Journal of Agricultural Science; Vol. 5, No. 1; 2013
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Effects of Paper Mill Sludge Application on Physical Properties of an Illitic Loess Slowly Swelling Soil with High Specific Surface Area and Wheat Yield in a Temperate Climate

S. Amini[1] & S.A.R. Movahedi Naeini[2]

[1] Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran

[2] Faculty member, Soil Science Department, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran

Correspondence: S.A.R. Movahedi Naeini, Faculty member, Soil Science Department, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran. E-mail: salirezam@yahoo.com

Received: October 31, 2012 Accepted: November 13, 2012 Online Published: December 14, 2012

doi:10.5539/jas.v5n1p295 URL: http://dx.doi.org/10.5539/jas.v5n1p295

Abstract

Physical aspects of paper mill sludge application for wheat production, their relative significance and interactions were investigated in a slow swelling-shrinking soil in a temperate climate by a field experiment. Other treatments were mineral fertilizers to gauge nutritional aspects. Treatment with N and K mineral fertilizers combined and the high rate sludge application as mulch, both increased yield when low potassium kinetics otherwise caused potassium deficiency in wheat. High specific surface may increase mechanical resistance to root growth and lower nutrient uptake (K). There are two potential apposing physical aspects of sludge application on swelling-shrinkage rate and K diffusion, also root growth (low mechanical impedance) and nutrient uptake; a positive interaction by increasing soil water content in root zone versus a negative interaction by decreasing diurnal soil temperatures to suboptimal values especially before wheat heading. Low soil temperatures under sludge may become critical for shoot propagation and head density at sub-optimal temperatures of cold years for wheat growth.

Keywords: paper mill sludge, soil amendments, potassium, soil mechanical impedance, soil specific surface, slow swelling-shrinking soils

1. Introduction

Organic wastes applied as mulches or incorporated in the topsoil influence soil physical properties and plant growth. Figure 1 summarizes the results of several works on soil physical benefits of incorporation, notably Jamison (1953); Jamison and Kroth (1958); Phillips and Kirkham (1962); Geiger (1965); Nakshabandi and Kohnke (1965); Rickman et al. (1965); Biswas and Khosla (1971); Morachan et al. (1972); Unger and Stewart (1974); Haryana et al. (1975); Gupta et al. (1977); Pagliai et al. (1981); Jaynes and Tyler (1984); Campbell (1985); Letey (1985); Macrae and Mehuys (1985); Kaddous and Morgans (1986); Thompson et al. (1987); Hornick (1988); Marsh and Rixon (1991); Marshall and Holmes (1992). Figure 2 summarizes results of several workers with mulching; notably, Lemon (1956); Allmaras and Nelson (1971); Chaudhary and Prihar (1974); Lal (1974); Hanks and Ashcroft (1980); Phillips (1980); Singh et al. (1987); Weill, et al. (1990); Gajri et al. (1991); Sharma (1991); Acharya and Sharma (1994); Gajri et al. (1994); Gill et al. (1996). Although important soil physical properties, aggregation, aggregate stability, pore size distribution and all physical properties influenced by amendments, only indirectly affect plant growth, because their relationship to crop production is through their effects on water relations, aeration, temperature and mechanical resistance to root growth (Letey, 1985; Gardner et al., 1999, Joudi & Movahedi, 2007; Joudi & Movahedi, 2008). Soil water content itself affects soil temperature, aeration and shear strength. As for moisture, temperature regime by amendments may also affect swelling-shrinkage rate, ion diffusion (potassium) and root growth.

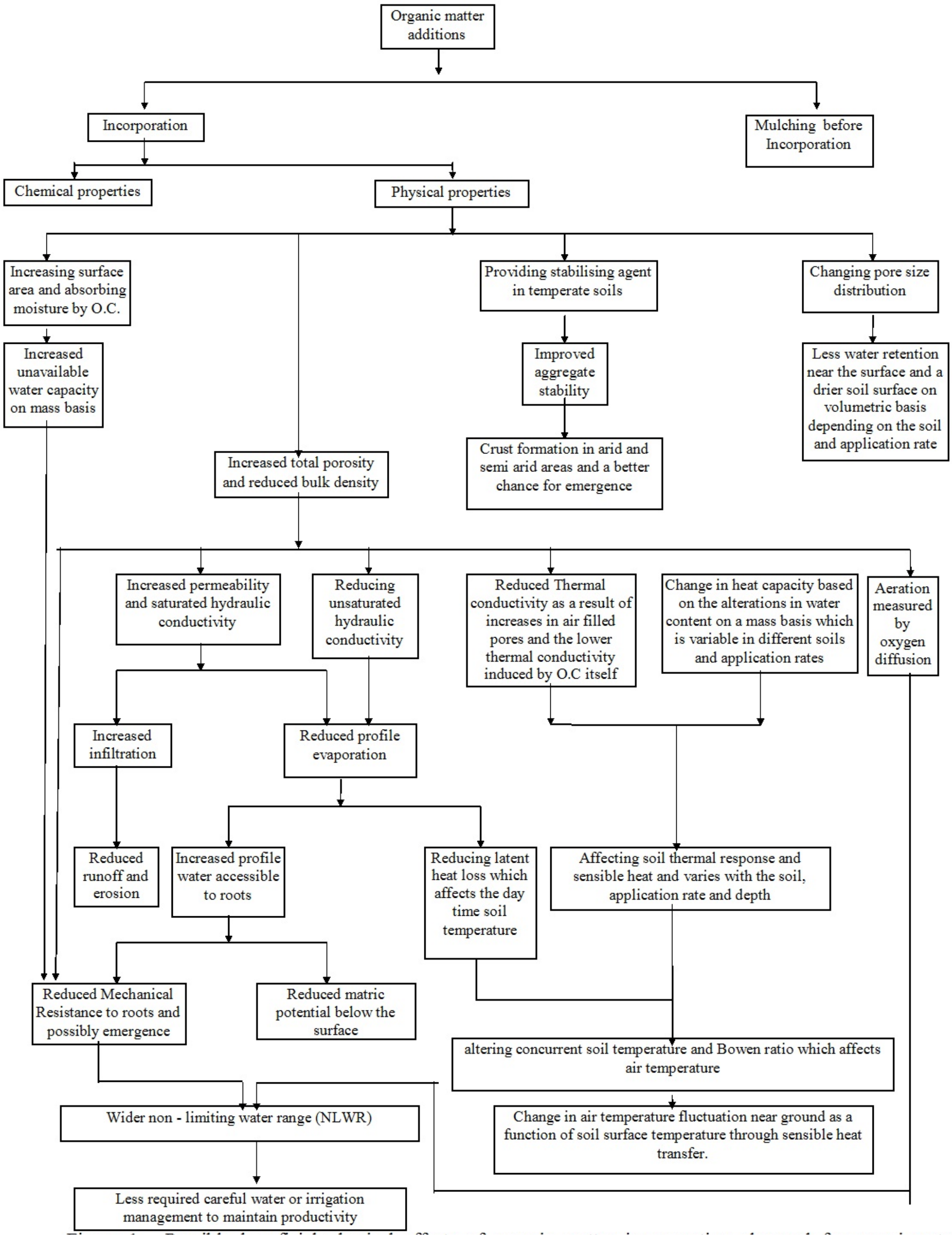

Figure 1. Possible beneficial physical effects of organic matter incorporation observed for experiments conducted under different climatic and soil conditions

Source: Prepared by the second author from references summarized in introduction

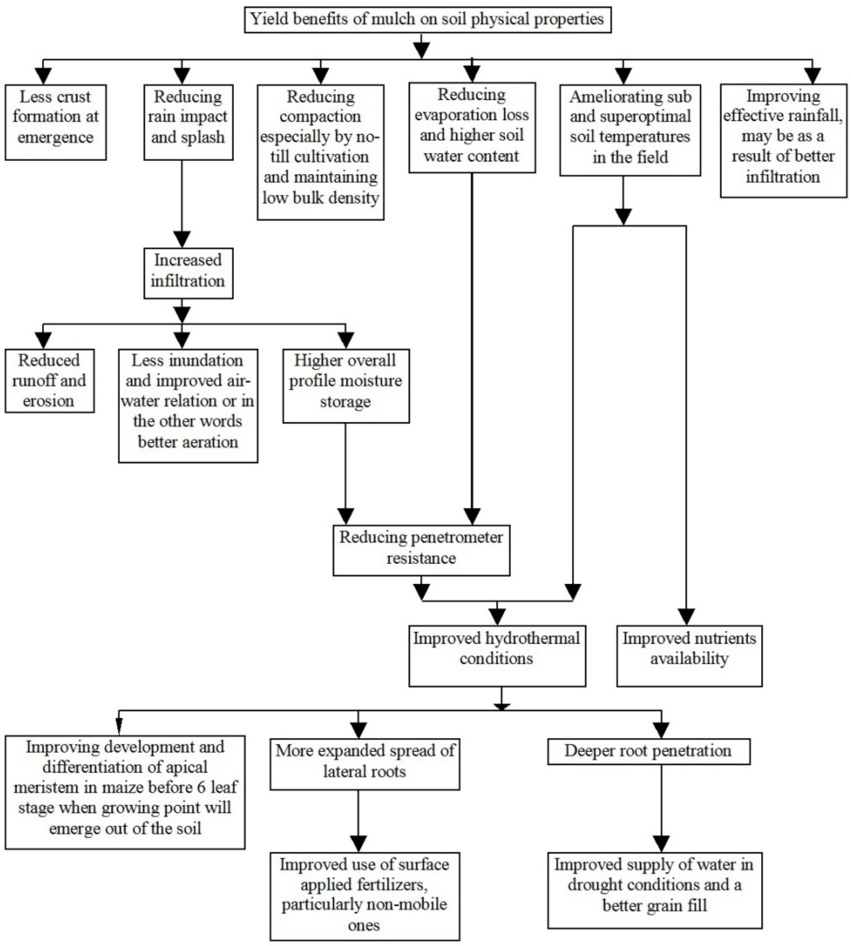

Figure 2. Possible benefits gained by mulching, depending on climatic zone and soil conditions

Source: Prepared by second author from references summarized in the introduction

High yield production and nutrient uptake by genetically modified plants require high applications of immobile nutrients with mineral fertilizers before planting which may harm plants due to high salt index. This may increase demands for slow release fertilizers especially organic amendments as they supply additional nutrients for plants as well. Limitations of phosphate supply, and un-sustainability of fossil fuel based fertilizers and their transport cost adds to the significance of organic residues for agricultural use (Francis et al., 1986). They supply large quantities of potassium due to preferential potassium uptake by higher plants (Wild, 1988). As for moisture, temperature regime by amendments may also affect ion diffusion (potassium) and root growth. As organic amendments paper sludges boost soil quality by raising soil organic matter content and improving biological, chemical and physical properties of deteriorated or degraded soils. Particular deinking and primary sludges are lime amendments. They increase and buffer soil pH when incorporated at high doses (Wallace & Terry, 1998).

