Land Development Works and Soil Erosion in Okinawa Prefecture*

Teruo HIGASHI**, Tadao C. KATAYAMA** and Akio SHINAGAWA**

Abstract

Soil erosion accompanying development projects on sloping lands, damages due to soil erosion and counter-measures for soil erosion in the Okinawa Islands are discussed, based on the publication "Counter-measures for Soil Erosion" (Department of Agriculture, Forestry and Fishery, Okinawa Prefectural Office, 1979c) and personal communication with Mr. K. Oshiro, Chief of the Soil Conservation Laboratory, Okinawa Prefectural Experimental Station, together with information obtained from our field survey in July of 1980 and reference review concerning soil erosion on the Okinawa Islands.

Introduction

Since 1972, Soil erosion and the transport of eroded soils have occurred extensively on the hillside slopes in the northern part of Okinawa Island and on Ishigaki Island. Severe erosion of fertile surface soils in agricultural farm lands have been caused by hastily conceived agricultural and civil engineering improvement projects. The soils transported by erosion into the ocean has decreased the productivity of fisheries and damaged the coral reefs in the vicinity. The functions of forests, dams and rivers as water discharge divices in the environment have also been influenced by the soil erosion. In order to maintain a natural environemnt and simultaneously promote the development of various industries in the same area, some conservetion plans, including a municipal ordinance issued by Higashi-son (1979), have been envisaged and put into use. The extensive soil erosion due to hasty improvement projects on hillside slopes in Okinawa Island and Ishigaki Island might be expected to occur in other islands of rainy subtropical and tropical regions, espcially those in the developing countries.

---

* This study was a contribution to "The Water-Land Interactive Systems Project", United Nations University (July, 1980).

** 東　照雄，片山忠夫，品川昭夫，鹿児島大学農学部
Faculty of Agriculture, Kagoshima University, Kagoshima 890, Japan.

Environmental Factors in Soil Erosion and Transport of Eroded Soils

I. Natural factors

1) Soils

Soil erosion has occurred in Red and Yellow Soils (Yamada *et al.*, 1973) on the mountainous and hilly regions of Ishigaki Island and the northern part of Okinawa Island, although these soils are not easily eroded (Department of Agriculture, Forestry and Fishery, Okinawa Prefectural Office, 1979c). The following factors seem to be influential in the extensive soil erosion of this area.

2) Precipitation and its characteristics

The average precipitation in the Okinawa Islands is approximately 2400 mm per year. However, the precipitation varies from year to year. For example, rainfall equalled 3619 mm in 1967 and 1517 mm in 1968, as recorded at the Nago Meteorological Station in the northern part of Okinawa Island (Nago City Office, 1979). The heaviest rainfall occurs during the rainy season of June and July and in the typhoon season of September and October. For example, the maximum rainfall per day was 458 mm, per hour was 109 mm, and in ten minutes was 21.4 mm (recorded at the Nago Meteorological station on October 7, 1969). On Ishigaki Island, 123 mm per hour was recorded in July, 1978. Ōnaga has shown that heavy rainfall (more than 6 mm per ten minutes) occurs, on the average, 50 times a year, that is 3 to 8 times more when compared with the frequency in other prefectures in Japan (Nago City Office, 1979). The stronger the rainfall and the larger the rain drops ($\phi > 1$ mm) are, the easier the soils are eroded.

3) Forests

Most of the forests on Okinawa and Ishigaki Islands consist of a second growth of the broad-leaved trees common in subtropical regions. Due to the uncontrolled cutting of trees and a delayed forest conservation plan, denuded forests are frequently found in these areas (Department of Agriculture, Forestry and Fishery, Okinawa Prefectural Office, 1979c). Only 7 % of the total forested lands is protected, which is far lower than the average value in the rest of Japan (Department of Agriculture, Forestry and Fishery, Okinawa Prefectural Office, 1979b).

4) Rivers

The rivers in Okinawa and Ishigaki Islands have a small catchment area, short channel and steep gradient (Department of Agriculture, Forestry and Fishery, Okinawa Prefectural Office, 1979c). Accordingly, discharge varies considerably depending on the weather conditions, and that often leads to the flow of transported soils into the ocean.

II. Socio-economic factors

1) Subsidies

Government subsidies for the development of various industries in Okinawa

Prefecture has increased from 8 billion yen in 1972 to 39 billion yen in 1980 (Okinawa Development Agency, 1980). This subsidy is allocated only for agriculture and fisheries. If we include subsidies from other sources, the total would be substantially higher. With such substantial subsidies, the enlargement and reclamation of the agricultural lands and construction of roads, harbor facilities, and private and public housing have increased greatly since 1972. These hasty developmental works are responsible for the accelerated soil erosion.

