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Original Research

Afforestation Effect on Soil Quality of Sand Dunes

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Abstract

This study, undertaken in the Kapiköy sand dune area of the southern Mediterranean coast in Turkey, determined the changes in soil quality along with consequent economical revenue following 35 years of acacia, eucalyptus, and stone pine plantations on a 4,900 ha sand dune site. Significant soil phosphate (190 kg/ha) and organic matter (approx. 4%) accumulation were determined in the zones of vegetation when compared to bare sand dunes within 35 years. Moreover, the local people's incomes from timber and stone pine nut production are increased, denoting a socio-economical improvement in the quality of life. Thus, the project appraised was successful not only for its positive effects on environmental parameters but also on socio-economic aspects. Lessons learned at Kapiköy set significant guidelines for recovering degraded marginal lands in the semi-arid Mediterranean coastal zone of Anatolia. Consequently, the outcomes of this study are expected to increase public awareness of the success of the aforestation projects with evident economic viability.

Keywords: sand dunes, organic matter, phosphorous, soil quality, humic substances, land management

Introduction

The degradation of natural resources has compelled governments to launch reclamation projects at affected sites for securing their resource bases. Degradation processes occur more easily and commonly on brittle environments where water, soil, and vegetation cover, along with the topography of the land, are the limiting factors [1]. These processes are at a climax on aridic and semi-aridic sand dunes, since dunes have low resistance against erosion, over-grazing, and cultivation due to their low water-holding capacity, insufficient plant nutrients, and the weak aggregation of particles [2]. So, commonly occurring natural events, like winds, become natural disasters when sand dunes are exploited by human interventions. The reclamation of coastal sand dunes asks for long-term field experiments, as the resilience capacities of semi-arid sand dunes are significantly lower when compared to other geologic/geomorphic formations [3], which is the case for the loose textural, carbonate-rich sand dunes of the Kapiköy area. The coastal sand dunes away from population pressure generally host wide ranges of fauna and flora [4]. The lagoon on the northern margin of the Kapiköy sand dune stands for a unique example of Mediterranean coastal biodiversity. The Akyatan lagoon (S. Turkey) is of significant international importance as the habitat of valuable bird species, with 200 thousand individuals and 268 species sheltered in the delta for the winter season, along with its egg-laying sites of the rare species of sea turtles [5]. Sand dunes have also been reported to prevent salt winds from reaching inland areas [3], which most likely has been the cause of the decline in inland crop production in Kapiköy

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following the degradation of the natural vegetation that fixes the sand dunes. Dunes were also documented to act as probable filters against agro-chemicals that are extensively used at inland fields by preventing their transportation to the adjacent sea. Thus, utmost consideration was devoted by the local Forestry Department of Adana, Turkey, to the fixation of the sand dunes for sustaining both the terrestrial and the marine ecosystem in the Kapiköy region. However, difficulties were encountered during the field implementations and evaluation on soil quality development, due to the scarcity of the relevant data obtained from similar sites [6]. So our research attempted to outline the effect of acacia, eucalyptus, and stone pine plantations along with natural vegetation on sand dune soil quality, as well as the economical output following 35-year reclamation by employing analytical and economical analyses in Kapiköy.

Materials and Methods

Site Description

The Kapiköy sand dune forest is located 65 km south of Adana city, on the southern Mediterranean coast of Turkey at 36°38`51.32``-36°33`03.18``N and 35°08`10.45``-35°20`06.92``E (Fig. 1). The Mediterranean climate is dominant in Kapiköy, with annual precipitation of 700 mm along with 18.4°C mean annual temperature. The sand dune area lies 14 km from the west to the east and 1.5 to 2 km from the south to the north, covering an area of 4,900 ha (Fig. 1). The parabolic sand dunes of Kapiköy, with their 20 m high ridges represent the highest sand dunes of Turkey. The Ministry of Environment and Forestry launched the forestation project in 1972, and 2,056 ha land was planted with eucalyptus, acacia, and stone pine for the protection of the 10,000 ha agricultural land on the north of dunes. The stone pine and eucalyptus forests cover 632 ha land and the acacia forests cover 1,424 ha out of the 2,056 ha area. 2,840 ha land, at the lower parts of the sand dune ridges, was allocated for natural succession of local salt-tolerant plant species because some parts between the ridges of the dunes are below sea level, with a high saline water table that limited tree growth. Afterward the annual timber production of the Kapiköy forest reached 2,000 m^3 along with 150 tons of stone pine nut cone in 2008.

