both by shoot and root for all the crops except Ca uptake by root. This study indicated that in Andisols where increase in bulk density, though still lower than what would be critical in other soils, adversely affected the growth and uptake of nutrients by crops studied.

Key Words: Andisol; Compaction; Soybean; Chickpea; Lentil

INTRODUCTION

Soil compaction influences agricultural sustainability through its effects on soil properties and crop development. Soil layers may become compacted naturally as a consequence of their textural composition, moisture regime, or the manner in which they were formed in place. Soil compaction is bringing an undesirable consequence of mechanization, which must be avoided (Hillel, 1980). Increasing usage of agricultural machineries usually imparts soils compaction, which is detrimental to the soil physical environment, especially in respect to air-water relationship and impedance to the development of plant roots. Soil compaction is now considered to be multidisciplinary problems in moist, temperate climatic zones of northern Europe and North America. However, there is increasing evidence of soil compaction problems in both humid and dry tropical climates (Kayombo & Lal, 1994) and even in Mediterranean type climates, where traffic intensities in extensive grain production are often very low (Holloway & Dexter, 1990). Soil compaction is also recognized as a component of worldwide soil degradation (Oldeman *et al.*, 1991). Compaction is now considered an important factor to be included in surveys of the incidence of soil degradation (Hammond, 1992).

The movement of liquid through soil depends on many known and unknown forces, associated with the internal energy of the soil liquid interaction forces and driving forces due to thermal, ionic, osmotic, gravitational, hydraulic and pressure gradient. The liquid and gas contents of a soil are rarely static. In general, as the quantity of liquid decrease the quantity of gas increases (Harris, 1971). Three-phase system of a soil undergoes changes as soon as the external strength exceeds the internal soil strength. Soil compaction can result

either in a higher bulk density or, when soil loading is attended with retarded water fluxes and high dynamic forces, in a completely homogenized soil characterized by a lower bulk density and a predominance of fine pores. Both increased bulk density and homogenization cause decrease aeration and increase penetration resistance, which results in impeded root development (Horn *et al.*, 1995). Although a lot of work has been done on many plant species, little information is available on the effect of compaction on the growth at the vegetative stages of crop development in low bulk density soil. An investigation was carried out to monitor the effect of compaction on vegetative growth and nutrient uptake by soybean, chickpea, and lentil in Andisols.

MATERIALS AND METHODS

The experiments were performed under controlled environment in a greenhouse at Iwate University, Japan in a randomized complete block design with three treatments and each treatment was replicated thrice. The crops used in the study were soybean (*Glycine max* L. cv. Suyutaka), chickpea (*Cicer arietinum* L.) and lentil (*Lens culinaris* Medic). Andisols of sandy loam texture was used for the growth of soybean while clay loam was used for the growth of chickpea and lentil. Soils having Andic properties from Ap horizon were collected from Iwate Prefecture, the northern part of Honshu Island of Japan. Soils were pumic Andisols (Melanudands). The soils were air-dried and screened through 2 mm screen to remove gravels and undecomposed plant debris and the properties of the composite soil samples were analyzed (Rahman, 1997) following the standard methods. Yoorin (Trade name of fertilizer: Ca, Mg, PO₄ and Si) was incorporated at the

