The only elements required by plants that are deficient in seawater are nitrogen, phosphorous and iron

Gordon Sato · Samuel Negassi ·
Adel Zaggaf Tahiri

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Abstract It has been known for some time that mangroves grow in the intertidal areas of desert countries where fresh water flows into the sea, but this phenomenon has not been understood. In Eritrea we observed that mangroves grow where infrequent rains flow into the Red Sea. We theorized that the fresh water must bring elements needed for plant growth that are absent in seawater. We compared the composition of seawater to that of Zarrouk's algae medium. All the elements in algae medium are in sufficient quantity in seawater except for nitrogen, phosphorous and iron. If we supply these elements we can grow any plant that can grow in seawater. We have also begun planting plants that can grow in sea water in the Sahara desert with sea water irrigation and fertilization with nitrogen, phosphorus and iron. We believe this will be major step in reducing hunger and poverty in the world.

Keywords Mangrove · Seawater · Planting · Desert · Fertilization

Introduction

In 1994, shortly after Eritrea gained independence from Ethiopia, one of us (GS) was searching for a way to produce food in Eritrea. He noticed mangrove trees growing in about 15% of the intertidal areas and camels eating the leaves. He picked out a promising site, and planted five seedlings. They quickly died. Puzzled, he examined plots of naturally growing mangroves, and noticed that they only grew where the seasonal rains flowed into the intertidal area. He reasoned that the fresh water must be bringing elements necessary for plant growth that are deficient in sea water. Along with Samuel Negassi (Sato et al. 2005) he compared the composition of seawater with Zarrouk's algae medium (Zarrouk 1966) and found that all the elements of the medium are present in seawater at approximately the same concentration as in the medium except for nitrogen, phosphorus, and iron. This analysis had never been done before by people interested in plant growth in seawater. This finding enables us to grow plants in areas where plants have not grown before including tropical deserts with seawater irrigation.

Materials and methods

A hectare of mature mangrove trees drops about 10 tons of detritus per year, which is about 20% protein. It drops two tons of protein per hectare per year. This

G. Sato (✉) · S. Negassi · A. Z. Tahiri
The Manzanar Project, 27 Cedar St.,
Wenham, MA 01984, USA
e-mail: manzanarmangrove@hotmail.com

requires about 0.3 tons of nitrogen per year in fertilizer based on the estimate that protein is about 15% nitrogen. If a polyethylene bag is filled with 250 g of urea and 250 g of diammonium phosphate, and one surface of the bag is punctured with several 12.7 mm holes and buried about 8 inches below the surface in the inter tidal area, the fertilizer is all gone in 1 month. With one hole the fertilizer would last 1 year. With one 3.5 mm hole adopted the fertilizer would last 4 years. Each bag would release 62.5 g of urea and 62.5 g of diammonium phosphate per year. Each bag would release about 45 g of nitrogen per year. We plant trees 2 m apart so there are 2,500 trees per hectare and each tree has a bag of fertilizer embedded a few inches away. The bags release about 110 kg of nitrogen per hectare per year. With recovery of nitrogen from detritus this seems sufficient as judged by the good growth of trees. We plant trees by imbedding a can whose top and bottom have been removed in the soil, and held in place with iron wire poles. A seed is placed in the can and prevented from washing away by covering the can with a wire mesh. This arrangement prevents the trees from being uprooted by encircling seaweed. A picture is presented in the experimental section.

Results

Figure 1 shows an area where five mangrove seedlings were planted and quickly died. About two thousand seedlings were planted with a bag of fertilizer that furnished nitrogen and phosphorus, and a piece of iron was planted nearby. The seedlings all survived, and grew very well.

Figure 2 shows the same scene after 10 years of growth.

Figure 3 shows our planting of seeds in a tin can with top and bottom removed held in place with iron rods. The iron mesh was removed to take the picture. This method allows us to plant the seeds in the final location and removes the need for transplantation.

Figure 4 shows a large area of new planting of mangroves, by our methods, near the village of Hargigo in an area where mangroves had not previously grown.

Figure 5 the same area after several years of growth. We have planted over a million trees in similar regions of Hargigo.

Fig. 1 Shows an area where five seedlings without fertilization quickly died. This shows a planting of a few thousand seedlings with fertilization after a year of growth

Fig. 2 Shows the same scene after 10 years of growth

Fig. 3 Shows our method of planting seeds

Fig. 4 Shows an area where our method of planting was used

Figure 6 shows the planting of 2,000 *aviceneae germinans* mangrove plants in the Sahara desert in the vicinity of Tarfaya, Morocco. The trees were raised in a nursery in Mauritania, and brought by truck to Morocco. The trees were grown in the nursery for over 1 year before they were planted in the desert. The roots were highly developed in their

Fig. 6 Planting mangroves in the Sahara Desert, Morocco

long period in the nursery and the trees have grown quite well after transplantation. We also transplanted 200 *nitraria retusa* plants that were grown in a nursery in Mauritania. The *nitraria* is good foliage for animals, and it produces berries that are eaten by man. We also planted in the desert the grass *spartina maritima* that was brought from Portugal 500 years

Fig. 5 Same area as Fig. 4; 5 years later

Fig. 7 Gordon Sato and the Governor of the Tarfaya Region, Mohamed Ali Habouha

ago and was established in a shallow bay that is periodically flooded by fresh water which is its source of nitrogen, phosphorus and iron. We plan to make extensive plantings of this grass.

Figure 7 Gordon Sato and the Governor of the Tarfaya region, Mohamed Ali Habouha, who participated enthusiastically in the planting of sea water plants.

Discussion

The finding that seawater contains all the elements contained in algae medium at appropriate concentrations except for nitrogen, phosphorus, and iron has several consequences. First of all it allows us to grow mangroves where they have not grown before by providing these elements. Secondly, it explains the need for fresh water for the growth of mangroves in desert countries. It also suggests how much of the world's poverty could be eliminated in desert countries by fertilizing and planting mangroves and *Spartina* grass in the intertidal zones. For instance, virtually the whole coast of Mexico could be planted and the country considerably enriched by the increase in fishes and the feeding of livestock. Finally, by making it possible to irrigate the deserts with sea water and grow mangrove trees and *Spartina* grasses it makes feasible a gigantic step in combating hunger and poverty in the world. We are currently initiating such a project in Tarfaya, Morocco. Tarfaya, in the

Sahara desert, has consistent and strong winds which make it feasible to pump sea water with windmill pumps. It also has a semi-enclosed bay that contains naturally growing sea grass, *Spartina Maritima*, which was brought by the English from Portugal more than 500 years ago. This grass will serve as a reservoir from which we can produce desert meadows. We also plan to fertilize the sea bottom off shore from Tarfaya to encourage the growth of seaweed and increase the amount of fish. This has been done by the Japan Steel Corporation under the leadership of Dr. Naoto Tsutsumi and has resulted in the growth of seaweed and the increase in fishes. Carried out worldwide this can reduce much of the world's poverty and hunger.

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