Soil Sampling Methods

The Kapiköy plantations were established in 1973, 1980, 1989, and 1999 with acacia (*Acacia cyanophylla* lindley), eucalyptus (*Eucalyptus camaldulensis*), and stone pine (*Pinus pinea*). Sites between ridges were left for natural plants due to the high saline water table. The mode of soil sampling was determined in connection with tree growth, namely by observing the stone pine-acacia relationship, yielding larger tree stands in stone pines with close proximity to the acacia trees. Stone pines close to acacia trees were observed to develop larger tree stands (biomass) than single ones. Thus, soil samples were collected on the borders in between the acacia and stone pines. The leguminous acacia trees most probably supplied nitrogen to the stone pine and eucalyptus stands [7], whereas the stone pine rhizosphere supplied phosphorous to the acacia via mycorrhizal hyphea [8]. The rapid growth rate led the Forestry Directorate to embed acacia strips between stone pine plantations. However, due to the shorter life span of acacia than stone pine, after a 10-12 years growth period, acacia trees were cut down and cleared, followed by the subsequent plantation of new acacia saplings. Soil sampling was based on the stone pine-acacia canopy of 1973, 1980, 1989, and 1990 sites, and bare sand dunes as control. Surface soils with 5 parallels at each site were collected

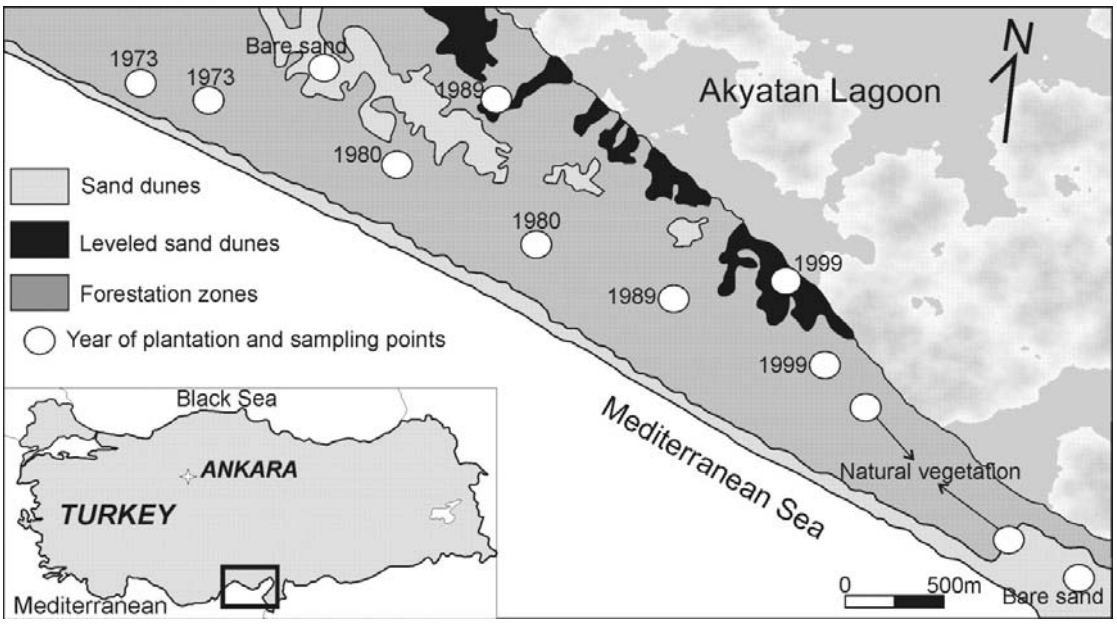

Fig. 1. Location of Kapiköy and sampling points.

