THE ROLE OF SOIL PROPERTIES VARIABILITY TO RECLAMATION SUCCESS ON THE LIGNITE STRIP-MINED LAND IN NORTHERN GREECE

O PAPEL DA VARIABILIDADE DAS PROPRIEDADES DO SOLO NO SUCESSO DE RECUPERAÇÃO DAS MINAS DE LIGNITE DO NORTE DA GRÉCIA

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ABSTRACT

The present paper present some of the adverse ecological parameters studied for the assessment of reclamation of the lignite spoil heaps of Ptolemaida in North Greece. Natural revegetation was the first step before reclamation began and it was studied. Natural vegetation of lignite spoil heaps was heterogeneous and 7 plant communities were identified, described and mapped. Soil samples geographically positioned indicated that the spoil heaps were heterogeneous and with many unfavourable physicochemical properties. Soil properties were related to natural vegetation and were indicators in assessment of reclamation potentiality of the site. Surface soil temperatures reached 62°C during summer and temperature difference observed between the lightest and darkest spoil materials was 12°C. Between a bare soil and a soil covered by natural vegetation, the soil temperature difference was nearly 20°C. In order to understand the variation of soil properties, graphical interpretation was done with the use of geostatistics in a geographic information system. Cross validation was used to compare the prediction performances of the geostatistical interpolation algorithms. Site quality was estimated from soil properties and natural vegetation composition. The prediction maps resulting from the interpolation techniques help to determine which areas had optimal conditions for forest species development and landscape reclamation success.

Keywords: Geostatistics; Landscape Reclamation; Soil Temperature; Lignite Mine.

RESUMO

O presente trabalho apresenta alguns dos parâmetros estudados para a recuperação dos taludes de desperdício nas minas de lignite de Ptolemaida no Norte da Grecia. A re-vegetação natural foi a primeira etapa antes do inicio da recuperação. A vegetação natural nos taludes de desperdício das minas era heterogénea e 7 comunidades phytosociológicas foram identificadas. Amostras de solo georreferenciadas demonstraram a heterogeneidade do local e com propriedades fisico-químicas desfavoráveis. As propriedades do solo foram relacionadas à vegetação natural e ambos poderiam ser indicadores na avaliação do potencial da recuperação. As temperaturas de superfície do solo alcançaram 62°C e com diferenças de 12°C observadas entre os materiais os mais claros e os mais escuros, que alcançava diferenças de 20°C em sítios sem cobertura vegetal. A fim compreender a variação de propriedades do solo foram usadas técnicas de geoestatistica em sistema de informação geográfica. A qualidade local da zona em estudo foi estimada pelas propriedades do solo e da composição natural da vegetação. Os mapas da predição que resultaram das técnicas de interpolação geoestatistica ajudaram determinar que áreas precisem melhoramentos locais e que áreas tiveram condições óptimas para o desenvolvimento da floresta e o sucesso da recuperação da paisagem.

Palavras-chave: Geoestatistica; Recuperação da Paisagem; Temperatura do Solo; Mina de Lignite.

JEL Classification: Q01; Q15; Q24.

1. INTRODUCTION

In Greece, lignite is the most important energy resource for the electric power production, but mining continues without planning for subsequent rehabilitation, and the Greek landscape is changing significantly through lignite surface mining. Following the appropriate program in all stages of mining the area can return to the society even improved and ready for uses as agriculture, forestry, recreation, sports, industrial areas and others (Wang *et al.*, 2001).

Although, every reclamation trial has to fight with peculiar problems caused by the adverse ecological conditions that are present. Species selection appropriate for the climate and soil, irrigation, fertilisation and additional soil were suggested for many reclaimed lignite mines (DePruit *et al.*, 1982; Hart *et al.*, 1999). Several researchers have studied the use of natural revegetation and forest establishment on the spoils some years before those areas to be rehabilitated to agricultural lands (Alexander, 1989; Wade, 1989). Seeding of the spoils to minimize erosion suggested from some authors (Rosiere *et al.*, 1989), but was not supported from others because is not allowing or is delaying the establishment of more profitable species (Chambers *et al.*, 1987; Andersen *et al.*, 1992).

The establishment of natural vegetation and reforestation help to cover and stabilise the soil, to start biological activity, soil genesis and generally impose the physical and chemical properties of the spoils soil, thus agriculture can be re-established to these areas 20-30 years after reclamation. (Warman, 1988; Gonzalez *et al.*, 1991)

Soil characteristics with similar vegetation associations were shown to be reasonable autochthonous indicators of soil degradation and rehabilitation (Paniagua *et al.*, 1999). Bioindicator-based studies have the potential to make a major contribution to optimise different reclamation systems and to influence policies governing landscape management and transformation (Iverson & Wali, 1982; Pakeman *et al.*, 1997; Paoletti, 1999).

Prior to the mining of heavy minerals, the vegetation diversity has to be investigated to serve as a benchmark for the future rehabilitation of the area (De Villiers *et al.*, 1999). Topsoil replacement improved the physical and chemical properties of the soil and water retention in some extreme microenvironments, decrease the high surface soil temperatures and helped in fast and diverse establishment of natural vegetation and microorganisms (Day & Ludeke, 1990).

Soil temperature is another indicator of the ecological status of an area and an important soil property. The soil temperature changes are affecting soil properties, soil genesis and plant growth. High soil temperatures increase water evaporation in the upper soil layers and decrease water availability to plants. The thermal soil properties depend on the type of soil, soil roughness, air porosity, moisture, soil colour, specific weigh of the soil, wind velocity, clouds, topography, air temperature, relative humidity, chemical properties, soil structure and vegetation cover (Geiger, 1973). Snow and organic matter also reduce fluctuations in soil temperature. A dark-coloured soil and a light-coloured sand may absorb, respectively, about 80 and 30% of incoming solar radiation (Foth, 1984).

When reclamation or restoration starts is important to provide specific scientific biological information and incorporate it in a geographical information system to support decision making during the design of the reclamation or conservation plan (Panagopoulos & Hatzistathis, 1995). In order to understand the variation of soil properties a graphical interpretation of those could be obtained through geostatistical techniques. Geostatistics provide inexpensive maps of a given area and decrease uncertainty (Chilès & Delfiner, 1999).

