Dam Reservoir Sediments as Fertilizers and Artificial Soils. Case Studies from Portugal and Brazil

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Abstract – The purpose of our work is resolving the global problem of scarcity/degradation of soils and some classical problems in the world dams, by turning them into a global resource. Through geological, geochemical and fertility study of bottom sediments from Portuguese and Brazilian reservoirs, we evaluated their suitability for agricultural use. The transformation mechanisms inherent to erosion, transport and accumulation in the bottom of reservoirs leads to a significant enrichment of nutrients, converting the sediments into a renewable natural resource prone to sustainable use.

I. Introduction

There is growing concern over the construction of dams, for environmental reasons. Thus dams break important ecological links and over-use of dam lake water for irrigation frequently produces damage in soils, because of precipitation of salts such as sulphates. The continents must be flushed, and dams inhibit this [1].

We are studying sediments that accumulate in dam reservoirs, from a point of view of their possible removal and use. Dam reservoir sediments are composed of contributions from two main sources, natural erosion products and agricultural over-erosion products. Their accumulation encompasses a number of problems, technical and environmental, including filling of the reservoir and rendering it useless, changing the properties of the reservoir water and precluding much needed access to the seashore of normal sedimentary products. Additionally, in agricultural regions, reservoir sediments include also a large part of the topsoil lost as a result of agriculture, generally a highly erosive process.

Our ultimate goal is to define the feasibility of extracting the dam reservoir sediments, using part (related to agricultural over-erosion) as fertilizers, or artificial soils, and feeding the remaining, coarser fraction (related to normal erosion) to the riverbed beyond the dam, where it can eventually reach the seashore.

The whole project consists of

(1) Selection of suitable reservoirs for study and possible remediation;
(2) Study of the nature, distribution and rates of deposition of reservoir sediments;
(3) Detailed physical, mineralogical and geochemical study of representative reservoir sediments;
(4) Fertility tests on sediment samples; and
(5) Economical study of the full-scale process of sediment extraction, transport and deposition at agricultural sites.

Up to now we have conducted studies in steps 1 to 4. We are preparing step 5 through identification of suitable partners with expertise in mud removal, bulk transportation and economics. A short description of each step follows.

II. Steps and Concepts

A. Selection of reservoirs

The project started in Portugal a few years ago [2] [3]. The first studied reservoir (Maranhão, Évora District, Portugal) was carefully selected among Portuguese reservoirs, using diverse criteria, which included

a) Location in an active agricultural area,
b) Drainage of a large, geologically diverse area in an agricultural region free from polluting industries,
c) Adequate size/depth for a preliminary study and
d) Sufficient age for an already large accumulation of sediments.

Our early results were extremely encouraging [2] [3]. We decided to expand the project and study other reservoirs. Initially these included the Monte Novo and Divor reservoirs of southern Portugal [4] selected in view of their advanced state of sediment infilling and relevance to the water supply of Évora, a major city in the interior of Portugal.

Following a marked decrease in agricultural development in vast regions of Portugal (partly as a consequence of European Union's Common Agricultural Policy) we decided to continue our studies elsewhere. Our first contacts were with Brazil, with immediate success. Thus we have already started studying two dam reservoirs in Brazil, Passo Real and Capingüi, located in the state of Rio Grande do Sul [5] [6]. There are marked differences between the Portuguese and Brazilian reservoirs, derived from marked differences in the nature of drainage areas and especially from the very contrasted weathering/erosion regimes (temperate versus sub-tropical).

Thus two additional reservoirs from northern and central Brazil will be studied in the near future, in the framework of an international research project under preparation. These reservoirs develop under distinct climatic conditions, respectively wet tropical and dry tropical, characterized by high leaching rates and salt movement from soils to the hydric systems inward. Considering the strong relation between precipitation/temperature and the weathering rate of soils and rocks, this study aims at comparing the properties of sediments accumulated in reservoirs under various climatic conditions and determining the effect of weathering reactions on the fertility index of sediments.

