65 години

Аграрен университет - Пловдив, Научни трудове, т. LV, кн. 2, 2010 г.
Юбилейна научна конференция с международно участие
Традиции и предизвикателства пред аграрното образование, наука и бизнес
Agricultural University - Plovdiv, Scientific Works, vol. LV, book 2, 2010
Jubilee Scientific Conference with International Participation
Traditions and Challenges of Agricultural Education, Science and Business

THE EFFECT OF RECYCLED RESIDUAL PAPER PULP APPLICATION ON THE YIELD OF THREE PLANT SPECIES UNDER VARIABLE SOIL AND CLIMATE CONDITIONS

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Abstract

This study investigated main effects of recycled residual paper pulp (RRPP) used as soil amending material, on the yield and other agronomic characteristics of lettuce, cabbage and sweet corn as well as in major soil properties affecting crop growth and yield. It was conducted for two years and in two soil types (clay loam and sandy loam) representing also variable climate and was applied in four application rates (0-1-2-and 4% by volume) in the top soil surface (0-15 cm). The plants were managed using minimum inputs under the LISA (Low Input Sustainable Agriculture) system. The material is a waste product form a major cardboard manufacturing company in Greece. Main application of this is for incineration, land-filling and recently the soil application of it has been evaluated. The results indicated that the RRPP increased soil organic carbon in some cases significantly, it did not affect pH and EC, and increased yield of all plant species in both years. The material has not contributed additional heavy metals in both soils, a major requirement for using it for soil applications. Due to encouraging results, the study will be continued for two more years and include other plant species and properties of crops and soils in the investigation.

Key words: *recycled paper, soil improvement, organic matter, sweet corn, lettuce, cabbage*

INTRODUCTION

Paper production processes generate large amounts of byproducts. Production of paper and board globally reached 367 million tonnes in 2005 (Mies et al., 2006). The paper pulp industry is the sixth largest producer of industrial pollutants, following the oil, cement, leather, textile, and steel industries (Ali and Sreekrishnan, 2001). The pollutants from the paper pulp industry are classified as gases, effluents, and solid wastes. The last category includes recycled residual paper pulps (RRPP), which are also known as solid clarifiers and paper mill sludges (Levy and Taylor, 2003). Wastewater treatment processes at pulp and paper mills include primary treatment, where primary sludge is produced after neutralizing, screening, and sedimenting the suspended solids (Beauchamp et al., 2002; IFC, 2007).

The most common method of disposal is landfilling (Levy and Taylor, 2003; Nunes et al., 2008; Phillips et al., 1997). Stringent environmental regulations and increased cost have forced the industry to search for disposal alternatives. Incineration is one alternative (Tucker and Douglas, 2006; Vagstad et al., 2001; Oral et al., 2005), but the high water content of sludge hampers efficient combustion (Phillips et al., 1997).

Another alternative is to use the byproducts as soil amendments. Depending on the treatment process, sludges are characterized by modest concentrations of N, P, and K (Levy and Taylor, 2003). Mediterranean soils tend to be low in organic matter content due to climatic conditions, which are characterized by a prolonged hot and dry summer, followed by heavy precipitation during the fall (Nunes et al., 2008). Additionally, past bad management practices resulted in soils having low levels of organic matter (Koukoulakis et al., 2000). The main soil properties that require improvement are soil organic carbon, pH, cation exchange capacity, and water holding capacity.

The objective of this long term (>4 years) research study is to evaluate the effect from application of various rates of residual paper pulp on: a) important chemical and physical properties affecting crop growth in two soils (a clay loam and a loamy sand), b) the productivity of *lettuce*, *Lactuca sativa* and *Zea mays* var. *saccharata* grown on these soils and c) the temporal "residual" effect on soils and crops, after no more RRPP is applied.

MATERIALS AND METHODS

The study takes place in Greece from 2007 to 2011 and will be further continued, at two fields with different soil textural classes and climatic conditions: 1) a clay loam located at American Farm School at Thermi, near to Thessaloniki, and 2) a loamy sand located at Kolchiko, near Lagada, Thessaloniki. The distance of the two sites is approximately 60 km. Each field was 0.1 ha in area and was divided into 16 experimental plots. The experimental plots were each 3 m in width and 10 m in length (total area of 30 m^2). To reduce side effects from residual paper pulp applications on adjacent experimental plots, each plot had a 2 m-wide borders within the replications, and 1.5 m-wide borders among replications. This design also facilitates the statistical analysis as a "block".