Contrary to their wide range of presumed physical and nutritional benefits, amendments benefit plants only to degree to which they meet limiting plant growth factors in different soil and climatic conditions. Limiting plant growth factors vary with regional and temporal variations; hence mode and intensity of amelioration by organic wastes. Figures 1 and 2 are extracted from the results of different experiments, conducted in different climatic zones and various soils and therefore the same results may not stand everywhere. Physical and nutritional effects by amendments on plant growth may be additive and synergistic (positive interactions) or antagonistic (negative interactions). As the climatic and soil conditions are shifted further away from optimum, the ameliorating effects of mulch and incorporation are expected to magnify. Soil physical and nutritional limitations are enhanced by marginal rain and temperatures due to more limited root growth (Jalota & Prihar, 1990) or transfer of ions from soil to roots (Havlin et al., 2005).

Contrary to negative effects on root growth and plant nutrient uptake by increasing mechanical resistance, high soil specific surface may enhance mineral weathering and the ionic enrichment of electric diffuse double layers (especially potassium). With a fixed quantity of ions according to their exchange capacity, electric diffuse double layers are semi-permeable membranes which are impermeable to cation loss (except by exchange) but permeable to water. Therefore act as osmometers allowing soil swelling-shrinkage. A difference in osmotic potential provides the driving force for truncated diffuse double layers (TDDL) to imbibe water from bulk soil solution and achieve full extension or by water loss to soil solution to achieve greater truncation (Hillel, 1980). Osmotic potential readjustments in soil solution and TDDL are rapid in rigid soils and hence ionic diffusion. Swelling-shrinkage could be also relatively rapid with high permeability of coarse pores located between the coarse colloids (montmorillonite). Swelling soils contain either colloids of high cation exchange capacity (montmorillonite in vertisoils) or high external specific surface (illitic clays) with small micelles (Marshal & Holmes, 1992). Internal specific surface does not control swelling because interlayer swelling is minimal relative to inter-micellar swelling (van Olphen, 1977). External and total specific surfaces were 112 versus 117 m^2g^{-1} for illitc clay and 66 versus 732 m^2g^{-1} for montmorillonite (Marshal & Holmes, 1992). Osmotic equilibration between TDDLs and surrounding solution to attain complete imbibitions and extended diffuse double layers requires about 15 days with small pores within small micelles of fine (illitic) clays (Hillel, 1980). With 43.8% volumetric soil water content for 24 hours saturation (incomplete swelling), 130 m^2g^{-1} specific surface and 1.36 g cm^{-3} dry bulk density, a uniform water film on soil particles is 2.5 nm thick at the site of experiment with illite dominance in clay fraction (Movahedi & Rezaei, 2009). This would be even less when soil is drier. Two and half nano-meter is less than the thickness expected by fully extended double layers in non saline normal soils. Bolt et al., 1978 also pointed out that diffuse double layer may not be fully extended with a soil specific surface greater than 100 m^2g^{-1}, when saturation time limited. With slowly swelling-shrinking soils (SSSS's), increased truncation diminishes TDDL-B.S. contact surface and increases potassium diffusion path from colloidal surface to bulk solution. Temporal nature of soil water content in temperate climatic zones negates complete osmotic readjustments and maximum potential swelling as they are slow processes (except with paddy rice cultivation). It maybe hypothesized that increased DDL truncation with high specific surface in SSSS's may affect ion diffusion and availability for plants (K) despite ample quantities present in diffuse double layer. Status of aggregation affects swelling-shrinkage rates in soils with high specific surface and hence potassium availability. In high specific surface soils with illite dominance in clay fraction, potential potassium deficiency therefore, could be a function of potential swelling with the ambient climatic conditions (as affect root zone soil wetness) and the status of aggregation. Potassium availability was increased with increased status of aggregation in these soils (Alaeddin, 2011). Ca antagonistic effect reduced potassium root uptake with calcium super-phosphate (low applications). High applications as $CaSO_4$ or $CaCl_2$ increased potassium desorption and availability however (Vafakhah, 2011; Farhangi, 2011).

Since TDDLs and soil solution act as osmometers, the slower the osmotic potential readjustments with SSSS's, the greater the osmotic potential difference at any point in time which incurs greater cohesion between soil particles and hence mechanical resistance. Organic amendments may affect soil water content.

According to Darcy's law, hydraulic conductivity and gradient control hydraulic flux density within micellar pores and hence swelling-shrinkage rates. Fluidity is influenced by soil temperature and hence hydraulic conductivity. Hydraulic gradient and mechanical resistance are influenced by soil water content. Organic amendments modify soil temperature and water both.

With a temperate climate along Caspian Sea (north Iran) and an illitic high specific surface SSSS's, the objectives of this research were:

1) to describe soil potassium availability for wheat;

2) to investigate the effect of sludge application with two modes of application (incorporation and mulch) and two rates on soil temperature, dry bulk density, water and mechanical resistance.

Looking into modes of amelioration by paper mill sludge and also interactions. That is to compare the effects of sludge on wheat growth that were mediated by changes in nutrient (K) supply with those mediated by soil physical properties or the plant water stress with limiting status of aggregation for potassium diffusion

2. Materials and Methods

2.1 The Site and Climate

The field trials were located on the estate of Gorgan University of Agricultural Sciences and Natural Resources (Pardis), Golestan province, Iran (approx. 37° 45' N, 54° 30' E. altitude 13 m A.S.L.). The average annual rainfall (1991-2004) was 545.8 mm and mean air temperatures (1991-2004) were 8.5 ℃ for January, 8 ℃ for February and 9.9℃ for March; close to minimum for tillering and shooting. Tillering and shooting occurred early February and early March respectively. For the year of trial (2005), the January to June rainfall and maximum May temperatures (at milk stage) were 365 mm and 19.9 ℃. Although these temperatures are sub-optimal for the crop, by regional standards, 2005 was wet and moderate. Mean daily temperature for optimum growth and tillering is between 15 and 20℃ for wheat. Mean daily temperatures of less than 10 to 12℃ during the growing season make wheat a hazardous crop. For winter and spring wheat, minimum daily temperature for measurable growth is about 5℃ (Doorenbos & Kassam, 1979). According to Sys, 1985, daily temperature for optimum growth at vegetative stage is between 8 to 12℃ for wheat in Iraq. Spring wheat varieties are used in Golestan province by winter cropping, because chilling requirement for heading (vernalization) is not met for winter wheat due to mild winters of most years. Base, optimum and maximum temperatures for the variety used (Triticum aestivum, Var. Tajan) were 4.14 ± 2.04, 28 ± 0 and 37.0 respectively (Ahmadi, 2007)

2.2 Treatments

Treatments were 50 t ha^{-1} (I_{50}) and 100 t ha^{-1} (I_{100}) paper mill sludge incorporated with top soil (I treatments), 50 t ha^{-1} (M_{50}) and 100 t ha^{-1} (M_{100}) paper mill sludge applied as mulch (M treatments). Applications were based on sludge dry weights. Other treatments were $N_0P_0K_0$, $N_{92}P_0K_0$, $N_0P_{50}K_0$, $N_0P_0K_{83}$, $N_{92}P_{50}K_0$, $N_{92}P_0K_{83}$, $N_0P_{50}K_{83}$, $N_{92}P_{50}K_{83}$. Subscripts are kg ha^{-1} N, P and K. Fertilizer sources for N, P and K were urea, triple superphosphate and potassium sulfate. Triple superphosphate, potassium sulfate and also one third urea were incorporated to soils to a depth of 0.20 m in respective treatments with mineral fertilizers immediately before drilling with a spade. One third of urea was incorporated at tillering and the remaining one third at heading using a manual furrower.

The land had been ploughed and disked before any treatments were applied. For the mulch treatments the paper mill sludge was applied uniformly over the land immediately after sowing manually. Where the sludge was to be incorporated (I_{50} and I_{100}), it was initially applied uniformly as a mulch and then incorporated to a depth of 0.2 m manually using a spade before drilling.

Seeds were treated with 5,6-dihydro-2-methyl-1,4-oxathiin-3-carboxamide fungicide powder (Vitavax®, Uniroyal Chemical Co. USA) before drilling. Fenoxaprop-p-ethyl 5 g L^{-1} herbicide (Puma®Super, Bayer CropScience Inc. Canada) was applied early March for curbing Oat (Avena sativa). Other weeds such as Turnip (Brassica napus), Milk Thistle (Silybum marianum) and Bastard Cabbage (Rapistrum rugosum) were removed later manually.

2.3 Experimental Design

A completely randomized block design was used with plot size 3 m×2 m. Each treatment was replicated three times. Soil was a Typic Haploxerepts (Rahmat Abad soil series) of silty clay loam texture from a loess origin. Paper mill sludge with a dry bulk density of 250 kg m^{-3} and approximately 70% water content was applied on December 30, 2004 and laid on M treatments immediately after drilling or incorporated in the I treatments immediately before drilling at the same day. Wheat was drilled on 30 December 2004 with seeds 0.02 m apart, and 0.15 m between the rows, equivalent to 3300000 seeds per hectare.

2.4 Physical, Chemical and Mineralogical Compositions of Soil and Sludge

A composite soil sample was obtained from 0-0.25 m depth from the site of the experiment for physical, chemical and mineralogical determinations. Soil textural class was silty clay loam by the hydrometer method (Klute, 1986). Soil particle and the sludge size distributions were obtained with lazer (using Malvern MASTERSIZER-S) and on a series of sieves respectively. 20, 40, 60, 80 and 100% of paper mill sludge particles were less than 0.16, 0.48, 1, 9 and 15.8 mm in diameter, respectively which are much larger than most soil particles, reducing bulk density when mixed with soil. Other determinations were soil and sludge organic carbon content using a potassium dichromate method (1.43 and 22.4%, respectively) and soil saturation percentage from a saturated soil paste (49%). Bulk density was obtained through core sampling.