B. Sampling of Sediments in Dam Reservoirs

We have mapped the distribution of sediments through the floors of the reservoirs from a regular sampling net, relating this distribution not only to distance to the dam wall, but also to the position and importance of the various water streams that feed the reservoir [6]. In all the reservoirs, sediments were collected with a Shipeck dredge and a modified Van Veen dredge. In Portugal the collection was made on the most representative periods in the annual cycle (February and September); and in Brazil in February only. Furthermore, we have tried to relate sedimented products to their source materials, through mutual comparison.

Sedimentation rate studies were limited (because of equipment limitations) to comparison of winter/summer dredges but will include piston core sampling and yearly deposition rate studies.

C. Mineralogical and Geochemical Studies

Sediments were subjected to most studies routinely used for the evaluation of soil fertility [6]: grain size, organic matter, pH(H_2O), N Kjeldahl (total nitrogen except the most soluble form, nitrates) available macronutrients (P, K), available micronutrients (Fe, Mn, Cu, Zn, B, Mo), cation exchange capacity (CEC) and exchangeable cations. To have a more complete knowledge regarding the sediments capacity for nutrients retention, we have also studied total elemental geochemistry (major and minor elements), clay minerals identification, characterization and semi-quantification and detailed analysis of granulometric distribution (silt-clay and sand fraction).

To test the fertility level of sediments, each parameter was compared with:

1. Corresponding medium interval as defined for various pattern soils;
2. Chemical and mineralogical composition of parent rocks / soils that develop on them by weathering.

D. Fertility Tests

Simultaneously, reservoir sediments were tested as artificial soils and as additives to soils, via mixtures with various proportions of inert materials. All experiments were conducted with appropriate reference samples and plants tested were selected on the basis of economic interest and biological suitability as indicators of substrate adequacy. In a first step we have conducted fertility test with tulips with a few representative sediments from Maranhão reservoir and with one sample of commercial high quality potting soil used as a reference [2] [3]. Results were evaluated by an empirical and dimensionless "Success Index", which relates all measurable growth parameters. This preliminary study confirmed the good quality of Maranhão sediments for agricultural use, as they compared perfectly well with top quality commercial potting soil.

In a subsequent step fertility experiments were conducted with pepper plants in a controlled greenhouse. In these tests, to have a comparative growth rate, we have used (1) a mixture of sediments from Monte Novo reservoir (representative sample of Portuguese reservoirs); (2) a common soil from southern Portugal (Luvisoil, FAO, 1988) and (3) a chemically inert matrix (for better physical support), under six different conditions: 1 – 100% soil, 2 – 75% soil + 25% sediment, 3 – 50% soil + 50% sediment, 4 – 90% soil + 10% sediment, 5 – 25% sediment + 75% inert, 6 – 50% sediment + 50% inert. We have done weekly measurements of a few growth parameters: growth rate, flowering/ fructification period, flowering open, number/weight of fruits.

III. Factors that determine the sedimentation within the reservoirs

Concerning the properties of sediments, Portuguese and Brazilian reservoirs can be divided in two distinct groups, owing their diversity to basic factors that determine the sedimentation within these hydric systems: (1) climatic conditions that lead to different types and rates of weathering reactions and (2) varying rock compositions at the drainage basins.

i) Climatic conditions: Portuguese reservoirs are under a Mediterranean climate, with a dry hot summer and a rainy winter. From autumn to spring sedimentation rates are higher, as a consequence of the higher efficiency of rain erosion. However, the settlement of most fine-grained particles takes place in the summer, when hydrodynamic activity is less intense. The sub-tropical climate of Brazilian reservoirs is characterized by homogeneous rain distribution along the annual cycle. These conditions lead to a much higher intensity of rock and soil weathering followed by an extreme leaching of soluble elements.

ii) Basin drainage lithology: Besides the various rates of weathering reactions, the large diversity of rocks at the drainage basins enhance distinct nature of the accumulated sediments.