The experiment consisted of four treatments. Each treatment was replicated four times. Each replicate was randomly assigned to one of the 4 plots within each replication (block).

Recycled residual paper pulp

The recycled residual paper pulp (hereafter referred to as RRPP) derived from the precipitation tank of Macedonian Paper Mill S. A, at Gefyra, Greece, the largest carton boxes producing company in Greece. The RRPP was air-dried for a period of 15 days. The dried pulp was finely ground at a factory's facilities in Thessaloniki, Greece and resulted in pulp particles in size <4 mm, with most particles in the fine powder size. The ground pulp was then placed in individual plastic bags (45 L bag^{-1}) for transport, application in field and storage.

The pulp was hand-applied to the soil surface of the designated experimental plots at the beginning of the first and second growing seasons using the following four application rates: 0, 1, 2, and 4% v/v calculated for the top 0.15 m soil depth (or 0, 1.5, 3, and 6 L m^{-2} or 0, 15, 30, and 60 m^3 ha^{-1} or rates can be converted to tons/ha considering an average material BD of 0.637 Mg m^{-3}). A rotary tiller was used to incorporate the pulp into the topsoil (0.15 m soil depth). Soil samples were collected twice from this depth each year – at the beginning and end of each growing season. Samples were air dried, sieved through a 2 mm sieve and stored in the laboratory room.

Planting schedules and crop species cultivated

During each growing season, two crops were grown at each experimental site. Lettuce (*Lactuca sativa*) seedlings were planted using a 1.5 m row spacing and a 0.5 m plant spacing within the row. After this crop, sweet corn (*Zea mays* var. *saccharata* Legend F1 hybrid) was sown. Sweet corn was sown with a 4 row pneumatic planter. The corn was planted with a 0.75 m row spacing and a 0.15 m plant spacing within the row.

During both years LISA (Low Input Sustainable Agriculture) cultivation practices were used. On first year, an organic pesticide based on *Bacillus thuringiensis* (Bactospeine ®) was use for the control of cabbage caterpillars on both experimental sites. No fertilizers and synthetic pesticides were applied. Although LISA practices were followed when possible during the second year, it was necessary to use small amounts of fertilizers and some synthetic herbicides (Treflan ®) (in one case only at Kolhiko, 2008). At planting, 5 kg/ha of 11-15-15 start-up fertilizer was applied on both fields at the beginning of the second growing season.

In both years, the crops were irrigated by drip irrigation lines with emitters spaced at 0.5 m and with an output of 4 L h^{-1}. The sweet corn was irrigated by drip irrigation and by some supplementary overhead irrigation with a watering gun.

Cultivation practices included manual and mechanical weeding.

Soil chemical and physical properties

Soil properties measured were: 1) soil reaction (pH), 2) saturation electrical conductivity, 3) bulk density and porosity, 4) volumetric water content, 5) apparent electrical conductivity, 6) temperature, 7) organic carbon, 8) heavy metals, 9) total N, 10) and NO_3-N and NH_4-N. Top soil physical and chemical properties were measured in the Agronomy & Soils Laboratory of Perrotis College, Thessaloniki, Greece. Additional analyses ($CaCO_3$, P_20_5, K_20, total N, NO_3-N, NH_4-N and heavy metals) were also provided from the Soil Chemistry and Physiology Lab, Faculty of Agriculture, University of Belgrade, Serbia (Professor Valdo Licina).

Soil reaction (pH) and saturated electrical conductivity was measured in the laboratory using an 1:1 mixture of soil:distilled water (v/v) with a combination pH-EC electrode (Model HANNA HI 9811). Soil bulk density and porosity were measured taking undisturbed soil samples with the “cylinder method:” .Undisturbed soil cores were collected with 100 cm^3 stainless steel cylinders. The cylinders were pressed into the soil to a depth of 0.15 m. Soil organic carbon was measured with the Walkey-Black wet combustion method (Walkey and Black, 1934; Walkey, 1947). Periodical measurements in the top soil (0 to 0.15 m) for soil volumetric water content (VWC), apparent electrical conductivity (ECa), and temperature were performed with the WET ® sensor and the HH2® datalogger.

Agronomic measurements

Plant properties and agronomic characteristics measured were: 1) leaf chlorophyll level, 2) yield (fresh weight of lettuce, cabbage, and corn ears). Relative leaf chlorophyll level (SPAD units) was measured in five representative plants from the middle experimental row with a Minolta SPAD 502 ® leaf chlorophyll meter. Each of the five readings was the average of three leaf readings per plant taken at various leaf ages (low-middle-upper leaf was sampled and averaged at each plant). For sweet corn, SPAD measurements were taken at the same day of the two harvestings. In lettuce, SPAD units were measured in the last harvest set.