Table 1. The litter accumulation at acacia, stone pine, eucalyptus, and acacia-stone pine stands (g/m^2) of the 1973, 1980, 1989, and 1999 plots sampled in 2000, 2004, and 2008.

Year of sampling	Acacia				Stone-pine				Eucalyptus				Acacia+stone pine			
	'73	'80	'89	'99	'73	'80	'89	'99	'73	'80	'89	'99	'73	'80	'89	'99
2000	928	888	1,056	1,060	1,312	1,392	1,312	1,256	768	776	756	708	1,888	1,924	1,912	1,792
2004	940	848	1,028	1,032	1,336	1,368	1,348	1,260	788	784	732	704	1,892	1,920	1,908	1,804
2008	932	856	1,084	1,008	1,340	1,344	1,316	1,268	780	780	756	688	1,872	1,908	1,924	1,796

from regularly-spaced plots for analyses. At each plot, a surface sample was collected according to the horizon designations of United States Department of Agriculture Soil Taxonomy [9] to a maximum depth of 50 cm, since only one soil series with a single surface horizon (Ah) was determined in the site (Typic xeropsamment, Soil Survey Staff, 2006) due to the uniform sandy parent material. All soils have a pale yellow (2.5Y 7/4) profile color with darker surface color of 2.5Y 6/4 [10] (Fig. 2).

Soil Physical, Chemical, and Mineralogical Analyses

Soil samples were collected in 2000, 2004, and 2008 for comparison of soil quality parameters from the stands of 1973, 1980, 1989, and 1999, plus natural vegetation and sand dune, along with organic debris for determination of litter accumulation. Soils were air dried and sieved through 2 mm mesh for chemical and mineralogical analyses, namely for pH, electrical conductivity (EC, dS/m), $CaCO_3$ (%), cation exchange capacity (CEC, cmol kg^{-1}), phosphorous fractions, and organic matter (%) by wet digestion and dry combustion [11], humic substances and texture (%). Analyses were undertaken according to procedures outlined in the Methods of Soil Analysis Part 3 [11] and Part 5 [12]. Micromorphological observations of humic substances were performed with a Philips XLS-30 scanning electron microscope (SEM) equipped with a DX-4 EDAX system.

Results and Discussion

Soil Physical, Chemical Properties

The major approach of the study, as mentioned above, was to determine the physical, chemical, and mineralogical changes of the plantation plots of 1973, 1980, 1989, and 1999, and monitoring the differences of the soils and litter of the three 4-year interval sampling periods (2000, 2004, and 2008) over the plantation plots. The bare sand dunes were considered as reference for determining the changes since the initiation of the project. The acacia-stone pine stands had higher organic litter accumulation rates followed by the stone pine stands compared to the other single stands, where the eucalyptus stands were the lowest (Table 1). Low organic litter accumulation is a common phenomenon for eucalyptus plantations with sparse under-story growth [13] compared to the acacia-stone pine plantation with a dense under cover. This phenomenon led to a change of plantation management at the site, considered by the