Soil specific surface area (130 $m^2 g^{-1}$) was determined using Ethelene glycol monoethyl ether method (Carter et al., 1965). Mica (illite) was the dominant soil mineral with X-ray diffraction technique (Kittric & Hope, 1971) using a D8-ADVANCE Model. Other minerals were smectites, kaolinites and chlorites in a descending order (Johns et al., 1954).

The sludges obtained from Mazandaran wood and paper mill (Iran). In this mill, mechanical and chemical methods (both Kraft and sulfite processes) are used for pulping or wood fiber breakdown. The paper mill sludge used for this research is a mixture of primary and secondary sludge (combined sludge). N, P, K, Ca and Mg percentages were 1.2, 0.25, 0.128, 0.412 and 0.145, respectively. pH was 7.38 and electrical conductivity 3.1 ds m^{-1} in the soil paste extract.

2.5 Measurements

Volumetric water contents were determined gravimetrically on soil cores (204 cm^3) for 0-0.10 and 0.10-0.20 m depths at 17 February, 6 March, 5 May, 13 May, 27 May and 5 June, 2005 on six occasions by oven drying. At same dates mechanical resistances obtained in field with a portable cone penetrometer. Using permanent thermocouples soil temperature measurements at 0.20 m were taken at around 06.00 A.M. and 3.00 P.M. at same dates in order to provide a diurnal contrast. Dry matter percentage and crop cover percentage (using a ruler) were also established. In ruler method a 1 meter ruler first is laid parallel to rows and under the crop canopy touching the stems. The uncovered soil percentage is thus established. Next the ruler is laid perpendicular to rows and the uncovered soil percentage also established. This must be repeated randomly at selected locations within the same plot. Considering the distance between rows, the cover percentage is calculated. In this method the cover percentage determined by ruler is multiplied for both perpendicular and parallel states, assuming the row spaces are 1 m apart. Since the row spaces were 0.20 m apart in this experiment, a correction factor was used (1/0.2) (Cook, 1986).

Fresh and dry yield obtained at six occasions during growing season to obtain dry matter percentage. At harvest 1 m^2 from the centre of each plot was harvested manually for determining fresh yield. A sub-sample was used for determining dry grain and straw yield. Head densities (per square meter) were also recorded at harvest.

Data analysis used an ANOVA method with the SAS statistical package (version 6/12) and regressions with Excel (version 5).

3. Results

3.1 Dry Grain Yield, Shoot Dry Matter and Head Density

Differences between treatments for dry grain yield, shoot dry matter and head density (heads per square meter) were significant by analysis of variance ($P<0.01$). Dry grain, shoot dry matter yield and head densities are found in Table 1 for different treatments. $N_{92}P_0K_{83}$ and high rate mulch application returned greatest shoot dry matter yield (grain+straw). Shoot dry matter with $N_{92}P_{50}K_{83}$ was less than $N_{92}P_0K_{83}$. Greatest head density obtained under incorporation treatment with both rates and high rate mulch application.

3.2 Shoot Dry Matter Percentage at Six Occasions during Growing Season

Differences between treatments for dry matter percentage was not significant by analysis of variance at the first occasion but it was significant for other measurements ($P<0.05$). Dry matter percentage with $N_{92}P_0K_{83}$ and high rate mulch was greater than other treatments during growing season (Table 1), resulting lower plant tissue water relative to other treatments.

Table 1. Dry Grain yield (Kg ha^{-1}), shoot total dry matter at harvest (Kg ha^{-1}), head density (grain heads per square meter) and shoot dry matter percentage at six occasions during growing season

Treatment	Dry grain yield	Shoot total dry matter	Head density	Percentage dry matter					
				17 February	6 March	5 May	13 May	27 May	5 June
$N_{92}P_0K_0$	3465.3^{bcde}	9033^{cd}	313.3^{d}	16.69^{b}	21.31^{bc}	30.76^{abcd}	39.61^{abc}	66.36^{bcd}	79.49^{b}
$N_0P_{50}K_0$	4105.3^{abcd}	9783^{cd}	360^{bc}	21.14^{ab}	22.65^{abc}	31.49^{abc}	40.63^{abc}	69.17^{abc}	80.4^{ab}
$N_0P_0K_{83}$	3630.7^{abcd}	9233^{cd}	339.6^{cd}	21.56^{ab}	21.87^{abc}	30.98^{abcd}	39.58^{abc}	67.54^{bcd}	79.9^{b}
$N_{92}P_{50}K_0$	4262.8^{abcd}	10500^{c}	360.3^{bc}	21.96^{ab}	22.86^{abc}	31.82^{abc}	41.04^{abc}	70.06^{ab}	80.9^{ab}
$N_{92}P_0K_{83}$	4729.8^{ab}	13450^{a}	359.6^{bc}	24.88^{a}	24.43^{a}	35.1^{a}	44.1^{a}	75.73^{a}	83.83^{a}
$N_0P_{50}K_{83}$	3957.3^{abcd}	9600^{cd}	353.67^{cd}	21.04^{ab}	22.23^{abc}	31.17^{abc}	40.11^{abc}	68.35^{abcd}	80.08^{ab}
$N_{92}P_{50}K_{83}$	4401.6^{abc}	10800^{bc}	355^{c}	21.2^{ab}	22.95^{ab}	31.9^{ab}	41.48^{ab}	70.25^{ab}	81.04^{ab}
I_{50}	2264.3^{ef}	7883^{d}	410^{a}	18.9^{b}	20.32^{c}	26.49^{cd}	37.07^{bc}	62.16^{cd}	78.23^{b}
M_{50}	3076.1^{def}	8517^{cd}	333.3^{cd}	21.87^{ab}	21.07^{bc}	30.1^{abcd}	38.68^{bc}	65.4^{bcd}	79.15^{b}
I_{100}	2158^{f}	7783^{d}	398.3^{ab}	19.38^{b}	20.27^{c}	25.76^{d}	36.63^{c}	61.25^{d}	77.59^{b}
M_{100}	4825.3^{a}	13233^{ab}	373^{abc}	22.83^{ab}	23.97^{a}	35^{a}	44^{a}	75.5^{a}	83.7^{a}
$N_0P_0K_0$	3207.7^{cdef}	8450^{cd}	254^{e}	22.82^{ab}	20.73^{bc}	29.55^{bcd}	38.28^{bc}	65.05^{bcd}	78.83^{b}

Means within the same column followed by the same letter are not statistically different at $P = 0.05$ (Fisher's LSD)

3.3 Soil Particle Size Distribution

Table 2 shows soil particle size distribution. 30.5 percent of the soil particles were smaller than 2 micrometer in size, excluding soil textural class from the clay category because clay soils contain at least 35% clay. 2.8 percent of the soil particles were smaller than 0.2 micrometer in diameter and 0.135% less than 100 nanometer (nano particles), producing a high specific surface. The measured soil specific surface was 130 m^2g^{-1}. A high specific surface may be expected even with medium textured soils when they contain high quantities of very fine clays. Colloids (less than 10 micrometer in diameter) form 66% of the soil mass but less than 0.2% is occupied by coarse sand (Table 2). As already mentioned in introduction, SSSS's are expected with high quantities of illite and specific surface.

Table 2. Particle size analysis by lazer method

Particle Size (micrometer)	Rep1 (%)	Rep2 (%)	Average (%)	Standard Deviation	Cumulative Percentage
0.054	0.002	0.004	0.003	0.001	0.003
0.063	0.004	0.011	0.0075	0.0035	0.0105
0.073	0.01	0.024	0.017	0.007	0.0275
0.085	0.023	0.048	0.0355	0.0125	0.063
0.099	0.051	0.093	0.072	0.021	0.135
0.116	0.107	0.176	0.1415	0.0345	0.2765
0.135	0.213	0.314	0.2635	0.0505	0.54
0.157	0.392	0.521	0.4565	0.0645	0.9965
0.183	0.663	0.807	0.735	0.072	1.7315
0.213	1.033	1.164	1.0985	0.0655	2.83
0.249	1.461	1.544	1.5025	0.0415	4.3325
0.29	1.822	1.843	1.8325	0.0105	6.165
0.337	1.992	1.97	1.981	0.011	8.146
0.393	1.996	1.958	1.977	0.019	10.123
0.458	1.964	1.913	1.9385	0.0255	12.0615
0.533	1.912	1.852	1.882	0.03	13.9435
0.621	1.791	1.741	1.766	0.025	15.7095
0.724	1.723	1.679	1.701	0.022	17.4105
0.843	1.715	1.683	1.699	0.016	19.1095
0.982	1.736	1.71	1.723	0.013	20.8325
1.145	1.792	1.765	1.7785	0.0135	22.611
1.333	1.876	1.842	1.859	0.017	24.47
1.553	1.941	1.908	1.9245	0.0165	26.3945
1.81	2	1.975	1.9875	0.0125	28.382
2.108	2.126	2.103	2.1145	0.0115	30.4965
2.456	2.32	2.296	2.308	0.012	32.8045
2.862	2.606	2.574	2.59	0.016	35.3945
3.334	2.962	2.916	2.939	0.023	38.3335
3.884	3.359	3.292	3.3255	0.0335	41.659
4.525	3.731	3.645	3.688	0.043	45.347
5.271	4.028	3.925	3.9765	0.0515	49.3235
6.141	4.209	4.095	4.152	0.057	53.4755
7.154	4.28	4.16	4.22	0.06	57.6955
8.335	4.24	4.121	4.1805	0.0595	61.876
9.71	4.113	4.001	4.057	0.056	65.933
11.312	3.936	3.837	3.8865	0.0495	69.8195
13.178	3.738	3.652	3.695	0.043	73.5145
15.353	3.556	3.502	3.529	0.027	77.0435
17.886	3.415	3.393	3.404	0.011	80.4475
20.837	3.288	3.295	3.2915	0.0035	83.739
24.276	3.142	3.166	3.154	0.012	86.893
28.281	2.945	2.965	2.955	0.01	89.848
32.947	2.672	2.667	2.6695	0.0025	92.5175
38.384	2.313	2.264	2.2885	0.0245	94.806
44.717	1.868	1.773	1.8205	0.0475	96.6265
52.095	1.422	1.246	1.334	0.088	97.9605

Table 2. Continued

Particle Size (micrometer)	Rep1 (%)	Rep2 (%)	Average (%)	Standard Deviation	Cumulative Percentage
60.691	0.977	0.751	0.864	0.113	98.8245
70.705	0.532	0.358	0.445	0.087	99.2695
82.371	0	0.112	0.056	0.056	99.3255
95.963	0	0.017	0.0085	0.0085	99.334
111.797	0	0.039	0.0195	0.0195	99.3535
130.243	0	0.129	0.0645	0.0645	99.418
151.733	0	0.23	0.115	0.115	99.533
176.769	0	0.297	0.1485	0.1485	99.6815
205.936	0	0.296	0.148	0.148	99.8295
239.915	0	0.225	0.1125	0.1125	99.942
279.501	0	0.112	0.056	0.056	99.998
325.619	0	0	0	0	99.998