Portuguese reservoirs have a remarkable geological diversity, very important in relation to textural, geochemical and mineralogical studies of sediments. This diversity is higher in Maranhão, which has, as sources of the sediments, a Cenozoic sedimentary cover over Paleozoic and Precambrian formations of the Variscan Fold Belt [7]. This basement includes a large diversity of metasediments (shales, and pelitic schists, greywackes, quartzites, conglomerates, carbonate rocks), metavolcanic sequences ranging in composition from acid to basic rocks and an intrusive massif (granitic rocks with different geochemical features and mafic and ultramafic intrusive bodies) [8], [9], [10]. The Cenozoic sedimentary cover is mainly detrital [8], [11]. The geological setting of the other Portuguese systems (Monte Novo and Divor) is less diverse, composed mainly of schists with some basic and acid volcanics, intrusive acid rocks (tonalitic and granitic rocks) and scarce zones of Miocene cover (shales, conglomerates and carbonates rocks) [8], [9], [11].

In Brazilian reservoirs (Passo Real and Capingui) the parent rocks at the drainage area have a more homogeneous composition: tholeitic basalts associated with fewer zones of felsic volcanics and detrital cover [12], [13].

The diversity of these two basic factors that determine the sedimentation within the reservoirs, produce a distinct assemblage of weathered products, mainly composed by secondary minerals, especially clay minerals. These minerals, where mineral/organic nutrients are preferentially concentrated, are the major sources of sediments deposited in the bottom of reservoirs, as they are the more susceptible particles to weathering, due to its low density and fine texture [6]. During weathering, transport and deposition processes, there occur complex transformation mechanisms of both chemical and physical nature (ionic exchange, cationic fixation) [14]. These mechanisms are more pronounced in Brazilian systems, owing the higher water/rock ratio. As a consequence of distinct rates of mineral transformation, within each system and comparing the two groups of reservoirs, there is a high sedimentary diversity in relation to (1) texture, (2) mineralogy and (3) geochemistry.

Regarding (1) the great diversity of basic factors that determine the sedimentation within the reservoirs, (2) the mineralogical and chemical transformations subject to occur during erosion/transportation of particles from the weathering rock/soil profile to bottom reservoirs and (3) the selective erosion of soil particles that leads to a preponderance of colloidal minerals and organic compounds with high cationic exchange capacity, we can easily explain the evident chemical and mineralogical differences between sediments and the parent material (weathered rocks and soils developed on them).

IV. Physical, Chemical and Mineralogical Characterization of Bottom Sediments from Reservoirs

As a rule, in studied reservoirs the concentration of the most important chemical elements for the fertility of sediments, under total, soluble and exchangeable forms, far exceed the corresponding medium values (1) for soils in general and (2) for parent soils. This shows clearly the good quality of the bulk sediments for agricultural use. The increase of most available forms (soluble and exchangeable) of nutrients is enhanced by the particular textural and mineralogical properties of sediments.

A. Texture

Grain-size distribution clearly evidences the important influence of the drainage basin lithology. The sedimentary distribution in the bottom coincides with the major contribution of fine material; most sediments fall in the silty clay and clayey silt textural classes and are mainly deposited in the old watercourse bed along the reservoirs (large depths). Average grain size increases to the margins.

In Portuguese reservoirs the various textural classes reflect the large sedimentary diversity, owing to (1) large geological diversity of the drainage basins and (2) local and seasonal fluctuation of the hydraulic flow, which produces distinct energetic conditions inside the lakes.

Concerning the fertility of the sediments, the high contribution of fine-grained particles is extremely important as they are the more chemically reactive part of any hydric system; they enhance the accumulation of organic matter and have higher potential of interaction with the water column.

B. Clay Mineralogy

Sediments from the two groups of reservoirs have distinct characteristics in relation to the mineralogical composition of the clay fraction (Fig.1), due to the remarkable diversity of the basic factors that determine the deposition inward: (1) climatic conditions and (2) parent rocks composition. Both factors provide different water-rock ratios and therefore different mechanisms of cation leaching/evacuation with subsequent different mechanisms of mineral transformation.