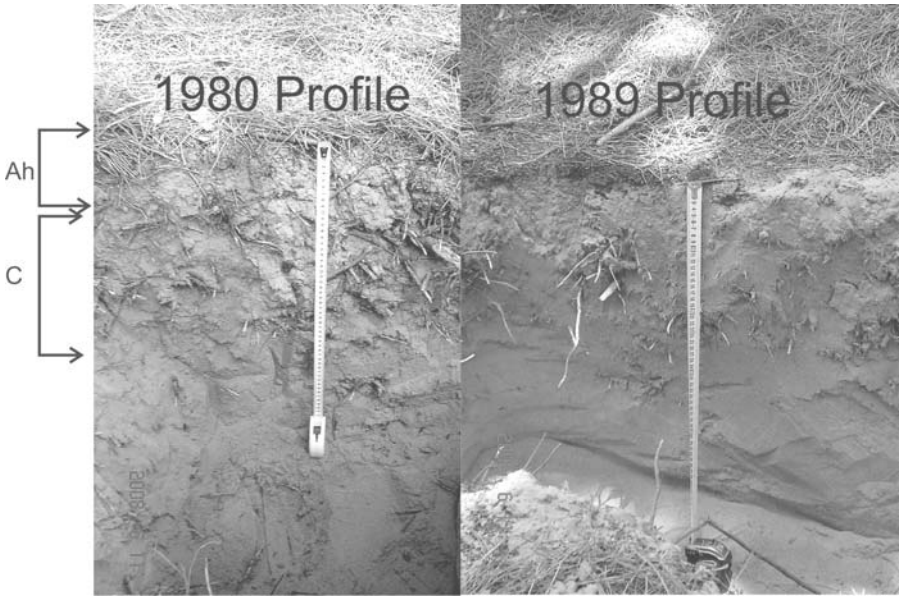

Fig. 2. Kapiköy soil profiles.

Table 2. The average chemical and physical properties of the Kapiköy soils.

	Horizon	Depth (cm)	pH	EC (dS/m)	$CaCO_3$ (%)	CEC (cmol kg^{-1})	Sand	Silt	Clay
1973	Ah	0-6	7.73	0.20	21.14	14.96	92.2	3.1	4.7
	C	6+	8.52	0.80	24.20	2.92	94.6	2.8	2.6
1980	Ah	0-5	7.62	0.23	14.12	18.11	93.6	2.9	3.5
	C	5+	8.12	0.65	23.81	2.29	95.2	3.0	1.8
1989	Ah	0-7	7.54	0.30	21.84	9.87	93.2	2.7	4.1
	C	7+	8.11	0.58	24.55	2.55	95.3	2.6	2.1
1999	Ah	0-6	7.52	0.21	20.95	14.1	92.4	3.1	4.5
	C	6+	7.98	0.65	21.80	2.61	94.8	2.7	2.5
NV	Surface	0-5	7.68	0.30	22.42	12.24	93.7	3.2	3.1
SD	Surface	0-5	7.72	0.42	23.65	2.82	95.1	2.5	2.4

NV – Natural vegetation, SD – Sand dune.

Table 3. The phosphorous fractions of the Kapiköy soils (µg/g) at 1973, 1980, 1989, and 1999 stands sampled in 2000, 2004, and 2008.

	Available P			Organic P			Inorganic P			Total P (organic+inorganic)		
	2000	2004	2008	2000	2004	2008	2000	2004	2008	2000	2004	2008
1973	18.0	18.2	18.1	53.3	53.7	52.8	283.2	284	283.7	336.5	337.7	336.5
1980	21.0	21.2	21.1	66.4	67.2	65.8	280.8	284.3	284.9	347.2	351.5	350.7
1989	18.8	19.2	19.0	49.9	49.7	49.3	289.3	289.1	289.2	339.2	338.8	338.5
1999	11.2	11.8	10.9	32.0	33.1	32.0	267.1	266.3	265.8	299.1	299.4	297.8
NV	27.5	28.1	27.3	42.9	42.8	42.7	314.1	317.3	316.5	357.0	360.1	359.2
SD	3.0	2.8	3.0	6.6	6.2	5.9	272	274.3	273.1	278.6	280.5	279.0

NV – Natural vegetation, SD – Sand dune.

Forestry Department of Adana, by establishing acacia-stone pine stands on the dune ridges, which were also expected to increase annual nut production. The current plantation is managed as strip plantation of acacia and stone pine on the dune ridges, which also increase annual nut production. The average pH, EC (dS/m), and $CaCO_3$ (%) values of the Ah horizons of the stands of 1973, 1980, 1989, and 1999 plantations, even though not at great variances, generally increased with depth (C-horizon), whereas the CEC decreased with depth at all stands (Table 2). This may be attributed to the relatively high organic matter and clay contents of the surface horizon [2]. The slight increase of clay at the surface implies an aeolian dust contribution from the Sahara [14]. Significant changes or fluctuations were not observed at the forestation plots as well as the natural vegetation sites among the 2000, 2004, and 2008 samples (Table 2). However, differences were determined for the bare sand dune (Table 2), which most probably reflect the occurrence of some stabilization in soil properties following the 35-year conservation when compared to bare sand dunes.