3.4 Dry Bulk Densities for 0-0.10 m Depth during Growing Season

Table 3. Means of dry bulk density (g cm^{-3}) at 0-0.10 and 0.10-0.20 m depth

Treatment	17 February	6 March	5 May	13 May	27 May	5 June
0-0.10 m						
$N_{92}P_0K_0$	1.04^{a}	1.05^{a}	1.1^{a}	1.12^{a}	1.14^{a}	1.15^{a}
$N_0P_{50}K_0$	1.05^{a}	1.07^{a}	1.1^{a}	1.12^{a}	1.14^{a}	1.15^{a}
$N_0P_0K_{83}$	1.05^{a}	1.07^{a}	1.13^{a}	1.13^{a}	1.13^{a}	1.15^{a}
$N_{92}P_{50}K_0$	0.99^{a}	1.02^{a}	1.05^{abc}	1.07^{a}	1.08^{a}	1.1^{a}
$N_{92}P_0K_{83}$	1^{a}	1.02^{a}	1.05^{abc}	1.08^{a}	1.1^{a}	1.11^{a}
$N_0P_{50}K_{83}$	1^{a}	1.02^{a}	1.09^{a}	1.1^{a}	1.1^{a}	1.12^{a}
$N_{92}P_{50}K_{83}$	1.07^{a}	1.1^{a}	1.15^{a}	1.15^{a}	1.15^{a}	1.13^{a}
I_{50}	0.8^{bc}	0.85^{bc}	0.93^{bc}	1^{a}	1.03^{a}	1.05^{a}
M_{50}	1.03^{a}	1.05^{a}	1.07^{ab}	1.08^{a}	1.1^{a}	1.11^{a}
I_{100}	0.78^{c}	0.8^{c}	0.91^{c}	0.95^{a}	0.99^{a}	1^{a}
M_{100}	0.98^{ab}	1^{ab}	1.05^{abc}	1.07^{a}	1.08^{a}	1.1^{a}
$N_0P_0K_0$	0.99^{a}	1.02^{a}	1.08^{ab}	1.1^{a}	1.13^{a}	1.15^{a}
Means	0.98	1	1.06	1.08	1.09	1.11
		0.10-0.20 m				
$N_{92}P_0K_0$	1.34^{a}	1.35^{a}	1.36^{a}	1.37^{a}	1.38^{a}	1.4^{a}
$N_0P_{50}K_0$	1.35^{a}	1.36^{a}	1.38^{a}	1.4^{a}	1.4^{a}	1.41^{a}
$N_0P_0K_{83}$	1.35^{a}	1.37^{a}	1.38^{a}	1.4^{a}	1.41^{a}	1.42^{a}
$N_{92}P_{50}K_0$	1.29^{a}	1.33^{a}	1.34^{a}	1.35^{a}	1.37^{a}	1.38^{a}
$N_{92}P_0K_{83}$	1.26^{a}	1.32^{a}	1.33^{a}	1.35^{a}	1.38^{a}	1.38^{a}
$N_0P_{50}K_{83}$	1.3^{a}	1.32^{a}	1.35^{a}	1.37^{a}	1.39^{a}	1.4^{a}
$N_{92}P_{50}K_{83}$	1.37^{a}	1.38^{a}	1.4^{a}	1.39^{a}	1.4^{a}	1.4^{a}
I_{50}	1.27^{a}	1.28^{a}	1.31^{a}	1.33^{a}	1.35^{a}	1.35^{a}
M_{50}	1.33^{a}	1.34^{a}	1.36^{a}	1.37^{a}	1.36^{a}	1.35^{a}
I_{100}	1.25^{a}	1.26^{a}	1.3^{a}	1.31^{a}	1.3^{a}	1.3^{a}
M_{100}	1.28^{a}	1.3^{a}	1.33^{a}	1.34^{a}	1.35^{a}	1.33^{a}
$N_0P_0K_0$	1.29^{a}	1.31^{a}	1.34^{a}	1.35^{a}	1.38^{a}	1.4^{a}
Means	1.30	1.32	1.35	1.36	1.37	1.37

Means within the same column followed by the same letter are not statistically different at P = 0.05 (Fisher's LSD)

Differences between treatments for dry bulk density were significant by analysis of variance with the first and second measurement ($P<0.05$). Sludge incorporation manifested minimum dry bulk densities throughout growing season (with all measurements; Table 3).

3.5 Dry Bulk Density for 0.10-0.20 m Depth during Growing Season

Differences between treatments for dry bulk density were not significant by analysis of variance for any of the six measurement dates ($P<0.05$). Dry bulk density values within 0.1-0.2 m with high rate mulch application and both incorporation treatments were still lower than $N_0P_0K_0$ throughout growing season (at all measurement dates) irrespective of statistics (Table 3).

3.6 Volumetric Soil Water Content for 0-0.10 m Depth during Growing Season

Differences between treatments for soil volumetric water content were significant by analysis of variance throughout growing season with the exception of the third measurement $P<0.05$).

High rate mulch application significantly decreased moisture loss and increased soil volumetric water content relative to $N_0P_0K_0$ throughout growing season; water content values were also greater than other treatments in Table 4. Soil water content for low rate incorporation was significantly greater than $N_0P_0K_0$ with two earliest measurements and for high rate incorporation with the three earliest measurements (Table 4). Relative to incorporation, the effect of mulch treatments on soil volumetric water content became more pronounced at the end of growing season when the evaporation potential was high. Soil water content was not also different with control and mineral fertilizers.

3.7 Volumetric Soil Water Content for 0.10-0.20 m Depth during Growing Season

Differences between treatments for soil volumetric water content were significant by analysis of variance ($P<0.05$) with the three last measurements (out of six measurements).

With the four last measurements, high rate mulch application significantly raised soil water content compared to all mineral fertilizer treatments and control ($N_0P_0K_0$). Soil water content with high rate mulch application was also greater than other sludge treatments irrespective of statistics (Table 4).

Table 4. Means of volumetric water content percentages, 0-0.10 m and 0.10-0.20 m depth

Treatment	17 February	6 March	5 May	13 May	27 May	5 June
			0-0.10 m			
$N_{92}P_0K_0$	21.16^{cd}	22^{d}	20^{bc}	17^{cd}	15^{c}	13^{b}
$N_0P_{50}K_0$	21.43^{cd}	22.95^{cd}	21^{bc}	19^{bcd}	16.03^{bc}	13.7^{b}
$N_0P_0K_{83}$	22.36^{bcd}	23.51^{bcd}	21.01^{bc}	18^{bcd}	15.01^{c}	14^{b}
$N_{92}P_{50}K_0$	21.56^{cd}	24^{bcd}	22^{abc}	18.46^{bcd}	15.06^{c}	12.8^{b}
$N_{92}P_0K_{83}$	19.65^{d}	21.5^{d}	19.06^{bc}	16.51^{d}	14^{c}	12.63^{b}
$N_0P_{50}K_{83}$	20.6^{d}	22^{d}	18.8^{c}	17.25^{cd}	14.2^{c}	13.2^{b}
$N_{92}P_{50}K_{83}$	21.66^{bcd}	23.01^{cd}	19.31^{bc}	16.83^{d}	14.33^{c}	13^{b}
I_{50}	25.9^{abc}	28^{abc}	23.03^{abc}	22^{abc}	19^{abc}	16.2^{ab}
M_{50}	22.6^{bcd}	28^{abc}	24^{abc}	23^{ab}	21^{ab}	19.4^{a}
I_{100}	27^{ab}	29^{ab}	24.5^{ab}	22^{abc}	18.7^{abc}	16.8^{ab}
M_{100}	30^{a}	31^{a}	27^{a}	25^{a}	22.5^{a}	20.5^{a}
$N_0P_0K_0$	19.9^{d}	21^{d}	18.98^{c}	16.95^{cd}	15^{c}	13.1^{b}
			0.10-0.20 m			
$N_{92}P_0K_0$	31.16^{ab}	35^{a}	30^{bc}	28^{bcd}	24.15^{c}	22.4^{c}
$N_0P_{50}K_0$	31.43^{ab}	34.9^{a}	29^{c}	27.5^{cd}	25^{bc}	23.5^{bc}
$N_0P_0K_{83}$	32.36^{ab}	36^{a}	29.4^{bc}	26^{d}	24^{c}	21^{c}
$N_{92}P_{50}K_0$	31.56^{ab}	35.1^{a}	31^{abc}	28.3^{bcd}	25.55^{bc}	23.05^{bc}
$N_{92}P_0K_{83}$	29.6^{b}	34^{a}	29.5^{bc}	27.05^{cd}	23.5^{c}	21^{c}
$N_0P_{50}K_{83}$	30.6^{ab}	34.5^{a}	31.5^{abc}	28.5^{bcd}	26.1^{bc}	23^{bc}
$N_{92}P_{50}K_{83}$	31.66^{ab}	36.2^{a}	32.2^{abc}	27.2^{cd}	23.3^{c}	21.7^{c}
I_{50}	33^{ab}	37^{a}	34^{abc}	32^{abc}	28.12^{abc}	25^{abc}
M_{50}	32.6^{ab}	37.6^{a}	34.4^{ab}	33^{ab}	30.1^{ab}	28.1^{ab}
I_{100}	34^{ab}	38^{a}	33.8^{abc}	32^{abc}	28.4^{abc}	26^{abc}
M_{100}	35^{a}	39^{a}	36.08^{a}	34.1^{a}	32^{a}	29.4^{a}
$N_0P_0K_0$	29.9^{ab}	33.93^{a}	$30b^{c}$	27^{cd}	24^{c}	22^{c}

Means within the same column followed by the same letter are not statistically different at P = 0.05 (Fisher's LSD)

3.8 Soil Mechanical Resistance (0.20 m depth) during Growing Season

Differences between treatments for soil mechanical resistance were significant by analysis of variance (P<0.01) with all measurements.