Fresh yield was recorded as the average of five harvested plants for the lettuce crops and ten randomly selected ears of sweet corn crop from the middle line of each experimental plot. All samples were harvested from the middle experimental row to avoid any edge effects.

Other data and observations recorded

Automated weather stations were installed adjacent to each of the study sites and recorded data at hourly intervals. Weather data collected at each site were: 1) air temperature and relative humidity (RH%) at 2 m, 2) rainfall (mm), and 3) wind speed and direction.

Statistical analyses

The field experiment was analyzed as a Randomized Complete Block Design (RCBD), and the four treatments were assigned in random within four replications or blocks. "Block" is the preferred statistical term since it avoids confusion with the term "replication" which is used when the analysis follows the completely randomized design (CRD). The main objective of the RCBD is to "keep the variability among experimental units within a block as small as possible and to maximize differences among blocks. If there are no block differences, this design will not contribute to precision in detecting treatment differences" (Little and Hills, 1978). The units in a block are as uniform as possible so that the observed differences should be primarily due to treatment effects (Steel and Torrie, 1980). The borders left around each experimental plot further facilitated the RCBD analysis. The 4 rates of RRPP were considered as continuous-nominal variables as well as the blocks, for the statistical analyses.

JMP® 8 software was used for the statistical analysis of collected data. Statistical analyses of treatment effects on soil and agronomic properties measured was carried out with one-way ANOVA by blocking treatments. All pairs mean comparison was done with Student's t-test. Furthermore, simple linear regression analysis with blocks was also used for data analysis.

RESULTS

Analyses of the RRPP material are provided in Table 1. The results show that the basic properties of this material are within the acceptable limits for crop growth. Also continuous analyses for heavy metals performed by MEL company did not show any excessive or beyond limit quantities. Independent analyses performed for this study concluded similar results. The most important property of RRPP is the high content of soil organic carbon –very important for amending low organic matter soils-and the high porosity, a property affecting water holding capacity. The electrical conductivity is within low to medium levels and is not expected to adversely affect plant growth and productivity. The study will investigate the effect on these and other soil properties after multiple and continuous applications of RRPP. The study includes two phases: a) a two year with RRPP application at each year and b) the follow up in the next two and more years on these properties without further application, Companion studies will continue to investigate the effect of application of RRPP.

Table 1. Mean values of basic properties of RRPP (mean value of 12 replications)

Property	Mean value
Bulk density, Db ($Mg\ m^{-3}$)	0.637
Porosity(%)	75.87
Soil Organic Carbon, SOC % (by wet combustion)	21.82
Soil Organic Matter, SOM=SOC%X1.724 (%)	37.61
pH (1:1)	7.64
Electrical Conductivity, EC 1:1 ($dS\ m^{-1}$)	0.54
Water content at initial output (%)	62.20

This study is the only one globally evaluating this residual material in pulverized (finer than granules) form and also under LISA management systems. Therefore, it represents a unique comparison database . During the last two years (2010-2011) a companion project to evaluate the "raw" form of this material is performed.

Results from the effects of the various RRPP treatments on SOC are presented in Table 2. All rates of the material increased SOC in both years. The most pronounced effect was shown on the initially low SOC sandy loam soil. The high rate of application was significantly different in both fields. These results justify the use of RRPP as a soil improving material for SOC. Beyer et al. (1997) and Aitken et al. (1998) reported similar results for paper pulp applied in soils.

Table 2. Mean values of Soil Organic Carbon SOC (%) at each soil type and for the two years of the study.

TREATMENT	SOC (Clay loam-2008)	SOC (Clay loam-2009)	SOC (Sandy loam-2008)	SOC (Sandy loam 2009)
RRPP (v/v)%	----%----	----%---	----%----	----%----
4	1.287a	1.658a	1.106a	1.321a
2	1.273a	1.609a	1.165a	1.17ab
1	1.273a	1.44b	0.958ab	1.108ab
0	1.246a	1.343b	0.782b	0.89b

Note: Numbers followed by the same letter are not statistically significant at $p<0.05$

The yearly results in each soil for the change of pH are shown in Table 3. The soil reaction (pH) in the clay loam soil did not change in both years, while pH increased statistically significant in the lightly acid sandy loam soil in both years. The increase in pH was almost proportional to the application rate. The behaviour of RRPP in the acid soil justifies the use of it as a material to increase soil reaction in acid soils. The follow up results of the next phase will further validate this hypothesis.