In Portuguese reservoirs, the Mediterranean climate of Southern Portugal associated with (1) remarkable variation on lithology of drainage basins, (2) weak intensity of rock weathering, (3) various alteration states of weathering products and (4) mixture after transport and sedimentation mechanisms, concur to a large variety of clay minerals and complex clay assemblages. The mineralogical composition of sediments is quite similar in the three cases, with variation of relative abundances only, and includes [6]:

- Potassium illites, with a variable Na/K ratio, Al^{3+}, Fe^{3+} or Al^{3+}/Fe^{3+} in the octahedral sheet;

- Dioctahedral Ca smectites, montmorillonite/nontronite variety often associated with illite/smectite mixed-layered;
- Trioctahedral chlorites with various amounts of Fe and Mg;
- Medium to highly disordered kaolinites;
- Randomly interstratified or mixed layer structures (chlorite-smectite, illite-smectite, illite-chlorite).

In Brazilian reservoirs, the sub-tropical climate of Southern Brazil together with (1) high intensity of rock weathering, (2) leaching of soluble elements (Ca, Na, K, Mg) and preferential accumulation of stable elements (Si, Al, Fe) and (3) intense transformation processes during cycles of erosion-transport-accumulation in the bottom of the reservoirs produce simpler clay assemblages dominated by kaolinite and Fe/Al oxides and an uniform distribution of abundances and chemical/structural characteristics of minerals along the reservoirs.

Concerning the fertility of the sediments, the mineralogy of sediments from Portuguese reservoirs is markedly more advantageous; the large variety of minerals present, including expanding clay minerals, often randomly interstratified and medium-disordered crystallized, favour high cationic adsorption and exchange capacity and the use of nutrients by plants, through slow release of components from relatively loose crystal structures.

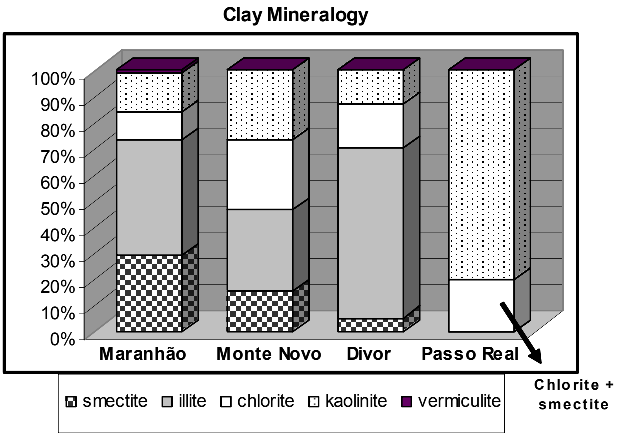

Fig. 1. Average mineralogical composition of the clay fraction of sediments from both groups of studied reservoirs.

C. Organic Matter and pH (H_2O)

In both groups of reservoirs organic compounds are concentrated in clay and silt fractions and the contents are usually within the medium interval for soils in general (2%-7%) [15]. In most reservoir sediments these levels are much higher than in the parent soils.

In Portuguese sediments pH values are neutral or near neutral (5.5-7.2), within the range considered most advantageous for the ready availability of most nutrients to plants [16]. The acid levels of Brazilian sediments (average pH: Passo Real – 5.2; Capingui – 4.2) may be a problem concerning its availability as agriculture soils or additives, because these conditions enhance (1) the release of high contents of exchangeable H+Al, which could be toxic to plants and (2) the solubility increase of some toxic elements such as heavy metals.

D. Geochemistry

The chemical composition of sediments is fundamental regarding their suitability for agricultural use and as for soils in general, it is important to have the knowledge of the nutrients and toxic element levels and the conditions that enhance their release and availability to plants. This study evidences that the nature and levels of chemical elements in the reservoir sediments are strongly related to [6]: (1) mineralogical composition of sources, (2) weathering processes during material transport to the reservoirs and (3) dynamic equilibrium between sediments and water. These factors constrain the grain-size and the nature/abundance/crystallinity of clay minerals of sediments, which are responsible for a propitious geochemical composition. The high levels were found in all the fractions considered, e.g. in the total "fraction" (a measure of existing reserve nutrients, provided that these elements are contained in minerals susceptible to weathering), in the exchangeable fraction (measure of the cations adsorbed on mineral and organic colloidal particles, easily available for plant nutrition) and in the soluble fraction (readily available for nutrition).