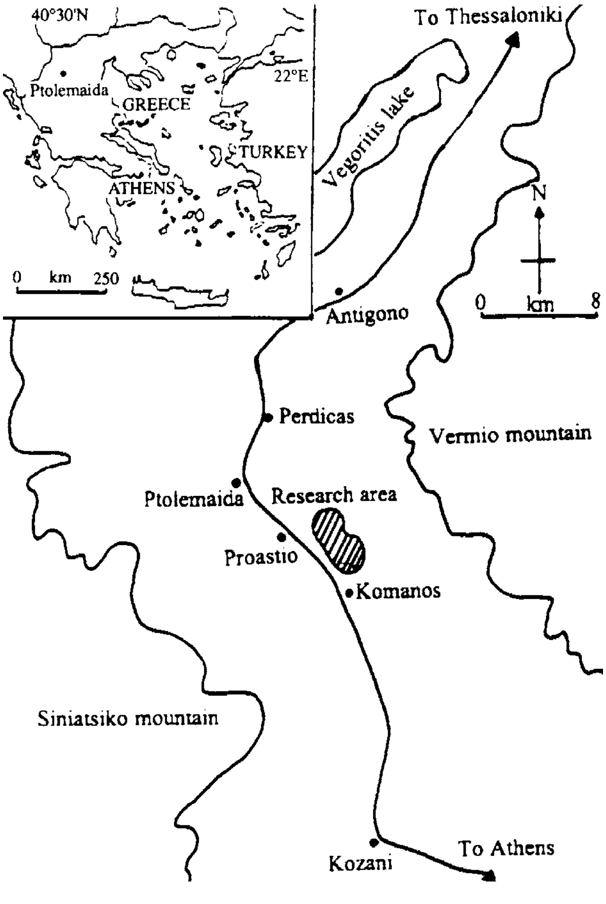
This study examines the geographical variability of relationships between natural vegetation and some soil properties of the lignite spoils of Ptolemaida and their influence on landscape reclamation success.

2. MATERIALS AND METHODS

2. 1 Description of the study area

Before mining began, the area was an almost plain valley with surrounding mountains that rise to an altitude of 1500 meters. The lignite mines studied are located in Northwest Greece near the city of Ptolemaida, in a valley with 667.5 meters mean altitude, at latitude 40° 30' North and longitude 22° East of Greenwich (figure 1). The valley is rich in lignite, with six active lignite mines in the area. Fourteen electricity-generating plants produce more than 70% of Greece's electric power. Until recently, of the 12,500 affected by mining only 400ha were rehabilitated and by the year 2025, it is estimated that the area affected by mining will be 20,000ha.

Figure 1. Location of the study area



The climate of the area is continental Mediterranean with very hot and dry summers and mild winters. Average annual precipitation is 551.26mm (Ptolemaida meteorological station, 35 years of record) with a maximum monthly average in November (68mm) and a minimum in August (27mm). Average annual air-temperature is 12.3°C with coldest month January (1.8°C) and warmer July (22.5°C). The absolute maximum air temperature during the research period was 41°C and the absolute minimum air temperature was -21°C. The dry period, relatively shorter than other regions of Greece, starts at the end of June and finishes at September.

The lignite of Ptolemaida is a soft brown to black coal with a low fuel value of 10-16Kj/g and sulphur content generally below 0.6%. The geological period of the lignite layers is the Pleistocene and the thickness of the lignite layers varies between 12 and 32 meters. The spoils are generally consisted of the materials that arise after the extraction of lignite. The transportation and deposition of the spoil materials were not programmed or planned.

The overburden of the lignite layers were mixed together with bad quality lignite and lignite gasification ashes (fly ash) and surface soil. The new soils that arise from this mixture were heterogeneous, unstable and unconsolidated, with a high pH and low compaction. The overburden that covers the lignite layers in the valley consisted of marls (forms of soft limestone characterized by high quantities of $CaCO_3$, alkaline and rich in bases), sediments, red-soils, alluvial, peat mould, earthy lignite, fossils, and others. The pH of the fly ash varies between 9 and 12. Soil analyses showed that the new soils are poor in nutrients and with some toxic elements.

Unplanned placement of the spoil materials provoke the instability of the new soils and the high risk of erosion. Topsoil in most of the cases buried in high depths and lost, self-igniting fires when unburned lignite is exposed close to the surface of the spoils, soil on the surface with unidentified properties, mineral toxicity and problems on vegetation survival in areas of high fly ash presence.

The vegetation of the Ptolemaida valley corresponds to the sub Mediterranean vegetation zone of *Quercetalia pubescentis* (Athanasiadis, 1986). The main forest species planted in the area were *Pinus nigra, Robinia pseudoacacia, Cupressus arizonica* and farmers grew wheat, corn, sugarbeet and livestock forage. Species composition on the spoils depend on the age of the spoil with Chenopodiacae species to dominate on newly established spoils and Compositae species on older spoils. Leguminous species are common on younger and herbaceous species on older spoils.

2. 2 Phytosociological study

For the phytosociological study were established 48 geographically positioned sampling areas of 1 m^2, on a lignite spoil where soil preparation for reclamation activities terminated 3 years before. For every sampling area the Braun-Blanquet method was used and soil type, percentage of soil cover by plants and plant vitality were also estimated. Species identification was done using Flora Europea of Tutin *et al.* (1964-1980). Phytosociological units were separated with criteria based on species physiognomy, ecology, flora and evolution (Athanasiadis, 1986). The method based on ecology and flora was assisting better on the target of the study, which was the ecological description of the separated communities that will arise from the plant-table process.

The method used by the present study was not based neither on the characteristic or differential species of the Zurich-Montpellier school, neither on the dominant species, but on the combination of the indicator groups that were appearing in the phytosociological units. In the same group were included all the species with the same or similar ecological behaviour. The ecological description of the separated plant communities was done with the help of the ecological properties of the indicator groups. Cluster analysis was used to identify groups in raw data and helped to find structure in it and to separate it in classes (Longman *et al.*, 1995).

2. 3 Soil study

The high spatial variability of spoils soil properties was estimated with 16 geographically positioned soil samples. The samples were collected every 7 meters on 2 cross lines passing from the 4 corners of the experimental field. Many soil and water parameters that could explain the cause of spatial variability in revegetation success were analysed. Thus, it was identified the soil colour, type of soil (lignite, peat, topsoil, fly ash, marl or mixture of the above) and percentage of vegetation cover.