Soil Organic Matter

The amount of organic litter, composed of leaves, stems, twigs, seeds, and barks accumulated under the acacia-stone pine canopy, varied plot to plot, and a close relationship was determined between the amount of the organic litter and soil organic matter (Tables 1 and 3) at all stands. The soil organic matter analyses of 1973, 1980, 1989, and 1997 stands were undertaken by employing two methods, namely wet digestion (WD) [10] and the weight loss on ignition (LOI) at 400ºC for 8 hours as stated by Ben-Dor and Banin [15]. Ben-Dor and Banin [15] reported intermediate results, with 80-90% of LOI (loss on ignition) at 400ºC occurring within the first 8 hours in semi-arid Israeli soils, which is similar to the climate of Kapiköy. This temperature also prevented the loss of minerals or structural water from clay, which affects the LOI-soil organic carbon measurement [16]. We also suggest that the presence of 2-3% olivine and feldspar minerals in Kapiköy sand dunes [7], which are easily dissolved in sulfuric acid during wet digestion, may yield higher organic matter values than the

actual in the spectrophotometer measurements. However, in contrast to this phenomenon, LOI at 400ºC yielded higher values than the wet digestion for all samples (Fig. 3), this shows the insufficiency of the wet digestion methodology at high organic matter contents, which was also stated earlier by Abella and Zimmer [16]. The highest average organic matter was determined at the surface horizon of the 1980 plot, with 6.62% (WD) and 8.61 (LOI) (Fig. 3), whereas the lowest value was determined at the bare sand dune followed by the 1989 plot with 2.33 % (WD) and 3.39 (LOI) (Fig. 3). The CEC of the soil samples (Table 1) revealed that the organic matter determined by weight loss on ignition is more accurate in Kapiköy soils (Fig. 3) as the sum of the clay and organic matter's CEC is more likely close to the organic matter determined by LOI.

Phosphorous Fractions

The contents of total, organic and available phosphorous in surface horizons are higher than in C-horizons at 1973, 1980, 1989, and 1999 stands (Table 3). The highest inorganic P was found at natural vegetation (314.10 µg/g), whereas the lowest is determined at the 1997 plot (277.3 µg/g). The highest inorganic P of the C-horizon is determined at the 1989 plot (298.4 µg/g), but the 1999 plot has the lowest value of 254.29 µg/g. The lower value of the acacia-stone pine canopy relative to natural vegetation may be due to the use of P by the acacia trees. The total, inorganic, organic, and available P values from 2000 to 2008 do not show a significant change, but when compared to the sand dune, the available and organic P revealed up to 7-9 fold increases at plantation stands and at the natural vegetation site (Table 3). Additionally, the reported presence of mycorrhiza under pine canopy [8] may be the reason behind the increase of organic P fractions at the sampled sites.

Humic Substances

Humic substances (HS) are considered the main components of organic matter, and play a crucial role in many important reactions such as nutrient cycling throughout the environment, as well as modifying uptake, bioavailability, transport, and fixation of colloidal materials in soils [17]. The humic acid (HA) and fulvic acid (FA) fractions are among the HSs of soils and are the indicators of maturation (stabilization) of organic matter. Moreover, the FA/HA ratio