a) Nutrient elements

Concerning the most important elements in the evaluation of the suitability of sediments for agricultural use, major macronutrients (N, P, K) must be distinguished, not only because they are indispensable elements for plant nutrition, but also because in the sediments they are the elements in higher concentration with respect to medium values in mineral soils and in parent soils in drainage basins.

i) Nitrogen and potassium: In both groups of reservoirs, Kjeldahl nitrogen and available potassium have high levels (Fig. 2 A, B) and in clayey/silty sediments they are usually far higher than average values for mineral soils (dotted-line in the graphs), showing the suitability of the bulk sediments as potassium and nitrogen fertilizers. The close relation between these elements abundances and clay fraction explain (1) the high levels and uniform distribution along Brazilian reservoirs, where sediments are homogeneous and mainly clayey and (2) in the Portuguese group, the increase in the summer, when hydrodynamic conditions are lower and the settling of fine-grained particles preferentially takes place.

In Portuguese reservoirs major nitrogen sources are basically effluent discharge from top draining while in Brazilian systems the input of nitrogen in the hydrological cycle is mainly due to the excessive use of fertilizers in soils. The high linear correlation between organic matter and nitrogen levels ($r \approx 0.9$), and the Kjeldahl nitrogen always >95% with respect to ammonia+nitrate [6], denotes that organic nitrogen is largely dominant in the reservoirs. In spite of the immediate unavailability of the organic nitrogen, our sediments have advantageous characteristics (fine-grained texture, mineralogy dominated by expansive clays, high K levels) to enhance the mineralization and further availability of organic forms and the adsorption of ammonia on clay minerals and exchange complexes of humic molecules.

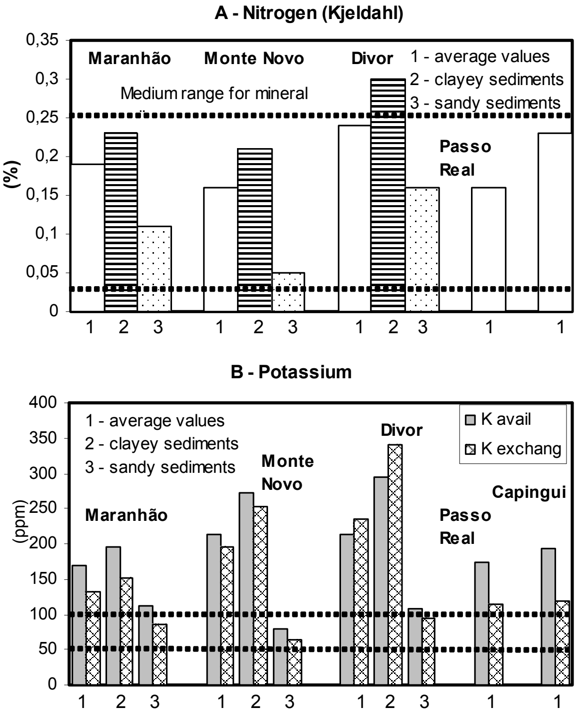

Fig. 2. Average nitrogen (A) and potassium soluble (B) levels of sediments from Portuguese and Brazilian reservoirs. Dashed-lines delimit medium range of total nitrogen for soils in general (after [15] and [16])

The availability of potassium for plant uptake has been studied through soluble (available) and exchangeable forms because due to the dynamic equilibrium between both, exchangeable potassium can be easily released by exchanging with other cations in solution or it can be directly absorbed by plants. In our sediments the evidence of this equilibrium is the high linear correlation between both forms (e.g. Maranhão: r=0.8, n=16). As for soils in general [15], the proportion of total K held in soluble and exchangeable forms is small, denoting that the majority of this element resides (1) in K-bearing feldspars and micas (reserve form) and (2) fixed in illitic clay minerals. The high/very high levels of available K in both groups of reservoirs denote the promptness of potassium forms transformation and its release for soluble phases (directly absorbed by plants).

ii) Phosphorus: Concerning this element, only sediments from Portuguese reservoirs are advantageous concerning their suitability for agricultural use. Available forms of P in clayey and silty sediments far exceed medium values for mineral soils (Fig. 3), enabling the use of fine-grained varieties as phosphorus fertilizers. These high levels can be explained by two main factors: (1) Fe-P and Al-P are the major phosphorus combinations in the bottom sediments and these fractions are the main sources of soluble P [17] and (2) sediments have chemical and mineralogical conditions appropriate to organic matter mineralization and solubility of adsorbed P on clay minerals/organic particles surfaces. The high levels of this nutrient are also very important to increase the availability of metallic micronutrients, because, according to Shuman [18], such high values enhance the release of micronutrients from exchange or interlayer positions to the soluble phase.