Soil samples were packed in polyethylene bags, transferred to the laboratory, weighted and dried. The fine earth fraction was analysed for the following: texture by sieve and pipette method, particle density, specific weight, available water content by pressure membrane extraction of saturated soil at 0.33 and 15 bar, total porosity, air porosity, organic matter, pH, electrical conductivity in 1:1 slurry of soil and distilled water, calcium carbonate ($CaCO_3$), available phosphorus, total nitrogen, and exchangeable calcium, magnesium and potassium by ammonium acetate extraction at pH 9.

Soil temperature during summer is a very important factor limiting reclamation success in the lignite mines of Ptolemaida, due to the black colour of lignite, which is the main element in the surface in most spoil area. For the estimation of the soil temperature were placed mercury thermometers at 0.5, 2.5, 11 and 17 cm depth, in three different soil colours: red (5R 4/7), light grey (10Y 7/1) and black (10YR 3/1). The red coloured area was a zone covered with surface soil; the grey was on areas represented by marl or fly ash and the black by lignite. Air temperature was measured under shadow, 50cm above the soil. The influence of shadow on soil surface temperatures at the black coloured area was examined separately.

Temperature readings were made at 15 minute intervals and average hourly values were recorded for each location. Air and soil temperatures were measured for a 20 day period during July.

2. 4 Statistical Analysis

Statistical analysis of the data included computation of the sample mean, variance and coefficient of variation for maximum and minimum soil temperatures measured at each depth and compared with the soil surface temperatures of a black coloured soil under shadow of natural vegetation and trees.

Two-way analysis of variance was used to determine significant differences ($P<0.05$) in maximum and minimum soil temperatures between shaded and unshaded areas. Comparisons of all means were examined with Fisher's protected LSD's and with Duncan's test. Regression analysis were used to identify significant correlations between soil temperatures in shaded and unshaded areas and between soil type and colour with natural vegetation species.

All data was entered into a field-scale geographic information system, and interlayer data analytical tools were utilized to quantify spatially dependent relationships (Kitanidis, 1997). A semi-variogram was produced for each soil property and several parameters that a semi-variogram can provide were analysed. Cross validation indicators and additional model parameters (nugget, sill and range) helped to choose the most appropriate model of the prediction maps for each soil property (Issaks & Srivastava, 1989).

Geostatistics could help to quantify the magnitude of spatial variability of selected properties, as well as model the spatial structure of the variability. This kind of information could be used in a modelling framework to increase the accuracy of model estimates by dissecting the landscape into distinct units which can be modelled separately (Issaks & Srivastava, 1989).

The Kriging interpolator that was used to create prediction maps of soil properties, assumes that the distance or direction between sample points reflects spatial correlation that can be used to explain variation in the surface (Armstrong, 1998).

3. RESULTS AND DISCUSSION

3. 1 Phytosociological research

Phytosociological units were determined with the help of the indicator plant groups. After the plant-table process, 7 indicator plant groups were separated in the table of species sampling. The result of the combination of the indicator groups published from Panagopoulos *et al.* (2001) and the ecological description of the 6 plant groups was done bibliographically and after an "on site" research (Ellenberg *et al.*, 1992).

Group A: Includes average drought species that appear in infertile, clay soils, with relatively high salinity, pH 8 and in relatively worm environments. The characteristic species of this group were: *Melilotus officinalis, Medicago lupulina, Cichorium endivia, Medicago coronata,* and *Dasypyrum villosum.*

Group B: Includes species of average humid areas, indicators of fertile soil with normal moisture and pH 7-8. The characteristic species of this group were: *Bilderdykia convolvulus, Carduus sp., Centaurea cf. depressa* and *Rumex crispus.*

Group C: Drought species, with large ecological adaptation, developing in medium fertile soil with pH 8 and warm environments. The characteristic species of this group were: *Tragopogon dubius* and *Reseda lutea.*

Group D: Species of average drought, with large ecological adaptation, growing in warm environments and average fertile soil with pH 7-8. The characteristic species of this group were: *Sonchus arvensis, Crepis foetida, Lappula squarrosa, Elymus repens* and *Crepis pulchra.*

Group E: The characteristic species of this group (*Calamagrostis epigejos*) can be seen in humid and cool environments, in soil of average fertility and pH 7-8.

Group F: Drought resistant species, growing in warm environments and soils with poor fertility and pH 9. The characteristic species of this group was: *Vaccaria pyramidata.*

Group G: Drought resistant species, expanding in warm environments with fertile soils and pH 7-8. The characteristic species of this group were: *Crepis pulchra, Avena barbata* and *Linaria genistifolia.*

In the following description of the phytosociological units the indicator plant group with a strong presence was represented with capital letter and when presence in the table was minor was recorded with small letter between parentheses.

Phytosociological unit E_1. Indicator plant group (d): This unit appeared in areas affected from topsoil that exists in a depth of more than 30cm and covered with lignite spoils. Soil was fertile and pH varied between 7.5-8. The forest species planted at the specific area had fast growth. Dead trees noted in that area were caused from the high soil surface temperatures. Natural vegetation was covering the soil between 40 and 50% and its shadow assisted in the survival of the new established forest species. Dominant species of this unit were *Bromus tectorum, Tussilago farfara* and *Carduus thoermeri*. Indicator value for this community had only the species *Bromus sterilis, Crepis foetida* and *Lappula squarrosa* of group D. This plant community was characterized by the absence of any other indicator groups.

Phytosociological unit E_2. Indicator plant groups A(c): This unit could be seen in areas affected from topsoil. That soil had clay loam texture, pH 8-8.5 and high content of Na^+ (0.5-0.6meq/lit). The forest species planted in that area had low growth and survival. The soil was compacted and waterlogged. Hydraulic conductivity and air porosity were lower than in the other soil types of the spoil. Soil cover by natural vegetation was less than

50%. Dominant species of this unit were *Tussilago farfara, Bromus tectorum*, and *Artemisia vulgaris*. Indicator value for this community had *Melilotus officinalis* of group A that usually appears in compacted, clay and salty soils as noted by Ellenberg *et al.* (1992) and *Tragopogon dubius* and *Reseda lutea* of group C.

Phytosociological unit E_3. Indicator plant groups (a)B: This unit appeared in areas affected from topsoil mixed with marl, lignite and fly ash. Soil was loamy with pH between 7 and 8. The forest species planted in the area had good growth and survival. Dominant species of this unit were *Tussilago farfara, Centaurea solstitialis* and *Rumex crispus.* Indicator value for this plant community had the species *Cichorium endivia*, *Centaurea cf. depressa,* and *Carduus* sp.. This plant community was the intermediate stage between E_2 and E_4 and *Cichorium endivia* was increasing its presence by time. The main characteristic of this plant community was its relationship with group A species.