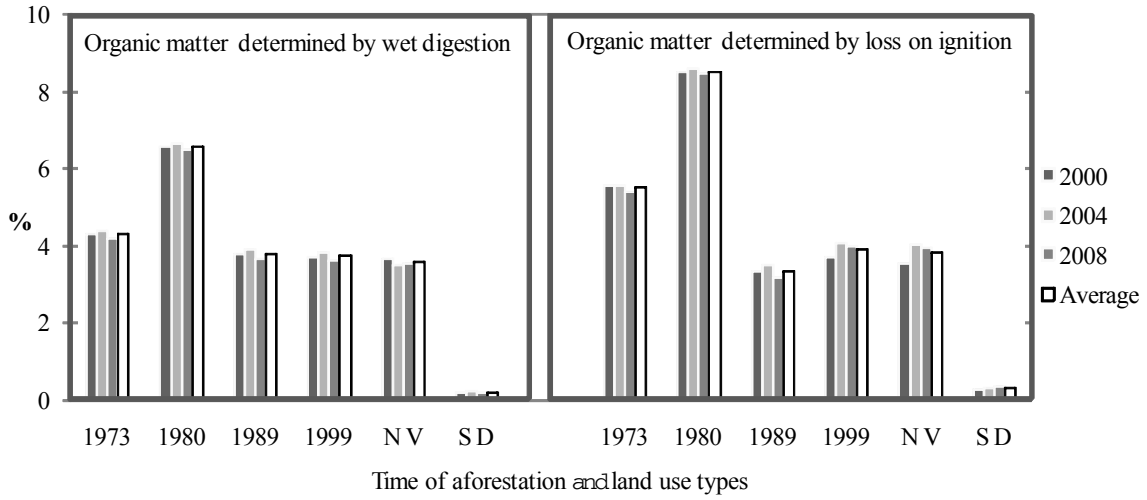

Fig. 3. Organic matter content of the Ah horizons (NV – Natural Vegetation, SD – Sand Dune).

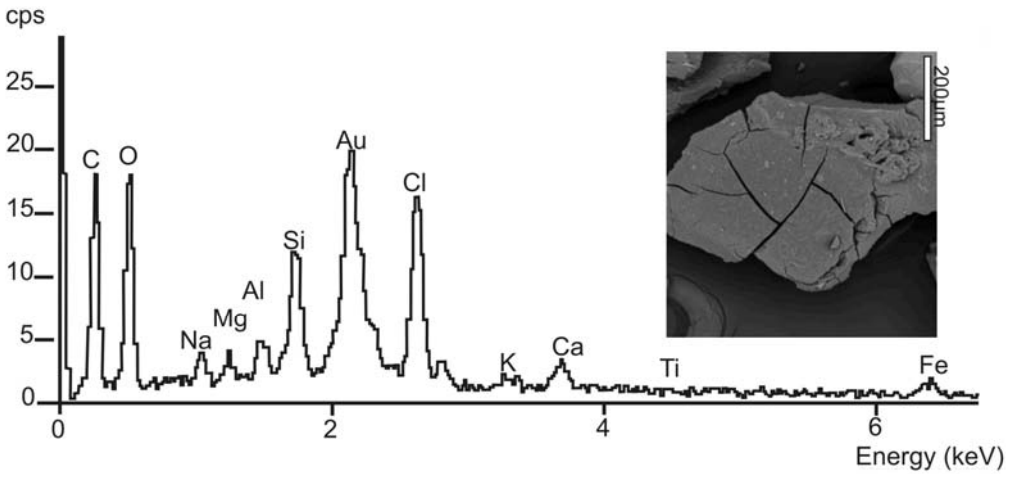

Fig. 4. Humic aggregate (SEM-microprobe) from 1980 plot.

Table 4. The averages of the humic substances of the Kapiköy soils for the 1973, 1980, 1989, and 1999 stands sampled in 2000, 2004, and 2008.