Table 3. Mean values of soil reaction (pH) at each soil type and for the two years of the study.

TREATMENT	**pH (Clay loam-2008)**	**pH (Clay loam-2009)**	**pH (Sandy loam-2008)**	**pH (Sandy loam 2009)**
RRPP (v/v)%				
4	7.450a	7.270a	6.975a	7.270a
2	7.338a	7.268a	7.000a	7.275a
1	7.225a	7.243a	6.925a	7.168a
0	7.413a	7.233a	6.463b	6.653b

Note: Numbers followed by the same letter are not statistically significant at $p<0.05$

Bulk density is a soil property affecting inversely proportional soils porosity. The higher rate of RRPP application caused significant reduction changes in bulk density in both soils (Table 4). Similar results were reported by Price and Voroney (2007). It is hypothesized that the increase of bulk density in the 2nd year may have been caused by the minimum tillage system used since only light cultivation was performed in the soil surface depth. Therefore, RRPP caused increase in porosity and in the water holding capacity of both soils. Results on surface soil volumetric water content not reported in this paper support the above hypothesis.

Table 4. Mean values of soil bulk density (**D_b**) at each soil type and for the two years of the study.

TREATMENT	**D_b (Clay loam-2008)**	**D_b (Clay loam-2009)**	**D_b (Sandy loam-2008)**	**D_b (Sandy loam 2009)**
RRPP (v/v)%	----Mg m^{-3}----	---- Mg m^{-3}----	----Mg m^{-3}----	----Mg m^{-3}----
4	1.098b	1.245a	1.108b	1.300b
2	1.177ab	1.253a	1.218ab	1.493a
1	1.194a	1.223a	1.268a	1.465a
0	1.198a	1.230a	1.210ab	1.460a

Note: Numbers followed by the same letter are not statistically significant at $p<0.05$

Yield of sweet corn increased in both soils and years (Table 5) almost proportionally to application rates, while the highest rate caused statistically significant increase. Similar results were shown for the lettuce yield (Table 6), where also the increase was diversified in each soil. Climate is expected to affect yield, mainly through the air temperature, while rainfall was close to both locations. The sandy loam location is colder in annual average by 1.2 °C from the clay loam. Results on cabbage grown the 1st year (not reported herein) also showed the same trend in yield increase. More crop species are under evaluation in the next phase.

Table 5. Mean values of sweet corn yield (fresh weight of ear) for each soil type and for the two years of the study.

TREATMENT	(Clay loam-2008)	(Clay loam-2009)	(Sandy loam-2008)	(Sandy loam 2009)
RRPP (v/v)%	----g/ear----	----g/ear----	----g/ear---	----g/ear----
4	323.1a	306.0a	252.0a	272.3a
2	295.9b	286.5b	249.7a	255.5ab
1	248.0c	285.3b	243.4ab	247.0ab
0	232.3c	283.0b	219.2b	223.0b

Note: Numbers followed by the same letter are not statistically significant at $p<0.05$

Table 6. Mean values of lettuce (fresh weight of head) for each soil type and for the two years of the study.

TREATMENT	(Clay loam-2008)	(Clay loam-2009)	(Sandy loam-2008)	(Sandy l oam 2009)
ΥΠΑΧ(v/v)%	---g/head---	----g/head----	----g/head----	----g/head----
4	701.8a	1301.5a	291.5a	422.5.3a
2	584.8ab	1029.5ab	282.3a	396.3.5ab
1	579.8ab	1010.8ab	257.0a	344.8ab
0	568.3b	892.8b	227.5a	273.5b

Note: Numbers followed by the same letter are not statistically significant at $p<0.05$

DISCUSSION

Results from the first phase (two years) of this study demonstrated the beneficial effects of RRPP to crops and soils. The material increased soil organic matter, did not affect adversely other important soil properties (pH, EC, Bulk density) and caused increase yield in the crops grown. Even under the LISA management schemes applied, the effect was shown to be positive a fact that supports the hypothesis that under more conventional management or organic management the RRPP could be similarly effective. The material therefore can be used for all forms of production (conventional, organic, integrated) with appropriate rates for each soil type. The next phase of this study will validate the "residual" effect of this material in a period of two more years without any further application and the companion experiments will compare the raw form of application.

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ACKNOWLEDGMENTS

Funding for this study was provided by MEL Macedonian Paper Mills, S.A., Kato Gefyra, Thessaloniki, GREECE (www.melpaper.com)