Phytosociological unit E_4. Indicator plant groups (a)Cd: The soil of the area where the community was developing had well mixed all of the spoil materials with higher content of fly ash and marl. Texture was sandy loamy and pH was varying between 7 and 8. Dominant species of this unit were *Tussilago farfara, Bromus tectorum* and *Carduus thoermeri,* but indicator value had the species *Cichorium endivia, Tragopogon dubius* and *Crepis foetida*.

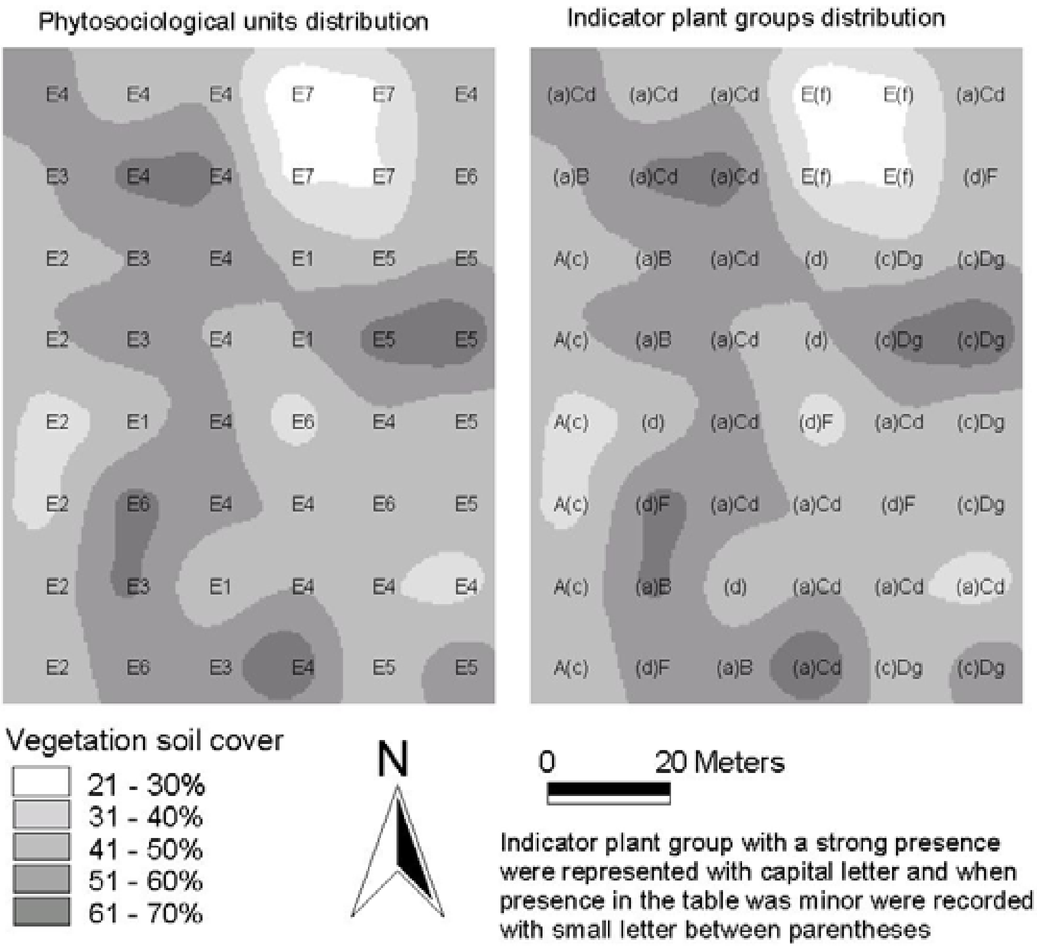
Phytosociological unit E_5. Indicator plant groups (c)Dg: This community was developing on soil that was a mixture of all spoils materials. Texture was loamy and pH was varying between 7 and 8. The forest species planted in that area had good growth and survival. Dominant species of this unit were *Tussilago farfara, Bromus tectorum* and *Lactuca serriola.*

Phytosociological unit E_6. Indicator plant group (d)F: This community appeared in soil similar to E_5 unit but in spots were fly ash content was high and, as consequence, pH was higher than 9. The forest species planted in that area had low growth but high survival. Seedling growth was low due to high competition from natural vegetation, but survival rate was high due to shadowing effect of almost total soil cover that kept low surface soil temperatures during summer. Dominant species of this plant community were *Bromus squarrosus* and *Bromus tectorum,* but indicator value had the species *Crepis foetida, Lappula squarrosa* and *Vaccaria pyramidata*. Ellenberg *et al.* (1992) cited that those species are indicator of calcareous, dry and infertile soils with pH 9.

Phytosociological unit E_7. Indicator plant group E(f): This unit appeared in areas of marl soil with loamy clay texture. Soil surface temperatures were lower than in the other sites of the spoil because soil colour was white. The forest species planted in that area had low growth but high survival. Dominant species of this community were *Tussilago farfara, Lappula squarrosa* and *Bromus tectorum.* Indicator value had the species *Calamagrostis epigejos* that is increasing its presence with time and *Vaccaria pyramidata*, which appears in spots around the area of *Calamagrostis epigejos*. Natural vegetation cover was less than 20%, but the forest species planted in that area had higher rate of survival for the reason that the lighter soil colour had moderate surface soil temperatures.

Geostatistics were used to quantify and visualise vegetation cover in areas that were not measured. Figure 2 illustrates the indicator plant groups and phytosociological units distribution in the experimental area and the vegetation soil cover after a Kriging (spherical) interpolation with lagged distance 10m and after taking in consideration all samples. Additionally, it was possible to examine the influence of phytosociological units and the indicator plant groups distribution on the soil cover. In the same figure it can be seen that plant groups E, F and A appear generally on areas with poor soil cover, while the plant groups B, C and D develop on areas with better soil cover.