	Horizon	HS	HA	FA	OM	HS/OM	FA/HA
		% (w/w)				(%)	
1973	Ah	1.43	0.62	0.81	5.59	25.58	1.31
	C	0.2	0.06	0.14	0.95	21.05	2.33
1980	Ah	2.03	0.85	1.18	8.61	23.58	1.39
	C	0.21	0.08	0.13	1.44	14.58	1.63
1989	Ah	1.02	0.41	0.61	3.39	30.09	1.49
	C	0.15	0.04	0.11	1.06	14.15	2.75
1999	Ah	1.1	0.45	0.65	3.95	27.85	1.44
	C	0.21	0.07	0.14	1.06	19.81	2
NV	Surface	1.52	0.58	0.94	4.07	37.35	1.62
SD	Surface	0.05	0.03	0.02	0.35	14.29	0.67

NV – Natural vegetation, SD – Sand dune.

reveals the dominancy of soil wetting cycles. The ratio FA/HA is inversely related to the length of the dry season, where the wet conditions act in favor of FA and the dry conditions are favorable to HA [18]. The HA and FA of soils determined in the study revealed the relation of age and soil organic matter conversion rate to HS along with assessing soil wetting conditions.

The highest HS, i.e. the HA, FA, and OM, are determined at the surface horizons of the 1980 plantation, at all samples collected in the intervals of 2000, 2004, and 2008 (Table 4). The lowest HS, HA, FA, and OM, apart from the bare sand dune, were determined at the 1989 planting, which is the one before the youngest plot (1999) (Table 4). The C-horizons of all stands have lower HS, HA, and FA than the Ah horizons. The low HS/OM, and the higher FA/HA ratios (lower HA) of the C-horizons (Table 4) revealed the dominant wet conditions at the soil profiles, which most probably is/has been due to the tree root characteristics. The subsequent dry conditions most probably favor the stability of organic matter in the soil profile during the summer droughts. SEM and microprobe analyses manifested the high C and O contents of the humic aggregates with trace amounts of Ca (Ca-humates) [19] and Mg precipitations, along with their uniform surface morphology revealing the stability of the humic materials in the soils, as well as the dominant dry conditions (Fig. 4).

Economical Input of Conservation

Increases in organic matter and available phosphorous manifested the benefit of the project implementation on soil quality following the 35-year conservation. The economic contributions of these parameters were calculated for highlighting the success of the story for income generation at local terms along with its positive environmental input.

We started by considering the well known fact that the weight of 1 ha of sandy soil (bulk density of sandy soil is approx. 1.6 g/cm^3 with 40% porosity) for a depth of 5 cm would be 800 tons, where, accordingly, the Kapiköy soils containing 4% of OM (the average level of OM for all the

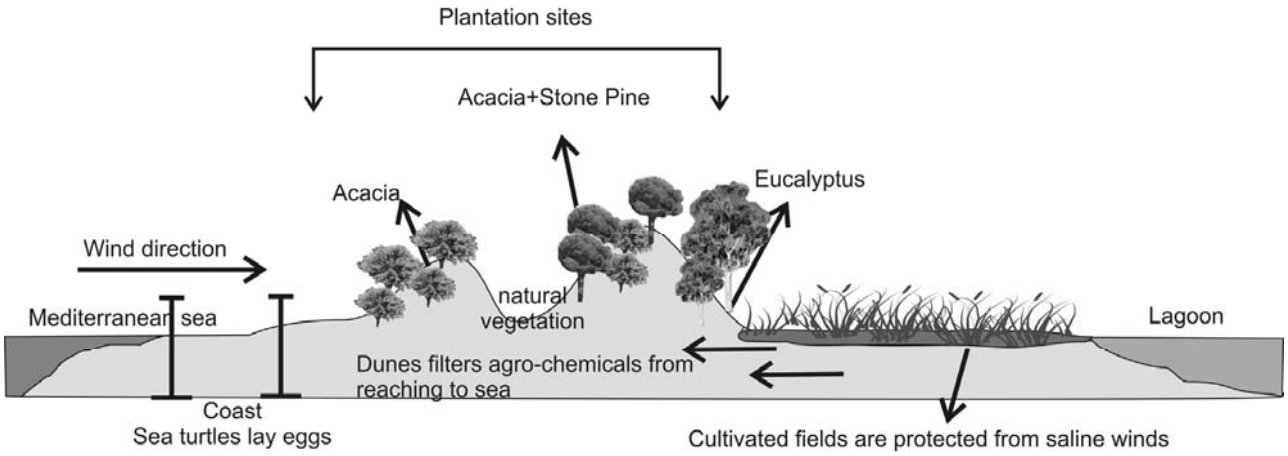

Fig. 5. Current management of the Kapiköy sand dunes.