recommended dose (8 g pot⁻¹) for Andisol of Japan and thoroughly mixed with the soil at the time of soil preparation. No extra fertilizers were used during the experiment. Polyvinylchloride (PVC) pipes 250 mm in diameter and 8.2 mm in thickness were cut into 500 mm lengths and were covered at bottom with a 5 mm thick plastic plate having 6.5 mm holes and were used for plant culture. Fifteen kilograms of air-dried Andisols (low bulk density soil: 0.52-0.56 Mg m⁻³) was taken in the PVC pots for surface compaction. To bring the soil water content at field capacity, the tops of the containers (pots) were covered with polyethene film after adding water to prevent evaporation and the soil was allowed to equilibrate at greenhouse temperature. After 45 h, the film was removed and compaction treatments viz. no compaction (C₀) by imposing 0 J compactive energy; medium compaction (C₁) by imposing 522 J compactive energy and high compaction (C₂) by imposing 1044 J compactive energy (Shafiq *et al.*, 1994) were imposed. The pots were again brought to field capacity prior to transplanting the seedlings. Seeds of the crop were germinated on moist blotter in a tray at constant temperature and than 6 healthy seedlings were placed inside the soil having different compaction levels. Seedlings were later thinned to four plants per pot and allowed to grow soybean for 42 days, and chickpea and lentil for 28 days. After transplanting the crops were protected against pests and diseases and the greenhouse temperature was maintained at 20°C during the day and 15°C at night for soybean growth and at 25°C during the day and 20°C at night for chickpea and lentil through out the study with 14 h photoperiod and the light intensity was 280 µmol photons m⁻² s⁻¹. Maintaining the greenhouse humidity at 70-80 %, the pots were kept at field capacity through periodic weighing and watering during the experiment. Plants were harvested at the end of the experiments. Roots were separated from soil by washing the soil over a screen surface. Roots were washed properly and separated from shoots. Roots were blotted up with paper towels. Shoots and roots were placed in an oven at 60°C for 2 days. Shoot dry matter (SDM) and root dry matter (RDM) were recorded. Both shoot and root samples were digested with HNO₃-HClO₄ (2:1) for determination of nutrients other than N. Nitrogen concentration of the shoot and root samples were determined by micro-Kjeldahl method as described by Jackson (1973). Phosphorus was determined by vanadomolybdate yellow colour method (Jackson, 1973) and K, Ca, Mg, Fe, Mn, Zn and Cu by Atomic Absorption Spectrophotometer (Perkin Elmer).

Uptake of nutrients was calculated from the concentration of nutrients. The tolerance index (TI) of crops was also calculated (Quartacci *et al.*, 2003). The means were calculated for all the parameters. Data were subjected to analysis of variance (ANOVA) and means were compared using Duncan's Multiple Range Test (Gomez & Gomez, 1984). Correlation coefficients between plant nutrient parameters and compactive energy were also calculated.

RESULTS

Shoot and root growth. Shoot and root growth parameters of soybean, chickpea and lentil, grown in Andisols of varying soil properties are presented in Table I. The shoot and root growth of all the crops significantly varied with the compaction treatments. In case of chickpea and lentil shoot and root dry weight decreased significantly when the compaction level increased from 0 J to 522 J and there was no significant difference in their shoot weight at 522 J and 1044 J energy. In case of soybean higher shoot dry weight was observed in 0 J treatment followed by 522 J and lowest in 1044 J treatment. Root dry weight in soybean decreased significantly with the increased energy levels. The root shoot ratio decreased with increased levels of compaction for soybean. The opposite trend was observed in case of chickpea and lentil. The decrease in root shoot ratio might be attributed to higher rates of development of shoots as compared to roots in soybean than the other crops. There was no significant difference in root to shoot ratio by different level of energy induced soil compaction in case of soybean. Tolerance index increased with compactive energy for soybean. On the other hand, in case of chickpea and lentil tolerance index decreased with compactive energy and increased for further increment of compactive energy.

Nutrient uptake by shoot. It is evident from the data (Table II) that induced compaction of soil created by different levels of compactive energy resulted in variation in the nutrient contents of plant shoot. Uptake of N, P, K, Ca, Mg, Fe, Mn, Zn and Cu by the shoots of soybean, chickpea and lentil were decreased when the compactive energy was applied to compact the soils, i.e., from 0 to 522 J. Increase in compactive energy from 522 to 1044 J further reduced the uptake of nutrients in almost all cases. The effect of compaction on the contents in soybean shoots were in general least pronounced than those of chickpea and lentil crops. Compared to control treatment, compaction created by 522 J energy resulted in significant decrease in the contents

Table I. Developmental features of grain legumes as affected by soil compaction

Crop	Energy(J)	SDM(g pot ⁻¹)	RDM(g pot ⁻¹)	TDM(g pot ⁻¹)	Root/Shoot ratio	TI
Soybean	0	6.85a	1.98a	8.83a	0.29a	100
	522	6.19a	1.67b	7.86ab	0.27a	0.89
	1044	5.43b	1.38c	6.81b	0.25a	0.87
Chickpea	0	2.66a	1.78a	4.44a	0.67b	100
	522	1.35b	1.53b	2.88b	1.13a	0.65
	1044	1.22b	1.42b	2.64b	1.16a	0.92
Lentil	0	0.87a	0.65a	1.52a	0.75b	100
	522	0.53b	0.56ab	1.09b	1.06a	0.72
	1044	0.42b	0.45b	0.87b	1.07a	0.80