Figure 2. Vegetation soil cover and phytosociological units distribution on the research spoil area



Indicator plant group with a strong presence were represented with capital letter and when presence in the table was minor were recorded with small letter between parentheses

3. 2 Soil physical properties

The physical properties of a soil govern its suitability for any further use of it. The bearing capacity, drainage, erodibility, moisture storage capacity, plasticity, ease of penetration by roots, aeration and availability of nutrients are related to the physical conditions of the soil. From the dataset of soil physical properties was analysed the distribution of data to get a better understanding of trends, directional influences and obvious errors. In most of the cases the data was not normally distributed presenting large spread and no symmetry. For hydraulic conductivity (Ks), and porosity that existed doubts about soil sampling and laboratory analyses it was decided to find the previous position of the samples in the field and repeat analysis of extreme values.

Kriging was chosen as the most appropriate technique because of the very low values of the mean cross-validation error of almost all production parameters studied and because kriging was offering the possibility of flexibility in assumptions required for the data to continue the study.

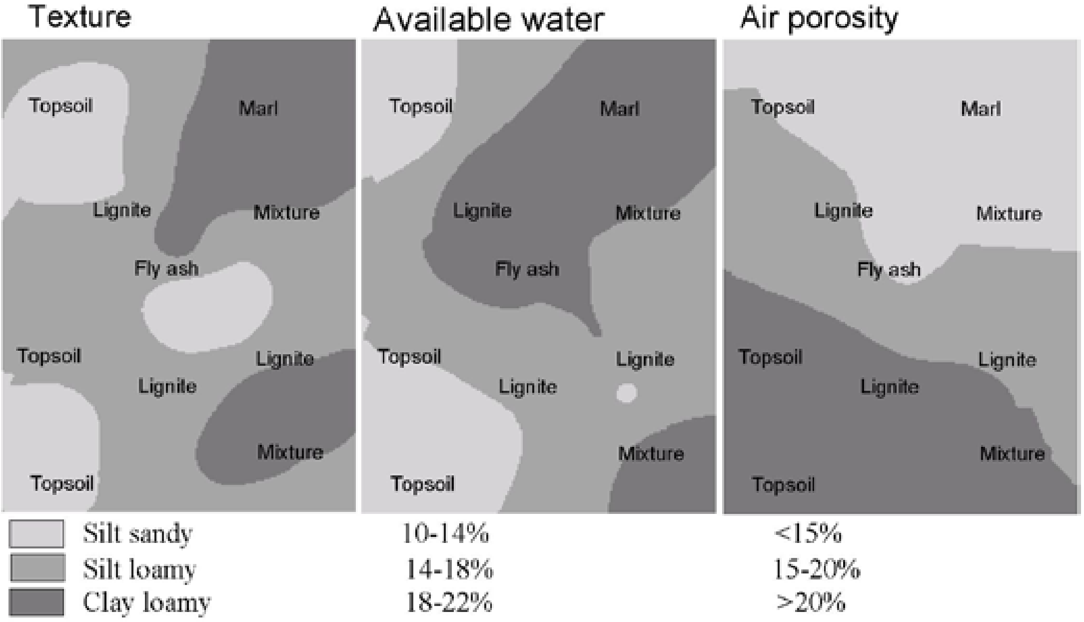
From the several parameters that the semi-variogram provided, the very high nugget effect indicated a big variance at short distance as it is mentioned also from Armstrong (1998). Lower nugget and sill and larger range were the semi-variogram indicators that helped to choose the most appropriate model of semi-variogram for the creation of the prediction map for soil properties.

Cross-validation was used to estimate which of the semi-variogram models could give the most accurate predictions of the unknown values of the field. The closer to 0 was the mean cross-validation error and the closer to 1 was the root-mean-square standardized error signified that the prediction values were closer to measured values (Wackernagel, 1995). When models presented similar values for mean cross-validation error and root-mean-square standardized error it was taken in consideration the lowest values of root-mean-square error and average standard error.

Exponential semivariograms were the most frequent for most factors studied. Particle size composition of the soils on the spoil heaps were varied primarily because of the composition of the soil mixtures on which soil forms. Generally, they were characterized as medium-textured silt sandy, silt loamy or clay loamy (figure 3).

Many authors have been studied the soil heterogeneity for forest and spoil soils (Schafer, 1979; Vauclin *et al.*, 1982; Grigal *et al.*, 1991; Boruvka & Kozák, 2001; Fitzjohn et al., 2002) with purpose to study the minimum area that can be treated uniformly during the vegetation establishment. Spatial heterogeneity, which is expected in such lands, has a pattern rather than being random, so surface sampling must be planned to accommodate this pattern (Eastment *et al.*, 1989). The USA standard soil sample distance is 69 meters, while Hardy *et al.* (1991) propose 140 meters as the most appropriate distance between samples. In the present study, ranges of variogram models were between 70 and 80 meters.

Figure 3. Distribution of spoil type materials assessed at the surface and some soil physical properties after kriging interpolation



Colour is the most obvious and easily determined soil property and usually is one of the first properties to be noted in a field description. Distribution of spoil type materials are assessed at the surface mainly from soil colour changes. Generally, the colour of the spoils in Ptolemaida was light grey to dark black, depending on water content, calcium carbonate, the percentage of unburned lignite and ash mixed with overburden and the presence of organic matter.

The significance of soil colour is its use as an indirect measure of other important soil characteristics and also in making many important inferences regarding soil genesis and land use (Kaleberta, 1978). In the spoils of Ptolemaida, dark coloured sites contain more lignite and some of them well accumulated humus; grey sites more fly ash and light grey sites a mixture of marls, sand, limestone and ash. Topsoil usually used in the lignite mines to mix with the other materials has generally red or brownish red colour.

Samples with high lignite content keep larger quantities of water available to plants. Topsoil had lower keeping water capacity because it had less organic matter and different texture and structure. In contrary, soil samples with more lignite had capillary water that was reaching 50.42%. However, the high amount of hygroscopic water decreased to 21.60% the available to the plants water.

Bulk density and particle density were measured to calculate total porosity and air porosity. Particle density was varying between 2.41 and 2.62 g cm^{-3}, depending on the presence or not of the organic matter. Bulk density was varying between 0.77 and 1.43 g cm^{-3}, depending on soil compaction, texture, structure and organic matter in soil.

Total porosity was higher than 45% in all samples, although air porosity of the heavy textured area was low with minimum value in high fly ash content area (8.9%). Physical properties should be improved with amelioration means before any other reclamation action in areas with air porosity lower than 20% (Papamichos, 1985). Clay and loamy soils are particularly susceptible to poor aeration when wet, because most of the pore space is water filled and the spaces or avenues for gas diffusion become discontinuous (Barth & Martin, 1984).