plantation plots except the OM level of the 1980 plot from Fig. 3) would contain 32 tons/ha organic matter equivalent to 156,800 metric tons for the 4,900 ha forested land. For achieving 4% of organic matter in studied soil, 261,333 metric tons of annual manure with 60% organic matter supply is needed. A metric tons of animal manure is about 40 USD in the Kapiköy region, thus, a total of 10,453,333 USD is needed for increasing the soil organic matter to a level of 4%. Moreover, for increasing the P contents of the bare sand (30 kg/ha P) in the studied area, 1,580 tons of TSP (triple superphosphate, fertilizer with 45% P) is needed to reach 190 kg/ha (average available P level of the soils, Table 3). This asks for an annual budget of 1,422,000 USD (1 ton TSP is 900 USD). Thus the overall input of organic matter and available phosphorous from the vegetation cover in Kapiköy is 11,875,333 USD. However, the project budget in the 1970s was only 150,000 USD and the annual maintenance of the station is 200,000 USD, which indicates a profit besides its invaluable environmental inputs.

Management

The Kapiköy forest site at present, besides its contribution to environmental quality (providing hatching sites for sea turtles, increasing C-sequestration in soils, acting as a buffer zone between the sea and the agricultural lands by filtering agro-chemicals that are extensively used on the northern margins, and protecting the inland areas from the hazard of the saline sea breezes) (Fig. 5) is a sample site for agro-ecosystem management and parallel increase in job prospects created by the Forestry Department for stone pine nut production. Alongside the above-mentioned economic gains in the region, other economic activities such as agro-ecotourism that may include well managed hunting grounds to attract local and foreign tourists, may also be included in the present management program of the area. These activities will most probably enhance employment opportunities, leading to increased incomes for the locals. Moreover, the management program, which is already implemented, is also crucial for sustaining the marine ecology that is already under the threat of the fishermen of the region. And ultimately, local people are not apt to convert forests illegally to cultivated land due to the job opportunities created via income generating forest maintenance. We strongly believe that activities of this kind would also encourage the local people to protect and develop similar areas along the coastal environments of the country.

Conclusions

This millennium can be pronounced as the awareness of the public and government on such ecological issues as land degradation and desertification reached their upper limits, particularly at marginal lands (sloping lands, desert fringes, and sand dunes). And, fortunately, the common perception on these issues is that they are the last lands to be brought into production and the primary lands to be abandoned. However, following abandonment, the negative processes in marginal lands prevail and erosion, landslides, and moving sand dunes (the case in Kapiköy) degrade the bordering productive lands.

The findings of this study outlined the soil quality changes following aforestation in Kapiköy sand dunes in a 35-year time-span from 1973 to 1999. The acacia plantations as strips between stone pine stands revealed better growth due to the mutual procurement of nitrogen and phosphorous, which yielded more organic matter accumulation in the soil profile than single acacia, stone pine, and eucalyptus stands. However, the high amounts of organic matter at natural vegetation, particularly in between ridges (where the saline ground water table was high), proved to be a successful story for natural succession at sand dune management as trees are not resistant to high ECs. The forest soils seemed to have reached a stable stage with their accumulated organic matter and phosphorous levels by time and the development of more and stable humic substances. The increase of organic matter also acts as a carbon pool, which is crucial for mitigating current global warming.

Environmental projects are criticized for their high budgets and low revenues, particularly large-scale ones more allegedly in developing countries, where funding is limited. However, the annual 2,000,000 USD pine nut and timber production of the stone pine/acacia stands along with the organic matter and phosphorus enrichment with prevailing cost of 12,000,000 USD in Kapiköy, created a forest rich in both natural and economic resources.

Acknowledgements

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