Soil mechanical resistance by both incorporation treatments was significantly less than all mineral fertilizers and also $N_0P_0K_0$ during growing season (Table 5). Soil mechanical resistance with high rate of sludge incorporation was less than the low rate application during growing season irrespective of statistics. Soil mechanical resistance was also significantly less than all mineral fertilizers and $N_0P_0K_0$ with both mulch treatments with 1st and 2nd measurements. Soil mechanical resistance with high rate mulch application was also less than low rate mulch during growing season irrespective of statistics.

Table 5. Means of soil mechanical resistance at 0.20 m depth (KPa)

Treatment	17 February	6 March	5 May	13 May	27 May	5 June
$N_{92}P_0K_0$	1965.9^{a}	1851.9^{a}	1997^{abc}	2102.4^{a}	2190.5^{a}	2220.3^{a}
$N_0P_{50}K_0$	2059.3^{a}	1926.8^{a}	2283.2^{ab}	2333.7^{a}	2352.1^{a}	2360.3^{a}
$N_0P_0K_{83}$	2021.9^{a}	1841.9^{a}	2084.1^{abc}	2158.3^{a}	2200.5^{a}	2227^{a}
$N_{92}P_{50}K_0$	2187.8^{a}	2000.2^{a}	2223.1^{ab}	2252.1^{a}	2263.6^{a}	2271^{a}
$N_{92}P_0K_{83}$	2125.6^{a}	1916.3^{a}	2196.1^{ab}	2244.5^{a}	2260.5^{a}	2277^{a}
$N_0P_{50}K_{83}$	2129.8^{a}	2006.5^{a}	2330.9^{a}	2347.1^{a}	2358.9^{a}	2371.4^{a}
$N_{92}P_{50}K_{83}$	2046.8^{a}	1963^{a}	2115.2^{abc}	2197.7^{a}	2218.7^{a}	2230.7^{a}
I_{50}	1124^{bc}	989.6^{c}	1281.6^{d}	1443.3^{b}	1590.4^{b}	1650.6^{b}
M_{50}	1464.1^{b}	1311.3^{b}	1883^{bc}	2030.2^{a}	2070.3^{a}	2120.4^{a}
I_{100}	1084.6^{c}	961.1^{c}	1109.5^{d}	1260.9^{b}	1440.1^{b}	1500.4^{b}
M_{100}	1306.5^{bc}	1202.4^{bc}	1744^{c}	2007.4^{a}	2051^{a}	2080.4^{a}
$N_0P_0K_0$	2202.3^{a}	2006.2^{a}	2285.3^{ab}	2295.7^{a}	2321.9^{a}	2340.1^{a}

Means within the same column followed by the same letter are not statistically different at P=0.05 (Fisher's LSD)

3.9 Soil Temperatures for 0.20 m Depth at 6 A.M. and 3 P.M. during Growing Season

Differences between treatments for soil temperatures at 6 A.M were significant by analysis of variance with the first (P<0.01), second (P<0.01) and the fourth measurement (P<0.05). They were also significant at 3 P.M. with all measurements (P<0.01).

High rate mulch significantly increased 6 A.M. soil temperatures relative to $N_0P_0K_0$ and also mineral fertilizers by the two earliest measurements, relative to low rate mulch by the first measurement and relative to high rate incorporation by 1st, 2nd, 4th and 5th measurements. With low rate mulch, 6 A.M temperature was greater than low rate incorporation by 1st, 4th, 5th and 6th measurements. Generally speaking, both mulch treatments raised 6 A.M temperatures during growing season relative to other treatments, in some occasions irrespective of statistics (Table 6).

Mulch treatments both significantly lowered 3 P.M soil temperatures compared to $N_0P_0K_0$ and also mineral fertilizers during growing season with the exception of the third measurement which returned insignificant reductions. By 3rd, 4th and 6th measurements, temperature with the high rate mulch was significantly lower than the low rate mulch and also lower than the high rate sludge incorporation by last four measurements. With 1st, 4th and the 5th measurements, low rate mulch lowered 3 P.M soil temperatures compared to low rate incorporation (Table 6).

Table 6. Means of soil temperature (℃) at 0.20 m depth at 06:00 and 15:00 h

Treatment	17 February	6 March	5 May	13 May	27 May	5 June
06:00 h soil temperatures						
$N_{92}P_0K_0$	4.33^{de}	5.7^{e}	17.7^{ab}	19.5^{abc}	21.36^{abc}	22.56^{abc}
$N_0P_{50}K_0$	4.23^{de}	5.8^{e}	17.66^{ab}	19.33^{bc}	20.9^{bc}	21.9^{c}
$N_0P_0K_{83}$	4.76^{de}	6.3^{cde}	17.7^{ab}	19.4^{bc}	21.2^{abc}	22.4^{abc}
$N_{92}P_{50}K_0$	4.33^{de}	5.96^{de}	17.6^{ab}	19.2^{c}	20.8^{c}	21.83^{c}
$N_{92}P_0K_{83}$	4.03^{e}	6.1^{cde}	17.6^{ab}	18.96^{c}	20.6^{c}	21.8^{c}
$N_0P_{50}K_{83}$	4.13^{de}	6.23^{cde}	17.83^{ab}	19.43^{bc}	21.13^{abc}	22^{bc}
$N_{92}P_{50}K_{83}$	4.16^{de}	6.16^{cde}	17.5^{ab}	19.06^{c}	20.66^{c}	21.8^{c}
I_{50}	4.86^{cd}	6.6^{bcd}	17.23^{b}	19.1^{c}	20.7^{c}	$22b^{c}$
M_{50}	5.83^{b}	7.3^{ab}	18.13^{ab}	20.3^{ab}	21.8^{ab}	22.9^{ab}
I_{100}	5.56^{bc}	6.73^{bc}	17.56^{ab}	18.9^{c}	20.53^{c}	22.56^{abc}
M_{100}	6.93^{a}	8^{a}	18.3^{a}	20.5^{a}	22^{a}	23a
$N_0P_0K_0$	4.3^{de}	6.03^{cde}	18^{ab}	19.9^{abc}	21.5^{abc}	22.7^{abc}
15:00 h soil temperatures						
$N_{92}P_0K_0$	13.1^{abcd}	16.5^{ab}	26.46^{abc}	30^{a}	31.9^{a}	33.13^{a}
$N_0P_{50}K_0$	12.96^{bcd}	16.13^{ab}	25.16^{cde}	29.3^{abc}	31.7^{a}	32.6^{a}
$N_0P_0K_{83}$	15.1^{a}	17.03^{a}	25.3^{bcd}	29.63^{ab}	31.83^{a}	32.9^{a}
$N_{92}P_{50}K_0$	14.6^{ab}	16.63^{a}	25^{cde}	29.5^{abc}	31.5^{a}	32.4^{a}
$N_{92}P_0K_{83}$	14.76^{ab}	16.6^{a}	24.9^{cde}	28.8^{bc}	31.36^{a}	31.9^{ab}
$N_0P_{50}K_{83}$	14.06^{abc}	16.86^{a}	27^{ab}	30^{a}	31.8^{a}	32.8^{a}
$N_{92}P_{50}K_{83}$	13.53^{abc}	16.5^{ab}	25.76^{bcd}	29.16^{abc}	31.5^{a}	31.96^{ab}
I_{50}	12.26^{cd}	15.06^{abc}	24.36^{de}	28.53^{bc}	31.03^{a}	32.1^{ab}
M_{50}	10.1^{e}	13.7^{cd}	24^{de}	26.4^{d}	29.4^{b}	30.23^{b}
I_{100}	11.3^{de}	14.5^{bcd}	23.5^{e}	28.4^{c}	30.9^{a}	31.73^{ab}
M_{100}	9.56^{e}	13^{d}	21.23^{f}	25^{e}	28.3^{b}	27.46^{c}
$N_0P_0K_0$	13.1^{abcd}	16.2^{ab}	27.56^{a}	29.5^{abc}	32^{a}	33.16^{a}

Means within the same column followed by the same letter are not statistically different at P = 0.05 (Fisher's LSD)

Both incorporation treatments raised 6 A.M soil temperatures significantly compared to $N_0P_0K_0$ with the first and second measurements and insignificantly with other measurements. They also lowered 3 P.M soil temperatures relative to $N_0P_0K_0$ with the third measurement and insignificantly with other measurements. Diurnal and nocturnal soil temperature differences (fluctuations) were significant between treatments for all measurements (data not shown) by analysis of variance ($P<0.01$). High rate mulching (100 MG ha^{-1}) reduced the seasonal midday soil temperature ranges from between 13.1℃ and 33.2℃ to between 9.6℃ and 27.5℃, averaging a 3.9℃ fall. Temperatures by high rate incorporation (100 MG ha^{-1}) dropped to between 11.3℃ and 31.7℃ instead, averaging a 2.1℃ fall. This drop was not detrimental to head density by sludge application in the moderate year of 2005 however it may become critical in cold years.

4. Discussion

Nitrogen ($N_{92}P_0K_0$) and phosphorous ($N_0P_{50}K_0$) fertilizers did not affect dry grain yield as yield production with these treatments (Table 1) are comparable with $N_{92}P_0K_0$ (3465.3 kg ha^{-1}), $N_0P_{50}K_0$ (4105.3 kg ha^{-1}) and $N_0P_0K_0$ (3207.7 kg ha^{-1}). $N_{92}P_0K_{83}$ (4729.8 kg ha^{-1}) and high rate of mulch (4825.3 kg ha^{-1}) both returned significantly greater dry grain yields relative to $N_0P_0K_0$ which may mean mulch improved yield by potassium supplementation. $N_0P_0K_{83}$ (3630.7 kg ha^{-1}) was not as effective as $N_{92}P_0K_{83}$ on yield. Combined N and K applications are normally more effective through some interactions than the individual K applications (Havlin et al., 2005). Potassium uptake may increase translocation rate of assimilates which uses energy from ATP that requires K for its synthesis. Nutrient root uptake (nitrogen fertilizer use efficiency) and plant growth may be improved by low concentration of assimilates in leaves. Potassium is also important as a counter-ion for NO_3^- transport in the xylem. Dry grain yield values with $N_{92}P_0K_{83}$ and high rate of mulch were also greater than other treatments (Table 1). Triple super-phosphate in $N_{92}P_{50}K_{83}$ diminished yield relative to $N_{92}P_0K_{83}$ by calcium release and lowering K: Ca+Mg ratio (Amini et al., 2012). Incorporation treatments lowered dry grain yield relative to other treatments (2264.3 and 2158 kg ha^{-1} for I_{50} and I_{100}, respectively); their difference with $N_0P_0K_0$ was not significant however. Sludge incorporation may also lower this ratio similarly. K:Ca+Mg ratio may be high in soil by mulch application as these cations are diverged due to a non linear exchange isotherm and greater dislocation by surface application and decomposition (Amini et al., 2012). Cations released by sludge decomposition are diverged along their traveling path in soil due to their non linear exchange isotherm and variable mobility. Due to greater rain infiltration, traveling distance and divergence are greater for surface applied cations by mulch relative to incorporation. Cation competition for entering roots (negative ionic interactions) and their antagonistic effect is minimized by mulch application (Amini et al., 2012) or using pure mineral fertilizers alternatively. When a nutrient ratio is optimal, optimum yield occurs unless some other limiting factor limits yield (Havlin et al., 2005). Plant nutrient ratios can be used to assess crop nutrient balance. For example K : Ca, K:Mg and K:Ca+Mg and other ratios are commonly used. Ca additions by a batch reactor experiment enhanced potassium desorption from water saturated soils, in the site of experiment (Rezaei & Movahedi Naeini, 2009).