Because of the lignite, ashes and humus at the surface, the loamy textured spoils keep much of their water as hygroscopic and capillary water, and they have low gravitational water (between 40 and 60%). With increasing fineness of texture, there is a tendency for diffusion rates to decrease in relation to the increasing amount of water through which the gases must pass (Armson, 1977).

In saturated soil most of the pore space is filled with capillary or hygroscopic water so aeration may be insufficient, especially during long precipitation periods. Foth (1984) says that as the water content of the soil increases, the diffusion path of oxygen to the root surfaces increases in length, causing a decrease in available oxygen for root respiration.

The spoils of Ptolemaida are structureless and fine textured, containing large quantities of ash and lignite so, that problems of aeration may explain why some hydrophilic species (such as *Salix alba* and *Rubus tomentosus*) have invaded the spoils naturally. However, in dry years, soil moisture deficits during summer may be a more important determinant of tree survival and growth than short-term winter water logging as it is mentioned also in a study of Moffat & Roberts (1989).

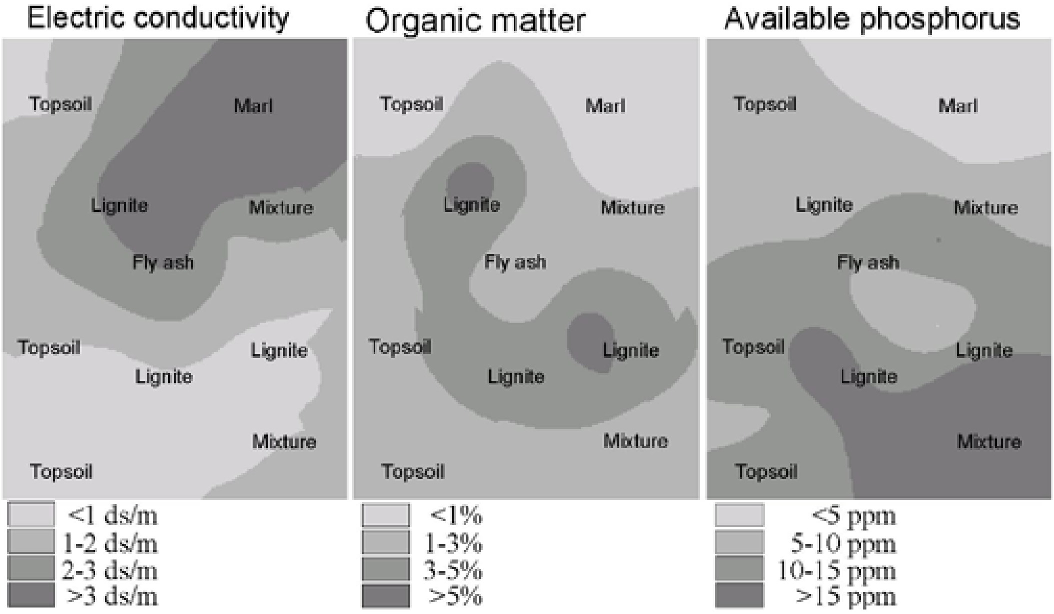
3. 3 Soil chemical properties

To estimate the soil chemical properties were measured pH, carbon, organic matter, $CaCO_3$, available nitrogen, available phosphorus, electric conductivity and the exchangeable cations of calcium, magnesium, potassium and sodium.

Usually the lignite mines are characterized by their low pH and the absence of calcium (Bussler, 1984). Although, in the lignite spoils of Ptolemaida, all soil samples had high pH, with an average of 8.08. $CaCO_3$ content was high in most samples, with higher values reaching 96.8%.

Soil electric conductivity was low in most of samples except on spots with high fly ash content and marl where it was found to have high electric conductivity (3.85 and 7.68 ds m^{-1} respectively). Soluble Na content was also very high on the same areas (9.95 and 15.65 cmolc kg^{-1}), indicating high salinity, resulting in poor plant growth. In the first map of figure 4 it can be seen the estimation map provided from geostatistical interpolation of electric conductivity. At that map was detected those high electric conductivity spots in the Northwest of the study area and it was suggested to use locally salt tolerant forest species and to wash the soil of the area for at least 2 consequent years.

Figure 4. Distribution of soil type materials as assessed from soil colour at the surface and some soil chemical properties after kriging interpolation



Carbon, organic matter and nitrogen were varying through the study area. Samples with high lignite content were rich in organic matter and nitrogen, while some topsoil samples were poor. Nitrogen is a limiting factor in tree growth. The average percentage of organically bound nitrogen in spoils was 0.18%, below the minimum satisfactory amount suggested by Papamichos (1985). The generally high percentage of organic matter was due to the presence of peat mould and unburned lignite in the spoils, which usually keep large amounts of carbon, but in a form not available to plants.

The amounts of organic matter and available nitrogen were directly related. The C:N ratio is an important factor influencing both the rate of decomposition and nutrient cycling, with low ratios favouring more rapid decomposition (Vimmerstedt *et al.*, 1989). C:N ratios were higher than 20:1 in all samples indicating slow decomposition and limited availability of nitrogen.

Available phosphorus varied between sites and was generally low (4.23-19.78ppm) in all samples. Most forest species need at least 15ppm to grow well (Papamichos, 1985). Areas with less than 15ppm phosphorus where located on the map that made from geostatistical interpolation of soil properties (figure 4) and compared with the map coming from bioindicator natural revegetation species (figure 2). It was found that species of phytosociological groups A and F appeared in areas with less available phosphorus. It was suggested to use sewage sludge as soil amendment of the areas that the above phytosociological groups were expanding. Fertilizer instead of sewage sludge as soil amendment was suggested to be avoided because those areas had low organic matter, clay loamy texture most physical properties needed improvement.

Exchangeable Ca was high on all sites, 32.71 cmolc kg^{-1} average indicating a possible deficiency in boron and potassium. Potassium in the spoils of Ptolemaida was low, 0.71 cmolc kg^{-1} average. Exchangeable Mg that must range from 20-33% of the exchangeable Ca (Papamichos, 1985) was less than 10% in the lignite spoils indicating Mg deficiency.