In Brazilian reservoirs, despite total P levels that compare well with values for Portuguese sediments, readily available P is much lower and it is low when compared with mineral soils. However, these values are higher than in the soils of their drainage basins. These low soluble contents are a consequence of the strong retention and immobilization of P by the prevailing mineralogy of sediments; the clay fraction is mainly composed of high levels of Fe/Al oxides and pH-dependent charge clay minerals (kaolinite), which are components positively charged and with an high surface area suitable for anions (orthophosphate) adsorption. Besides, the acid environment of sediments (pH 4-5) is not appropriate for P solubilization [17].

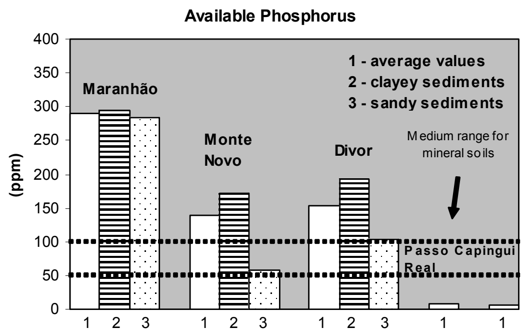

Fig. 3. Average phosphorus levels of reservoir sediments from Portugal and Brazil. Dotted-lines delimit the medium interval of available abundances for soils in general (after [15] and [16]).

iii) Metal Micronutrients (Fe, Cu, Zn, Mn): In each group of systems, sediments have similar distribution patterns of metal micronutrients. Total abundances are within the normal ranges despite being higher than in parent soils. These elements occur mainly coating or strongly adsorbed on the surface of functional groups of fine-grained particles (clay minerals, particles of Mn oxides and organic molecules); they can also be associated to Fe-Al-oxides through precipitation/ co-precipitation mechanisms. Mn is found as precipitated oxide [6]. Fe, Cu, Mn, Zn have high solubility, seldom exceeding the concentration considered toxic to the majority of soils. This results from the prevailing conditions on the bottom of the reservoirs (redox conditions and pH values from acid (Brazil) to near neutral (Portugal)), which enhance a decrease of cations retention on the exchange complex. Fe and Zn are higher in Brazilian reservoirs, due to the influence of basic volcanic rocks as major source of sedimentation. For concentration levels considered toxic, only Mn in the clayey sediments of Maranhão/Monte Novo and Fe in sediments of Brazilian reservoirs could represent a pollution problem. However, reduced forms of these elements are more soluble [19]. Therefore, if we use the sediments as agricultural soils or additives, under aerial conditions, metals will be more oxidized, decreasing their availability to plants.

b) Toxic elements (Pb, Ni, Cr, Cd, As, Hg, Ba)

Abundances of toxic elements (pollution and fitotoxic elements) are much lower than average values for mineral soils. Only Cr in some sandy sediments from two Portuguese systems (Maranhão and Monte Novo) is close to the upper limits of toxicity as proposed by the 86/278/CEE directive (Fig. 4). However, we noticed [6] that this element is into the crystal structure of a very resistant mineral to weathering mechanisms – chromite. This evidence and the decrease of metal absorption by plant owing the high availability of Ca and P in sediments, decrease the probability of toxicity and pollution promoted by this heavy metal [20].