*Means sharing similar letters are non-significantly different by DMRT at $P < 0.05$; TDM = Total dry matter.

of Fe, Mn, Zn and Cu in shoot of soybean plants. With further increase in compactive energy from 522 J to 1044J though the values showed a decreasing trend, the difference was statistically significant only with P, K, Ca and Zn contents of soybean plant. The uptake of nutrients by shoot of chickpea was reduced due to imposed compaction of soil. An examination of the data revealed that the content of nutrients obtained with zero compaction were significantly reduced due to application of 522 J compactive energy in case of all nutrients except magnesium. With further increase in compactive energy (1044 J), though the nutrient contents decreased except phosphorus, the differences were statistically significant only with copper. The uptake of nutrients by lentil showed a general decreasing trend to those of soybean and chickpea with the increase of compactive energy from 0 J. The highest uptake values were obtained with 0 J treatment and these values were significantly higher compared to 522 J treatment with N, P, Ca, Mn, Zn and Cu. Statistically similar values were obtained with all three treatments in case of K and Mg.

Nutrient uptake by roots. Nutrient uptake by roots as affected by induced compaction is presented in Table II. A decreasing trend was observed with increased compactive energy in the uptake of N, P, K, Mg, Fe, Mn, Zn and Cu by the roots of soybean, chickpea and lentil except the Ca contents of lentil and soybean. Nutrient contents of roots were also statistically varied at different levels. Calcium uptake by soybean shoots showed a decreasing trend but not

by the roots. However, the uptake of Ca by soybean roots increased with increased compaction level.

Relationship between compaction and plant nutrients.

Correlation studies between the uptake of nutrients by shoots and roots and level of soil compaction showed (Table III) that all the nutrients except Ca in root of soybean plant had negative relationship. Different parameters yielded different values of correlation coefficient but did not show any level of significance. Results of the experiments and correlation coefficient values showed that compaction reduced nutrient uptake values and the decrease was more pronounced with increased level of compaction.

DISCUSSION

Results indicated the detrimental effects of compaction on shoot and root development of grain legumes. Many researcher including O'Sullivan and Simota (1995) inferred that compaction affects soil dynamics, erosion, soil nitrogen and carbon cycling, cultivation energy requirement and effectiveness, pesticide leaching which affect the crop growth. It is clear that in general compaction of soil reduced shoot nutrient uptake of grain legumes. The effect of compaction decreased aeration and penetration resistance (Stepniewski *et al.*, 1994; Horn *et al.*, 1995), which alter transport, absorption and transformation of nutrients in plants (Glinski & Stepniewski, 1985; Lipiec & Simota, 1994; Veen *et al.*, 1992). Compaction also decreased the air porosity (Rahman & Ito, 1998) and thus reduced the rate of

Table II. Macronutrients (mg pot⁻¹) and micronutrients (µg pot⁻¹) uptake by shoot and root of grain legumes as affected by soil compaction

Crop	Energy (J)	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
Shoot										
Soybean	0	146.1a	47.46a	26.32a	30.42a	1.45a	1897a	531.9a	80.82a	89.37a
	522	135.3ab	45.15a	23.08a	27.86a	1.38a	1421b	427.9b	65.13b	69.31b
	1044	116.1b	39.56b	18.17b	20.22b	1.22a	1108b	395.8b	43.65c	68.76b
Chickpea	0	54.40a	38.40a	10.24a	15.74a	0.78a	2266a	230.4a	144.4a	58.35a
	522	27.40b	19.59b	5.16b	7.72b	0.70a	1064b	120.6b	62.61b	40.92b
	1044	24.19b	22.58b	4.80b	5.68b	0.61a	923b	103.2b	61.15b	30.02c
Lentil	0	11.36a	14.86a	2.77a	5.03a	0.42a	582.9a	137.8a	41.20a	20.82a
	522	6.99b	8.99b	2.15a	3.15b	0.38a	327.6ab	71.38b	25.46b	14.90b
	1044	6.50b	9.12b	1.60a	2.54b	0.36a	271.8b	63.20b	28.00b	12.50b
Root										
Soybean	0	47.84a	12.22a	9.46a	1.30b	0.32a	3119a	93.70a	597.9a	42.12a
	522	37.22b	9.34b	5.73b	1.67ab	0.25b	2937a	79.29b	360.3b	24.35b
	1044	29.91c	8.43b	5.68b	1.82a	0.24b	2852a	72.62b	287.9c	20.77b
Chickpea	0	19.18a	12.24a	2.06a	7.23a	0.23a	2714a	81.60a	181.3a	16.65a
	522	17.85a	11.21a	1.65a	7.37a	0.19ab	2529ab	77.88ab	165.2b	9.09b
	1044	16.74a	9.79a	1.63a	6.03a	0.10b	2340b	65.92b	137.7c	5.10c
Lentil	0	8.94a	7.32a	6.60a	0.84b	0.17a	1037a	121.6a	73.26a	10.10a
	522	6.90b	5.24b	4.14b	0.99a	0.11b	955.4a	89.24b	47.06b	4.20b
	1044	4.33c	3.59c	3.24b	0.41c	0.06c	538.4b	40.50c	33.75c	2.40c