3. 4 Soil temperature and moisture

A very important parameter limiting tree growth and survival of forest species planted on the lignite spoils of Ptolemaida is the high surface soil temperature during the hot summer days. This is due to the black colour of lignite leftovers mixed with overburden on the surface and the luck of shadow provided by revegetation.

Soil temperature during the two years of experiment was varying between 35°C on the surface when the weather was cloudy and 62°C during hot days. The highest values of soil temperature were measured at 0.5cm depth on a black coloured bare soil. The air temperature in all four areas were the soil temperatures were measured showed no significant differences between areas at any time of the day.

The average soil temperature at 0.5cm depth, at all mentioned times were statistically significant different (by Duncan's multiple range test at $P<0.05$), with the higher differences during the hot midday hours. The average soil temperature at 3:00 p.m. in the black coloured soil was 55°C (table 1), while the red coloured soil had 47.05°C soil temperature and the white marl soil 42.94°C. Deely & Borden (1969) found that the average temperature difference observed between the darkest and lightest spoil materials was approximately 15°C.

Table 1. Average soil-temperature at surface of a lignite spoil heap at different times of the day

Colour - Time	11:00 a.m.	1:00 p.m.	3:00 p.m.	5:00 p.m.
Black (10YR 3/1)	40.41^{a}*	49.65^{a}	55.00^{a}	48.29^{a}
Light grey (10Y 7/1)	35.05^{b}	39.76^{c}	42.94^{c}	39.94^{c}
Brownish red (5R 4/7)	36.29^{b}	43.76^{b}	47.05^{b}	43.64^{b}
Black with vegetation cover	32.70^{c}	36.35^{d}	35.41^{d}	35.11^{d}

* Values in the same column followed by different letters are significantly different by Duncan's multiple range test ($P<0.05$)

In natural environments, soil temperature can reach 65-75°C while in mines soil temperatures could reach 80°C when the air temperature was 45°C as stated by Lenichan & Fletcher (1976). Salisbury and Ross (1985) found that most plants die when exposed at temperatures between 44 and 50°C, although exist some resistant species that can survive at high temperatures. Young seedlings are more sensitive to high temperatures, in which the tissue start to die when the soil surface temperature is more than 52°C (Helgerson, 1990). Pinus and red-fir seedlings cannot survive more than 5 minutes in soil temperatures more than 54-55°C (Levit, 1980).

The lowest soil surface temperature during summer was measured at a black lignite soil under the shadow of the natural vegetation. Specifically, surface soil temperature under shadow at 3:00 p.m. was 19.49°C lower than the temperature of the same area at bare soil. The influence of shadow on soil surface temperatures was also large during all day measurements and differences were varying between 12 and 13°C. Under the protection of a four year old Robinia forest stand the difference of the temperature between bare and covered soil was reaching 24°C.

Moulopoulos (1947) mentioned that the soil temperature difference between a bare and a covered grassland was approaching 30°C. Geiger (1973) stated that plants absorb 38-84% of the sun radiation and with their respiration they regulate the temperature in the layer close to the soil. This has as result the soil surface temperature in areas covered with herbaceous vegetation to be 30% lower than bare soil and 40% lower when the soil is covered with forest.

Lee (1978) noticed that forest coverage decreases the air temperature during the hot summer days in comparison with the bare interspace areas and is keeping the temperature higher for longer period after sunset. In the lignite mines of Ptolemaida the highest temperature under vegetation cover was noted at 1:00 p.m., while in bare soil the highest temperatures were measured at 3:00 p.m.

Soil temperature of bare soil fall rapidly at afternoon times while under vegetation cover there was noticed a gradual decrease confirming the previous author. Between red and grey coloured soil there were significant differences at all hours except at 11:00 a.m. (table 1). At 11cm depth, there were significant differences between the darker area and all others. At 11 and 17cm depth the soil temperature continued to increase in all soil colours till late in the afternoon.

At 2.5cm depth, at 11 a.m. and 1:00 p.m., there were not significant differences between the white, red and black-shaded soil. At 3:00 p.m. there were differences at soil temperatures among all areas with the highest temperatures in the black soil followed by the red, the white coloured and soil under shadow (figure 5). At 5:00 p.m. there were no significant difference between the lignite and the red topsoil, because lignite decreased its temperature faster even though was warmed during midday more than the topsoil.

In figure 6 it can be seen the graphical interpretation of the soil temperature after kriging interpolation at various depths during the hottest time of the day. From those prediction maps it was resulting that dominant spoil material at the surface was influencing soil temperature. However, seedling survival on the black coloured soil was high and natural vegetation cover was higher in areas where the dominant material was topsoil or a mixture of lignite with topsoil and lower at spots with marl, fly ash or lignite.

Figure 5. Average air and soil temperature of a lignite spoil heap, at 3:00 p.m., in 3 areas with different soil types (lignite, topsoil and marl)