Three hundred and eighty mg kg^{-1} potassium at the site of experiment (Amini et al., 2012) is very high based on general calibration for the $NH4OA_C$ soil test (Havlin et al., 2005). Values near 600 mg Kg^{-1} are frequently reported at close vicinity (Sebti et al., 2009). Potassium was not sufficient however for wheat growth as is inferred from increased yield when potassium and urea fertilizers were used combined by $N_{92}P_0K_{83}$ treatment (Table 1). NH_4OAc soil test extracts potassium from TDDL all of which is not available to plants. Limited TDDL-soil solution interface with high specific surface SSSS's limits rapid diffusion rendering nutrients slowly available. Lack of strong correlation (0.41; P=0.0135) between soil potassium concentration and plant potassium uptake (Amini et al., 2012) suggests NH_4OAc soil test is not suitable for extracting plant available potassium from swelling soils characterized by high specific surface and illite dominance in clay fraction. Correlation between soil potassium concentration and grain yield and shoot dry matter were (0.45; P=0.01) and (0.34; P=0.05), respectively (Amini, 2007). 1 N NH_4OAc, extracts unavailable K from soils with high K release and retention properties of illitic nature (Havlin et al., 2005). Sodium tetra-phenyl boron mimics root potassium uptake by plants (Cox et al., 1996) and hence diffusion rate (important in swelling soils with high specific surface), whereas 1 N NH_4OAc extracts soil exchangeable and bulk solution potassium. High correlations (P=0.05) were found between sodium tetra-phenyl boron K soil test (by one minute extraction) and grain wheat potassium uptake (Talebizadeh, 2009) at the same experimental site. They were 0.90 and 0.71 with soil samples obtained before heading and at harvest, respectively. Similar values for NH_4OAc soil test were 0.53 and 0.63, respectively. Correlations between sodium tetra-phenyl boron soil test and grain yield were 0.91 and 0.74 before heading and at harvest, respectively. Similar values for NH_4OAc soil test were 0.54 and 0.65, respectively. With a different experiment (Vafakhah, 2011), correlations between sodium tetra-phenyl boron soil test and grain yield were 0.84 (P=0.01) and 0.73 (P=0.01) before heading and at harvest, respectively. Similar values for NH_4OAc soil test were 0.53 (P=0.05) and 0.54 (P=0.01), respectively.

Contrary to field experiments, diffusion and exchange rates may be rapid with high specific surface soils in batch reactors where less TDDLs are envisaged due to shaking and enhanced osmotic potential equilibration. According to Sposito (2008, page 228), readily exchangeable ions most probably engage in reactions with rates that are transport controlled, not reaction controlled. Even with diffusion taken as rate limiting processes for ion exchange there remains to distinguish between film diffusion and intraparticle diffusion. In general, soil particles with large specific surface areas should favor film diffusion, whereas those with significant microporosity should favor intraparticle diffusion. Similarly exchange reactions are expected to be intraparticle diffusion controlled as a result of large specific surface. The half life for the exponential decline in concentration of species i in the bulk aqueous solution phase decreases with increasing soil specific surface (Sposito, 2008, page 93).

Fine textured soils do not always point to very high specific surface, despite the general perception. A medium textured soil containing less total clay but more fine clays (such as silty clay loam soils in this research; Table 2) may exhibit very high specific surface (130 m^{2}g^{-1}). With a high specific surface, ions are kept in a thin water layer around soil particles slowly accessible to roots by diffusion. This may highly raise K sufficiency levels above the established general calibrations for various extractants. High specific surface soils containing fine clay particles may exhibit strong mechanical resistance to root growth by cementing various sizes of soil particles. Limited root growth limits plant nutrient uptake and yield. Soil saturated hydraulic conductivity with these silty clay loam soils was frequently observed to be less than 0.08 m day^{-1}, which is lower than what is expected from many clayey soils.

Low dry bulk density with both incorporation treatments was likely due to greater total porosity with sludge positioned between soil particles and its relative density. With a thick cover, high rate mulch application reduced compaction and the dry bulk density relative to low application. Total porosity is decreased and dry bulk density increased as environmental factors such as rainfall gradually slump and compact topsoil during the growing season. Note average values for different dates in Table 3 with all treatments. Effect of environmental factors on increasing dry bulk density was less pronounced for 0.10-0.20 m however. Low dry bulk density at soil surface (0-0.10 m depth) relative to 0.10-0.20 m could be due to higher porosity. Frequent topsoil desiccations below air entry value and subsequent colloid expansion by wetting through rainfall, incorporate more air into soil aggregates. Haines (1923, in Baver, 1959) explains this mechanism. Treatment effects were subtle at 0.10-0.20 m with less moisture variation relative to 0-0.1. Joudi and Movahedi Naeini (2007) also reported dry bulk density at 0-0.05 m was less than 0.05-0.10 m under wheat in the same field by measurements starting from early January.

Increased soil water content at 0-0.2 m with both incorporation treatments may be due to low dry bulk density. Low bulk density often increases macro porosity at the cost of micro porosity, decreasing unsaturated hydraulic conductivity, capillary rise and evaporation but increasing saturated hydraulic conductivity and infiltration. Joudi and Movahedi Naeini (2007) found that light expanded clay aggregates increased total and macro porosity and reduced evaporation rate with same soils. Water retention by paper mill sludge may also increase soil water content by incorporation, especially when is used at high rate. Organic matter absorbs and holds high quantities of water at potentials less than 15 bar (Baver, 1959). The greatest crop cover percentage (data not shown) and respective transpiration potential were also found with these two treatments. Different mechanisms control soil water content under mulch however, which are briefly as follows (Hofmann in Geiger, 1965): lower thermal conduction and solar energy supply to the soil surface for evaporation, increase soil solution concentration by dissolved organic salts lowering vapor pressure gradient for evaporation and also increasing vapor transfer path within the laminar air layer located between soil surface and turbulent atmosphere. With a thick mulch cover and the respective thick enclosed laminar air layer, high rate mulch application is expected to be more effective in curbing evaporation and retaining soil moisture than the low rate.

Despite high yield with $N_{92}P_0K_{83}$ and high rate mulch, their plant tissue water content was less than other treatments during growing season. High yield by these treatments is not therefore as a result of plant water stress alleviation. Despite different yield and canopy production, soil water content was not also different with control and mineral fertilizers. This also supports the idea that tissue water stress was not limiting yield. The mere fact that some mineral fertilizers increased yield production justifies this conclusion. Tissue water stress is not normally limiting in temperate climates for winter crops but soil water may limit nutrient diffusion. Potassium in soybean and corn leaves are less than sufficiency levels in dry years even with high levels of potassium fertilizer applications (Havlin et al., 2005). Increasing soil water content may accelerate potassium diffusion and root extension by lowering mechanical resistance. Increasing soil water content from 10 to 28 percent increases total potassium transport by 175% (Havlin et al., 2005). It is frequently observed that irrigation in the area surrounding the site of experiment and high rainfall at neighboring towns and provinces (Mazandaran & Gillan) increase wheat production. With sufficient nutrients, heat and sunlight water stress may emerge as limiting for some summer crops in Golestan province and irrigation may reduce the time lag between transpiration and root water uptake.

Incorporation treatments lowered soil dry bulk densities during first three measurements at the top 0-0.10 m. They reduced mechanical resistance throughout growing season however. Low dry bulk density by incorporation treatments is not therefore the only cause depressing soil mechanical resistance. Incorporation treatments did not also affect bulk densities at 0.10-0.20 m any time during growing season. With mulch treatments, low soil mechanical resistance could be due to increased soil moisture as they were not as effective as incorporation treatments on bulk density. Soil mechanical resistance is controlled by combined effects of dry bulk density and soil water content and impacts root extension, plant water and nutrient availability (Wild, 1988). Slow imbibitions and incomplete swelling of soils in sub humid climate of north Iran may induce greater cohesion and mechanical resistance in addition to cementing effects of high quantity fine clays in high specific surface soils.

Even a slight early season drop in dry bulk density with soil conditioners is expected to advance root growth and establishment of seedlings with marginal impeding physical conditions, and also advance the harvest where growing season is limited by the upcoming cold (Jalota & Prihar, 1990). Head density before shooting is the determining factor for the final wheat yield and Hosseini (2011) concluded an extra shallow tillage between rows of wheat after plant establishment in the same field site may lower mechanical impedance to root growth and improve yield. Aggregate dispersion and soil loss may not be a matter of concern in these soils by shifting away from minimum tillage. High specific surface soils cope with more intensified tillage as their aggregates may stabilize to initial status quickly as a result of their high quantities of fine active clay. Other means of increasing root density like using Azotobacter also improved yield (Sebti et al., 2009). Mechanical impedance is not usually limiting root growth and plant yield with aggregated loam soils in temperate climates by normal rain. It is limiting however with high specific surface soils. According to Wild (1988), there is a positive correlation between soil dry bulk density and mechanical resistance, given similar water contents. This may not stand when usual and high specific surface soils are compared which needs further research. Ameliorating mechanical resistance may also be more rewarding with high specific surface soils due to limited ionic diffusion from TDDL to bulk soil solution to replenish potassium which is the most limiting factor for wheat growth when N is in sufficient supply.