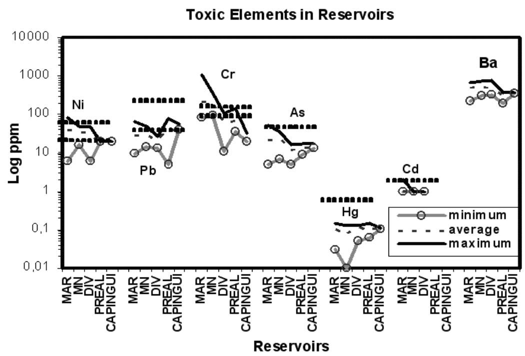

Fig. 4. Average, minimum and maximum concentration of toxic metals of sediments from the overall reservoirs. Dotted lines represent the range of toxic abundances (after 86/278/CEE directive).

Given the low levels of the toxic elements in both Portuguese and Brazillian reservoirs and the chemical and mineralogical characteristics of most sediments, which enhance strong fixation by adsorption, precipitation and co-precipitation, avoiding the passage to a soluble phase, we can safely conclude that the studied sediments will not generate any pollution problems after their aerial exposure for agricultural use. In spite the solubility increase of toxic elements under the new oxidation conditions, their release to soluble phases will not be an environmental problem because, besides having low contents, the more oxidised states of these elements are less toxic [20].

c) Cationic Exchange Capacity (CEC)

According to textural characteristics of sediments, cationic exchange capacity values are from medium (Brazilian reservoirs) to medium-high (Portuguese reservoirs), in relation to medium intervals fixed for different granulometric groups of soils [21]- Fig. 5.

Adsorption and cationic exchange phenomena depend mainly on clay size and organic particles, decreasing in proportion to increased particles size [6]. Given the relatively uniformity of both parameters in the two groups of reservoirs, the high levels in Portuguese sediments are probably related to pH values near neutral and higher contents of expanding clay minerals (pH- independent charge) –e.g. montmorillonic minerals, significant amounts of vermiculite and mixed layer structures.

In spite of similar values of CEC, both groups of reservoirs have evident differences concerning exchangeable cation levels: (1) in Portuguese reservoirs there is a clear preponderance of Ca^{2+} followed by Mg^{2+}. In this group all the systems have a relatively uniform exchangeable cation distribution, representing Ca more than 50% of total CEC; (2) unlike, in Brazilian reservoirs, the exchangeable acidity (H^{+}+Al^{3+}) prevails in the exchangeable complex of colloidal particles, denoting the low pH environment and the nature of major compounds with prevailing surface charge minerals (pH-dependent). These conditions can induce occasional problems on plant growth except if formation of complexes with organic molecules takes place [20].

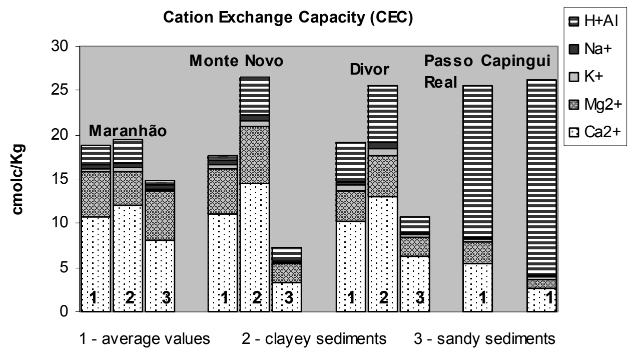

Fig. 5. Average values of cationic exchange capacity (CEC) and exchangeable cation distribution (within each bar). For each reservoir are represented average values for (1) bulk sediments, (2) clayey sediments and (3) sandy sediments. Dotted lines indicate medium values for soils in general (after [21]).

In view of (1) the importance of cationic adsorption/exchange capacity on the retention of nutrients, (2) the medium to high values of CEC as opposed to soils of drainage basins, (3) the high to very high exchangeable Mg contents in the overall sediments and (4) the large preponderance of Ca as exchangeable cation in Portuguese reservoirs, sediments of both groups of reservoirs have good conditions of fertility concerning the phenomena of retention and exchange of nutrients.

V. Fertility Experiments

The comparative study conducted with pepper plants using an appropriate reference sediment from one Portuguese reservoir (Monte Novo) shows that for all growth parameters (growth rate, flowering/fructification period, flowering open, number/weight of fruits, conditions 5 and 6 (mixture sediment + chemically inert)- see section II.D.) far exceed the results obtained by a common soil (Fig. 6). The best results, comparing with the other experimental conditions, which correspond to a mixture of various proportions of the reference sediment and the soil, are consequence of a better physical support that ensured an adequate aeration of the plants root system. In fact, in these samples, a better free drainage has been observed.