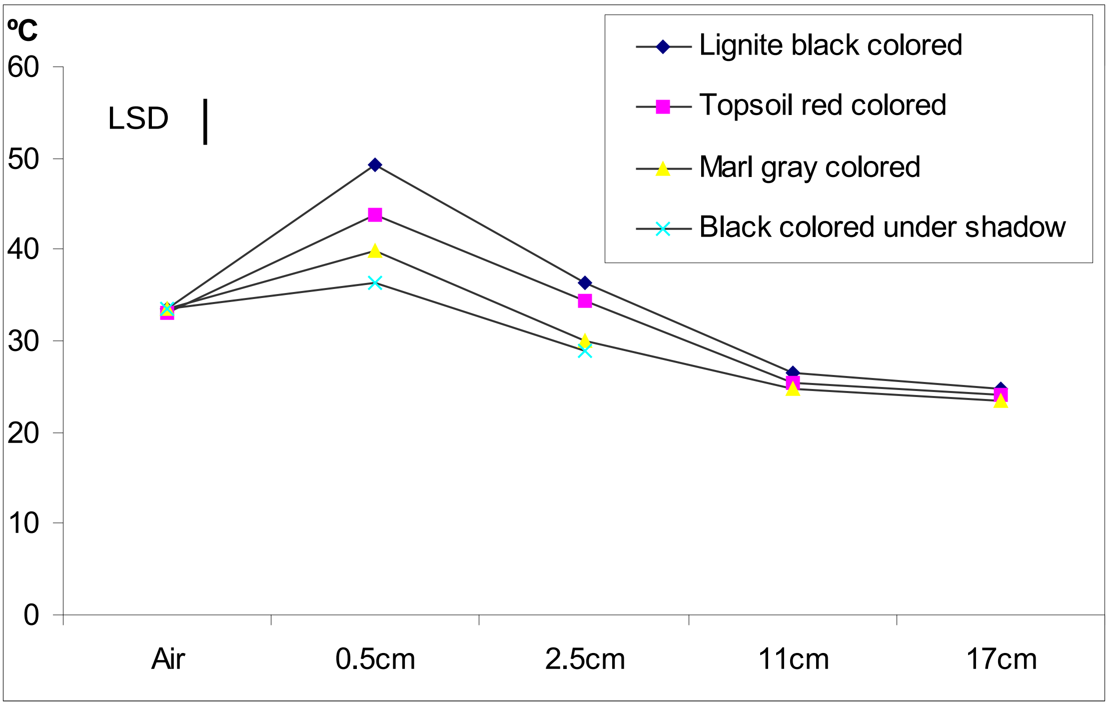
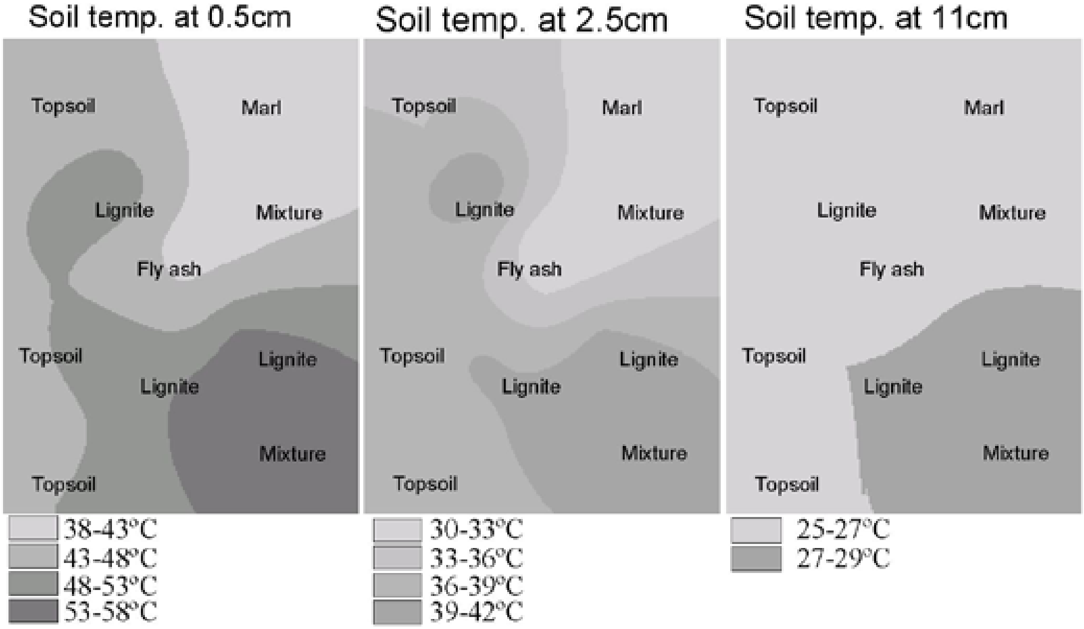


Figure 6. Distribution of soil type materials as assessed from soil colour at the surface and soil temperature after kriging interpolation



Surface soil temperature under shadow was 19.49°C lower than temperature at bare soil of the same area at the same time and type of spoil. Those 19.49°C difference was weighted depending on the percentage of vegetation cover and was subtracted from the prediction map of soil temperature at 0.5cm. The resulting prediction map was showing that highest temperatures occur on small spots with dominant materials lignite or fly ash. On those areas was suggested to take additional measures during afforestation to decrease heat damage and increase afforestation success.

Helgerson (1990) noted that when one or two year old seedlings are planted on a field already covered with vegetation heat damage is minimized. Richardson *et al.* (1987) mentioned that natural vegetation cover increases the success of forest species establishment. Thus, seedling survival will be minimum if their establishment were done on an early reclaimed bare spoil.

At the experimental area of Ptolemaida was suggested to start afforestation only when occur a relatively good soil cover with natural vegetation and never on black coloured bare spoil. Papamichos (1985) mentioned that 54°C is the temperature that the living plant tissues are dying and the best way to protect young seedlings from high soil temperatures was to plant them densely to be self shaded and to place light coloured materials at the base of the plants.

Soil moisture during summer at 30cm depth was 23% for the black coloured soil, 16% for the red and 17% for the white. Soil moisture was measured at a depth critical for the survival of tree seedlings and as the available to the plants water was lower than the hygroscopic water, was concluded that there was not available water for the plants during summer. These results depend mainly from soil physical properties and less from the soil ability to absorb or to reflect the sun radiation, for the reason that at 30cm depth, soil temperature was the same at all soil types.

4. CONCLUSIONS

The soil and natural vegetation of the lignite spoil heaps were spatially heterogeneous. The reclamation of environment at the lignite spoil heaps of Ptolemaida was composite and difficult due to adverse ecological conditions. Natural revegetation could be the first step before reclamation began.

Phytosociological research showed that drought resistant species of group A were limited in areas where clay topsoil was spread on the spoil. The average drought group B was decreasing as percentage of soil cover and soil fertility were decreasing. The groups C, G and D emerged in areas with high lignite content, with the first two to develop at infertile areas and the last in more fertile soils. Indicator group E appeared in a part of the spoil where marl was dominant at the surface and surface soil temperature was lower due to lighter soil colour. Group F appeared in small spots where fly ash was the dominant material (fly ash pH was higher than 9).

Soil properties were related to natural vegetation succession and both could be indicators in assessment of reclamation potentiality on the site. Geostatistics minimized the sampling cost with the estimation of a minimum sampling distance. Geostatistics proved to be useful tools for spoil soils where spatial distribution of soil properties and natural vegetation composition is determined more by human activity than by natural evolution.

Geostatistics helped to map with relative precision site quality. A geographic information system with the support of geostatistics could facilitate solutions locally on some specific soil quality problems. Soil amendments, irrigation, addition of light coloured materials on the surface or species selection could be decided for specific locations of the heterogeneous spoils. The construction of a geographic information system that links the information from prediction maps of soil properties and natural vegetation composition with database information of the reclamation species needs, could be a useful decision support tool on reclamation of surface mine areas.

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