The most limiting factor for wheat production was not soil mechanical resistance in this research as yield productions with incorporations were less than $N_0P_0K_0$, despite low soil mechanical resistance under these treatments. There maybe an interaction between mechanical resistance and potassium uptake through impacting root growth however. The degree to which changes in soil physical conditions by amendments involve an interaction or meet the most limiting plant growth factor is weather dependent and depends on factors such as evaporative demand of atmosphere for evaporation and soil temperature. With adequate rainfall and moderate temperature conditions alterations in aggregation or bulk density (also other soil physical properties) will have a smaller impact on the physical properties which directly affect plant growth (e.g. Temperature, moisture, aeration and mechanical resistance). For instance when rain is frequent and high, incorporation impacts on soil mechanical resistance are subtle and are not plausible in terms of plant response. The same applies to temperature and aeration.

Low thermal conductivity by organic mulch (sludge) possibly decreased diurnal and increased nocturnal soil temperatures through decreasing sensible heat exchange between soil and the mulch surface. Similar observations were already reported by Joudi and Movahedi Naeini (2008) in the same field site with organic mulch. Mulch and incorporation both increase thermal diffusivity for the incoming diurnal and outgoing nocturnal heat through increasing soil water content. This lowers diurnal and increases nocturnal superficial soil temperatures and minimizes daily fluctuations. Similar results were found for temperature fluctuation by Movahedi Naeini and Cook (2000) and Joudi and Movahedi Naeini (2008). The thick sludge cover by high rate mulch application was more effective in decreasing superficial thermal fluctuation than the low application. The effect of temperature on K uptake is through the changes on both K availability and root activity. Temperature controls sludge decomposition rate and K diffusion from exchange sites to soil bulk solution and hence K availability. It also affects water viscosity and fluidity and hence swelling-shrinkage rates.

Diurnal soil temperature values (averaged for the three replicates) for $N_0P_0K_0$, incorporation and mulch treatments were plotted against measurement dates in Figure. 3. This figure suggests greater diurnal temperature drops by organic mulch as seasonal temperatures increase. Movahedi Naeini and Cook (2000) also found similar results. Organic mulch is expected to be more efficient in curbing energy when facing greater diurnal thermal gradients. Greater yield by mulch treatments relative to $N_0P_0K_0$ suggests that the depressed yield by incorporation was not due to low diurnal soil temperatures however. Stronger antagonistic interactions may be at play (Ca). Both Ca and Mg compete with K for uptake; thus, soils high in one or both may require K fertilization for optimum K nutrition. Thus, the K availability is somewhat more dependent on its concentration relative to Ca and Mg than on the total quantity of K present (Havlin et al., 2005).

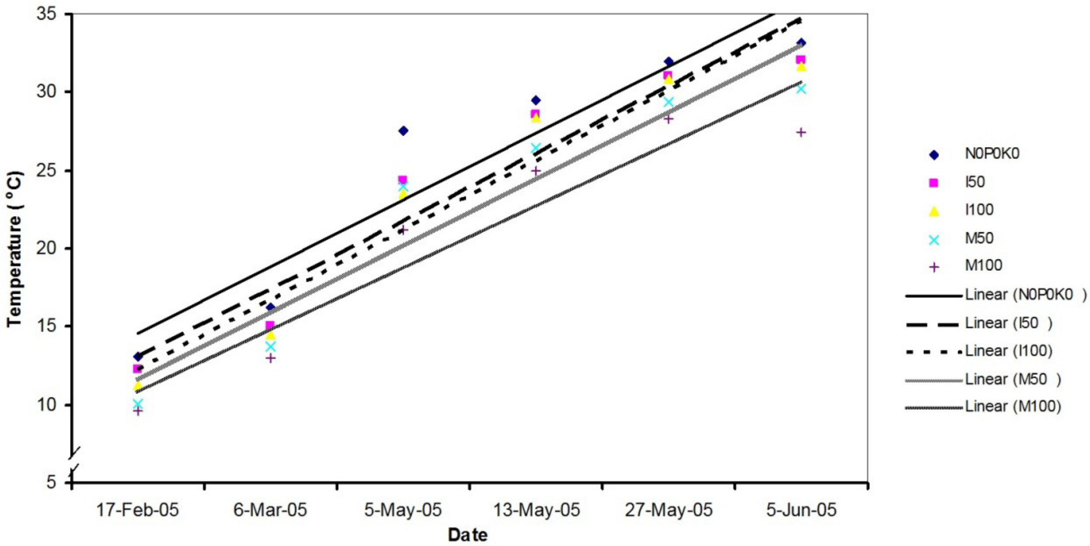

Figure 3. Regression relationship of soil temperature at 15.00 h as a function of time and paper mill sludge applica rate

5. Conclusions

Mulch and incorporation treatments both lowered diurnal soil temperature relative to $N_0P_0K_0$; in average 3.9℃ and 2.1℃ fall, respectively. Amendments may lower yield in cold years by shifting soil temperatures further away from optimum. At sub-optimal temperatures for wheat production under the temperate conditions of north Iran, the difference may be critical for shoot propagation and density before heading. Providing high K levels to increase K uptake at low temperatures (by sludge decomposition) overcomes adverse effects of low temperature on availability, swelling potential and diffusion (Havlin et al., 2005) however.

There were two potential apposing mechanisms affecting K diffusion by mulch and incorporation; a synergistic effect through increased soil water content in the root zone against depressed diurnal sub-optimal soil temperatures (antagonistic effect). Potential increased root growth by low mechanical resistance (synergistic effect) may also increase potassium uptake. Ca release into root zone by incorporation prevented manifestation of all synergistic benefits on K availability, diffusion and uptake however (Amini et al., 2012). Soil amendments increase yield, when the most limiting plant growth factor (or subsequent limiting factors) are met directly or through a number of interactions. Soil physical and non-physical growth factors interact and affect yield. Positive interactions were between root K uptake (also diffusion) and soil water, sludge decomposition rate and soil temperature. Negative interactions were between root K uptake and mechanical resistance, root K uptake (also swelling and diffusion) and soil temperature, K uptake and Ca additions. There is also an interaction between climatic conditions and soil water and temperature. Considering modes of amelioration by sludge for different soil and climatic conditions and their interactions helps manage quantities and modes of applications. Decomposition rate with mulch was greater than incorporation which lowers application rates with mulch when nutrients are concerned. In the current experiment in a soil with high specific surface illitic SSSS which may limit root growth and potassium diffusion, sludge application as mulch is favored because Ca interaction with K depressed potassium uptake and yield when the mode of application was incorporation. Soil amendments are versatile to meet limiting plant growth factors in different soil units and climatic conditions as they alter many soil physical properties and supply many nutrients.

Sludge application potentially enhances root growth, potassium uptake and yield by increasing soil water and lowering bulk density and mechanical resistance. Sludge may be more effective on yield production with marginal soil physical properties and climatic conditions. Mulch and incorporation did not lower water stress in this experiment by dry land culture. They may lower plant water stress in dry climates and with some sufficiently nourished summer crops in Golestan province however. Compared to ameliorating soil physical properties by sludge application and their interactions, greater credit may go to potassium supplementation through sludge decomposition with the soil and climatic conditions in this research.

Acknowledgement

This research was funded by Gorgan University of Agricultural Sciences and Natural Resources (Iran).

References

Acharya, C. L., & Sharma, P. D. (1994). Tillage and mulch effects on soil physical environment, root growth, nutrient uptake and yield of maize and wheat on an Alfisol in North-West India. *Soil & Tillage Research, 32*, 291-302. http://dx.doi.org/10.1016/0167-1987(94)00425-E

Ahmadi, M. (2007). *Predicting phenological development in wheat (Triticum aestivum)*. M.Sc. thesis, Department of Agronomy, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan , Iran.

Alaeddin, M. Z. (2011). *Physical and chemical parameters affecting plant available potassium in some soils of Golestan and Tehran Provinces* . M.Sc. thesis, Soil Science Department, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran.

Allmaras, R. R., & Nelson, W. W. (1971). Corn (*Zea mays* L.) Root configuration as influenced by some row-interrow variations of tillage and straw mulch management. *Soil Science Society of America Proceedings, 35*, 974-980.

Amini, S. (2007). *The effect of paper mill sludge on soil fertility and wheat growth*. M.Sc. thesis, Soil Science Department, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran.

Amini, S., Movahedi Naeini, S. A. R., & Mashayekhi, K. (2012). Effects of paper-mill sludge as a mulch versus topsoil incorporation on potassium uptake and the grain yield of rain-fed wheat in a high specific surface loess soil with illite dominance in clay fraction. *Applied and Environmental Soil Science,* Article ID 624824, 10 pages. http://dx.doi.org/10.1155/2012/624824

Baver, L. D. (1959). *Soil physics* (3rd ed.) (p. 489). New York, NY: John Wiley & Sons. Inc.

Biswas, T. D., & Khosla, B. K. (1971). Building up of organic matter status of the soil and its relation to the soil physical properties. Int. Symp. Soil Fert. *Evaluation, 1*, 831-842.

Bolt, G. H., & Bruggenwert, M. G. M. (1978). *Soil chemistry* (p. 281). Amsterdam , Netherlands : Elsevier Scientific Publishing Co.

Campbell, G. S. (1985). *Soil physics with basic transport models for soil plant system* (p. 150). Netherlands : Elsevier Science Publishers B.V.

Carter, D. L., Heilman, M. D., & Gonzalez, C. L. (1965). Ethelene glycol monoethyl ether for determining surface area of silicate minerals. *Soil Sci. Soc. Am. J, 100*, 356-360.

Chaudhary, M. R., & Prihar, S. S. (1974). Root development and growth response of corn following mulching, cultivation, or interrow compaction. *Agronomy Journal, 66*, 350-355.

Cook, H. F. (1986). *Assessment of drought resistance in soils*. Ph.D. Thesis, University of East Anglia. United Kingdom.

Cox, A. E., Joern, B. C., & Roth, C. B. (1996). Nonexchangeable ammonium and potassium determination in soils with a modified sodium tetraphenylboron method. *Soil Sci. Soc. Am. J, 60*, 114-120.

Doorenbos, J., & Kassam, A. H. (1979). *Yield response to water* (p. 199). FAO Irrigation and Drainage Paper. 33.

Farhangi, F. (2011). *Influence of soil incorporated calcium sulfate, calcium chloride and potassium chloride on the release of available K from two soils, with and without truncated electric diffuse double layers using breakthrough curves*. M.Sc. thesis, Soil Science Department, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan , Iran.