Fig. 6. Comparative growth rate of pepper plants in (1) a mixture of dam reservoir sediments (25%) + chemical inert (75%) (on the left) and (2) in a common soil from South Portugal (luvisoil, FAO, 1998), on the right.

Our fertility experiments confirm eloquently the high levels of nutrients, in soluble and exchangeable forms, of the Portuguese dam sediments. With respect to development /productivity of a nutrient-demanding species, pepper plant, sediments far exceed the results from a common soil. The lack of good drainage conditions of samples composed of a mixture of sediment and a clayey soil, due to the formation of impermeable layers, clearly show that bottom sediments from dam reservoirs with similar textural characteristics (high contribution of silt-clay particles) should be used as additive in a coarse-grained soil or on lands that ensure adequate free drainage.

VI. Conclusions

Considering the growing concern over the construction of dams for environmental reasons and the progressive degradation of soils as one of the major problems of our planet, we have studied sediments that accumulate in dam reservoirs, to test their feasibility for extraction and use as soils or additives in over-erosion regions. The selected reservoirs belong to two different groups (one from Southern Portugal including three systems and one from Southern Brazil including two systems) developed under distinct climatic conditions (temperate versus sub-tropical) with the purpose of determining the effect of weathering and leaching mechanisms on the fertility index of sediments.

In spite of marked differences between the Portuguese and Brazilian reservoirs, derived from marked differences in the nature of drainage areas and especially from the very contrasted weathering/erosion regimes, our results clearly show the good quality of sediments for agricultural use. For most variables, the overall sediments compare well or even exceed the corresponding values for soils in general.

The selective erosion of soil particles from drainage areas associated to (1) mineralogical and chemical transformations mechanism inherent to erosion, transport and deposition of eroded particles, (2) enrichment in organic compounds and (3) discharge of water from surrounding watersheds (agricultural runoff, sewage) rich in nutrients, leads to a significant increase of soluble and exchangeable forms of elements in sediments accumulated in reservoirs, in relation to corresponding levels of parent soils in drainage basins.

Sediments from Portuguese reservoirs have a higher fertility index, because their mineralogical composition, dominated by expanding clay minerals, often randomly interstratified, medium-disordered crystallized, facilitate the use of nutrients by plants, through slow release of components from relatively loose crystal structures. In sediments from Brazilian reservoirs, due to an acid environment (pH 4-5) and simpler clay mineralogy (preponderance of kaolinite associated with high levels of iron oxides) (1) phosphorus is strongly retained, giving low contents of soluble fraction and (2) exchangeable bases are scarce. Although nutrient levels are not as high as values found in Portugal, they are far higher than in soils collected in the drainage area.

This study shows that it worth evaluating the economic feasibility of removing reservoir sediments and using them for agricultural purposes in areas with scarce soils. Sandy sediments could eventually yield better results because they can be used as soils on their own, but the more clayey varieties, due to high nutrient abundances, can be used as fertilizers for poor quality soils.

We envisage several ways of removing and transporting bottom sediment from dam reservoirs, including dredging and slurry pumping and pipeline. The distance to which the sediment can be transported depends on the costs of the various processes involved. Contributions to meet these costs could come from several interested entities, including hydroelectric companies, local authorities and the farming units receiving the sediment. In the situations where transport is a severe limiting factor, the sediment could be used near the reservoir, with or without the help of greenhouses.

We could also evaluate the possibility of enabling the coarser fractions to travel beyond dams, to permit sediment transport and accumulation in coastal zones.

If the sediments removal becomes economically feasible, it may eventually resolve some classical problems in the world dams:

(1) The period of life of dam sediments filling with sediments;
(2) The water quality;
(3) The scarcity of soils in some regions;
(4) Sediment scarcity in coastal areas.

The process of removal and utilization of dam reservoir sediments can convert a problem into a global sustainable resource.

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