*Means sharing similar letters are non-significantly different by DMRT at $P < 0.05$.

Table III. Correlation co-efficients between nutrient uptake and compactive energy

Nutrient	Soybean		Chickpea		Lentil	
	Shoot	Root	Shoot	Root	Shoot	Root
Nitrogen	-0.9934	-0.9940	-0.9103	-0.9986	-0.9082	-0.9978
Phosphorus	-0.9725	-0.9578	-0.7826	-0.9958	-0.8562	-0.9978
Potassium	-0.9931	-0.8717	-0.8941	-0.8859	-0.9994	-0.9659
Calcium	-0.9610	0.9714	-0.9458	-0.8146	-0.9593	-0.7141
Magnesium	-0.9754	-0.9177	-0.9994	-0.9762	-0.9820	-0.9986
Iron	-0.9930	-0.9787	-0.9098	-1.000	-0.9378	-0.9320
Manganese	-0.9565	-0.9783	-0.9221	-0.9569	-0.9116	-0.9932
Zinc	-0.9960	-0.9558	-0.8736	-0.9887	-0.7810	-0.9827
Copper	-0.8775	-0.9336	-0.9913	-0.9844	-0.9714	-0.9559

respiration, which is vital for the active uptake of nutrients at the expense of the metabolic energy provided by respiration.

The reduction in plant growth associated with soil compaction may be related to the combination of increased root penetration resistance and the development of a rhizosphere environment that affects plant nutrient availability. The reduced root penetration caused by compaction restricts the soil volume available to plants for nutrient uptake (Voorhees, 1985). Rahman and Ito (1995) also observed that nutrient uptake by crop decreased with increased levels of compactive energy in a sandy clay loam Andisols. The compaction of Andisols by loading resulted in a progressive reduction of shoot and root development of crops as well as nutrients acquisition by crops. A high uptake of Ca in the soybean roots under compact soil condition was observed probably due to unsatisfactory translocation of Ca from root to shoot absorbed from Andisols. Furthermore, Ca makes the electrical bridge between carboxyl group and pectin chain to make it strong to soil compaction. This can be explained by the fact that like other soils, compaction decreased the rooting volume of plants (Rahman *et al.*, 1999) in Andisols and thus plant root exploited lesser volume of soil for obtaining nutrients and as a result lower amount of nutrients were taken up by plants.

CONCLUSIONS

The results indicate that plant growth decreased with soil compaction. Crops weights decreased drastically when the compaction level increased from zero J to 522 J while that was not severely affected by further increase in soil compaction from 522 J to 1044 J. The compaction of Andisols resulted in reduction of nutrients uptake by crops. Nutrients move to roots by diffusion and mass flow. Therefore, soil compaction affects the nutrient movement to roots through its influence on diffusion and mass flow. Soil compaction may also cause decrease in the amount of nutrients mineralized from soil organic matter. It is also established that the compaction decreased air-filled porosity of Andisol. For this reason macro- transport in the air-filled pore spaces as well as micro-transport from the air-filled pores to the root cells might be hindered. This study also indicated the necessity of studying the impact of compaction of Andisol in relation to nutrient uptake by crops in details.

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