Francis, C. A., Harwood, R. R., & Parr, J. F. (1986). The potential for regenerative agriculture in the developing world. *American Journal of Alternative Agriculture. 1*, 65-74. http://dx.doi.org/10.1017/S0889189300000904

Gajri, P. R., Arora, V. K., & Chaudhary, M. R. (1994). Maize growth responses to deep tillage, straw mulching and farmyard manure in coarse textured soils of N.W. India. *Soil Use and Management, 10*, 15-20. http://dx.doi.org/10.1111/j.1475-2743.1994.tb00451.x

Gajri, P. R., Prihar, S. S., Cheema, H. S., & Kapoor, A. (1991). Irrigation and tillage effect on root development, water use and yield of wheat on coarse textured soils. *Irrigation Science, 12*, 161-168. http://dx.doi.org/10.1007/BF00192288

Gardner, C. M. K., Laryea, K. B., & Unger, P. W. (1999). *Soil physical constraints to plant growth and crop production*. FAO Land and Water Development Division (p. 106).

Geiger, R. (1965). *The climate near the ground* (p. 611). USA: Harvard University Press.

Gill, K. S., Gajri, P. R., Chaudhary, M. R., & Singh, B. (1996). Tillage, mulch and irrigation effects on corn (Zea Mays L.) in relation to evaporative demand. *Soil & Tillage Research, 39*, 213-227. http://dx.doi.org/10.1016/S0167-1987(96)01061-6

Gupta, S. C., Dowdy, R. H., & Larson, W. E. (1977). Hydraulic and thermal properties of a sandy soil as influenced by incorporation of sewage sludge. *Soil Sci. Soc. Am. J., 41*, 601-605.

Hanks, R. J., & Ashcroft, G. L. (1980). *Applied soil physics* (p. 159). Germany: Springer-Verlag.

Haryana, H., Nath, P. K. J., Taneja, S. N., & Goyal, V. P. (1975). Effects of organic manuring on some soil physical properties of sandy loam soils of Hissar. *Journal of the Indian Society of Soil Science, 23*(3), 380-383.

Havlin, J. L., Beaton, J. D., Tisdale, S. L., & Nelson, W. L. (2005). *Soil fertility and fertilizers* (p. 527). USA: Prentice Hall.

Hillel, D. (1980). *Fundamentals of soil physics* (p. 143). London, United Kingdom: Academic Press Inc.

Hornick, S. B. (1988). Use of organic amendments to increase the productivity of sand and gravel spoils: Effect on yield and composition of sweet corn. *American Journal of Alternative Agriculture, 3*(4), 156-162. http://dx.doi.org/10.1017/S0889189300002435

Hosseini, M. (2011). *Potassium uptake and the yield of rain-fed wheat in a soil dominated by illite in clay fraction and high in specific surface as affected by different tillage systems*. M.Sc. thesis, Soil Science Department, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran.

Jalota, S. K., & Prihar, S. S. (1990). Bare-soil evaporation in relation to tillage. *Advances In Soil Science, 12*, 187-212.

Jamison, V. C. (1953). Changes in air water relationships due to structural improvement of soils. *Soil Science, 76*, 143-151.

Jamison, V. C., & Kroth, E. M. (1958). Available moisture storage capacity in relation to textural composition and organic matter content of several Missouri soils. *Soil Sci. Soc. Am. Proceedings, 22*(3), 189-192.

Jaynes, D. B., & Tyler, E. J. (1984). Using soil physical properties to estimate hydraulic conductivity. *Soil Science, 138*(4), 298-305.

Johns, W. D., Grim, R. E., & Bradley, W. F. (1954). Quantitative estimation of clay minerals by diffraction method. *J. sediment petrol, 24*, 242-251. http://dx.doi.org/10.1306/D42697B5-2B26-11D7-8648000102C1865D

Joudi, Z., & Movahedi, S. A. R. (2007). The effects of zeolite, LECA and compost amendments on soil water storage and evaporation. *Journal of Agricultural Sciences and Natural Resources, 14*(2), 20-31.

Joudi, Z., & Movahedi, S. A. R. (2008). The effects of zeolite, LECA and compost on soil water content and temperature. *Journal of Agricultural Sciences and Technology, 21*(2), 35- 46.

Kaddous, F. G. A., & Morgans, A. S. (1986). Spent mushroom compost and deep litter fowl manure as a soil ameliorant for vegetables (p. 138-147). In *Surface Soil Management Proceedings*. New Zealand Society of Soil Science-Australian Society of Soil Science Inc. Joint Conference, Rotorua , New Zealand.

Kittric, J. A., & Hope, E. W. (1971). A procedure for particle size separations of soils for x-ray diffraction. *Soil Sci. Soc. Am. Proc, 35*, 621-626.

Klute, A. (1986). *Methods of soil analysis, Part 1. Physical and mineralogical methods* (p. 1188). Madison , WI: American Society of Agronomy, Soil Science Society of America.

Lal, R. (1974). Soil temperature, soil moisture and maize yield from mulched and unmulched tropical soils. *Plant and Soil, 40*, 129-143. http://dx.doi.org/10.1007/BF00011415

Lemon, E. R. (1956). The potentialities for decreasing of moisture evaporation loss. *Soil Sci. Soc. Am. Proceedings, 30*, 120-125.

Letey, J. (1985). Relationship between soil physical properties and crop production. *Advances in Soil Science, 1*, 277-294.

Macrae, R. J., & Mehuys, G. R. (1985). The effect of green manuring on the physical properties of temperate-area soils. *Advances in Soil Science, 3*, 71-94.

Marsh, J. D. M., & Rixon, A. J. (1991). Effects of heavy additions of organic residues on physical characteristics of three soil types in Queensland, Australia. *Soil & Tillage Research, 20*, 109-122. http://dx.doi.org/10.1016/0167-1987(91)90129-L

Marshall, T. J., & Holmes, J. W. (1992). *Soil physics* (p. 374). Great Britain: Cambridge University Press.

Morachan, Y. B., Moldenhauer, W. C., & Larson, W. E. (1972). Effects of increasing amounts of organic residues on continuous corn: I. Yields and soil physical properties. *Agronomy Journal, 61*, 199-203.

Movahedi, S. A. R., & Cook, H. F. (2000). Influence of municipal compost on temperature, water, nutrient status and yield of maize in a temperate soil. *Soil Use and Management, 16*, 215-221. http://dx.doi.org/10.1111/j.1475-2743.2000.tb00196.x

Movahedi, S. A. R., & Rezaei, M. (2009). *Soil Physics, Fundamentals and applications* (p. 445). Gorgan , Iran : Gorgan University of Agricultural Sciences and Natural Resources Publications Series.

Nakshabandi, G. A., & Kohnke H. (1965). Thermal conductivity and diffusivity of soils as related to moisture tension and other physical properties. *Agricultural Meteorology, 2*, 271-279. http://dx.doi.org/10.1016/0002-1571(65)90013-0

Pagliai, M., Guidi, G., Lamarka, M., Giachetti, M., & Lucamante, G. (1981). Effects of sewage sludges and composts on soil porosity and aggregation. *Journal of Environmental Quality, 10*(4), 556-561.

Phillips, R. E., & Kirkham, D. (1962). Mechanical impedance and corn seedling root growth. *Soil Sci. Soc. Am. Proceedings, 26*(4), 319-322.

Phillips, R. E. (1980). Soil moisture. In R. E. T., G. W. Phillips & R. L. Blevins (Eds.), *Tillage Research: Reports and Reviews*, University Of Kentucky, College Of Agriculture And Agric. Exp. Stn., Lexington, Ky, 55-66.

Rezaei, M., & Movahedi Naeini, S. A. R. (2009). Kinetics of potassium desorption from a loess soil, soil mixed with zeolite and the clinoptilolite zeolite as influenced by calcium and ammonium. *J. Applied Sci, 9*, 3335-3342. http://dx.doi.org/10.3923/jas.2009.3335.3342

Rickman, R. W., Letey, J., & Stolzy, L. H. (1965). Soil compaction effects on oxygen diffusion rates and plant growth. *Cal. Agr, 19*(3), 4-6.

Sebti, M., Movahedi Naeini, S. A. R., Ghorbani, N., R., Roshani, G. A., & Movahedi, M. (2009). Suitable soil potassium extractant for a loess soil with illite dominance in clay fraction and the effects of Azotobacter and vermicompost on rainfed wheat tissue potassium concentration and uptake. *Journal of Agricultural Sciences and Natural resources, 16*(4), 59-75.

Sharma, B. R. (1991). Effect of different tillage practices, mulch and nitrogen on soil properties, growth and yield of fodder maize. *Soil & Tillage Research, 19*, 55-66. http://dx.doi.org/10.1016/0167-1987(91)90109-B

Singh, P. N., Joshi, B. P., & Singh, G. (1987). Effect of mulch on moisture conservation, irrigation requirement and yield of potato. *Indian J. Agron, 32*(4), 452-454.

Sposito, G. (2008). *The chemistry of soils* (2nd ed.) (p. 329). USA : Oxford University Press.

Sys, C. (1985). *Land evaluation*. Part III. Belgium : State University of Ghent. International Training Centre for post-graduate Soil Scientists.

Talebizadeh, E. (2009). *The effect of calcium, ammonium and potassium based phosphorous fertilizers on potassium uptake by rain-fed winter wheat in a potassium fixing loess soil with a dominance of weathered mica in clay fraction*. M.Sc. thesis, Soil Science Department, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan , Iran.

Thompson, P. J., Jansen, I. J., & Hooks, C. L. (1987). Penetrometer resistance and bulk density as parameters for predicting root system performance in mine soils. *Soil Sci. Soc. Am. J, 51*, 1288-1293.

Unger, P. W., & Stewart, B. A. (1974). Feedlot waste effects on soil conditions and water evaporation. *Soil Sci. Soc. Am. Proceedings, 38*, 954-957.

Vafakhah, M. (2011). *The effect of calcium bearing amendments on root zone potassium release and wheat uptake in soil dominated by illite in clay fraction and high specific surface*. M.Sc. thesis, Soil Science Department, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan , Iran.

Van Olphen, H. (1977). *An introduction to clay colloid chemistry* (2nd ed.) (p. 318). USA: John Wiley & Sons.

Wallace, A., & Terry, R. E. (1998). *Handbook of soil conditioners* (p. 596). USA: Marcel Dekker, Inc.

Weill, A. N., Mehuys, G. R., & Mckyes, E. (1990). Effect of tillage reduction and fertiliser type on soil properties during corn (Zea mays L.) production. *Soil & Tillage Research, 17*, 63-76. http://dx.doi.org/10.1016/0167-1987(90)90006-Y

Wild, A. (1988). *Russells soil conditions and plant growth* (11th ed.) (p. 991). London, UK: Wiliams Clowes Limited, Beccles and Colchester.