2) Enlargement and reclamation of agricultural lands

The enlargement and reclamation of agricultural lands are generall accompanied with the construction of agricultural and forest roads and the intended construction of a reservoir for irrigation purposes. Farm land and agricultural roads are often made by cutting into hillside slopes, with no diking and slope protection with such as grass planting. This usually causes huge amounts of soil erosion, especially in the rainy season. Moreover, private works using a bulldozer without any disaster prevention or slope protection causes more severe soil erosion problems than the public development works. The enlarged and reclaimed agricultural lands are often used for pineapple cultivation. These fields were previously steep slopes. The erosion is accelerated when nainfall occurs before planting, which is usually in the forms of non-contour cropping. When re-planting pineapple, the surface soils are usually truncated by bulldozers, mixing the soil and old pineapple stocks. Although the truncation of surface soils is harmful from the viewpoint of soil erosion and soil fertility there are several reasons for this practice as flattening of folded farm lands, labor saving and prevention of injury attributed to continuous cropping.

3) Non-agricultural land use

There are several cases in which soil erosion is caused by non-agricultural land development. Construction of public roads, especially non-paved roads, construction of sight-seeing and tourist areas, construction of private and public houses, construction of public institutions or facilities, and quarrying and stone crushing are some examples of non-agricultural land developments.

Soil Erosion and Assesment of transported Soils

I. Soil erosion

Soil erosion is generally caused by the dispersion of fine soil particles both by rain drops and the transportation of dispersed soils with the surface run-off. The degree of soil erosion is enhanced when the precipitation is heavy and the rain drops are large, and the infiltration capacity of the soils is weak. Acceleration of soil erosion occurs when the soil is located on steep and long slopes with no covering vegetation. On the sloping lands of Okinawa and Ishigaki Islands, sheet, rill, and gully erosion occur.

II. Assesment of the transported soils caused by soil erosion

Although no assesment of the transported soil caused by soil erosion around the Nagura River and Bay of Ishigaki Island has been done, some comparable data is

available on the Yabu River, which is situated in the northern part of Okinawa Island. Red and Yellow Soils (Yamada *et al.*, 1973) around the Yabu River are similar to those around the Nagura River of Ishigaki Island.

As described above, heavy rain falls (more than 6 mm par ten minutes) take place in these areas. Ōnaga (Nago City Office, 1979) showed that soils containing 32 % water were eroded by precipitation of 2.5 to 3.5 mm per ten minutes on 7° grades. He also indicated, as the results of field experiments, that precipitation of 1 to 3 mm per ten minutes was enough to cause soil erosion. Soil erosion, of course, depends not only on the precipitation characteristics but also on the following items ; the underlying bed rock, the length and the angle of the slope, the presence or absence of plant cover, the types of crops, the planting pattern and cultivation years, etc. . For example, the respective soil series of Red and Yellow Soils are different in water contents, liquid limit and plastic limit, depending on their texture, parent materials and clay mineral composition. The N-value of the standard penetration test for Red and Yellow Soils derived from gravelly sands was 6 to 10, while from phyllite was from 11 to 30 suggesting that the latter was more unlikely to be subjected to erosion.

The calcuated amounts of soil transported by erosion in the catchment area of the Yabu River, where the soils are derived from Diluvial gravelly sand layers, showed that about 7,700 to 1,160 tons/Km^2/year were removed by sheet erosion, and 61,900 and 90, 000 tons/Km^2/year were removed by rill and gully erosion, being transported from the fields of annual and biennial pineapple cultivations, respectively. Kadomura and Yamamoto (1978) and Yamamoto (1976) reported that soils on artificial slopes in the northern part of Okinawa Island had been subjected to erosion due to both the enlargement works of farm lands and to the large scale transfiguration of natural features, since 1970. They calculated the amounts of transported soils by soil erosion in these areas to be 10,000 to 50,000 m^3/Km^2/year from bare lands and pineapple fields of one year cultivation, and as high as 1000 m^3/km^2/year from just one gully in the fields. In general, the amounts of eroded and transported soils do not exceed 50 m^2/Km^2/year even from a steep slope, in the hilly regions under natural forest. Therefore, it may be said that the enormous soil erosion in this area has been caused by the intense transfiguration of the natural lands owing to the absence of any conservation practice.

Tokuyama (1980) showed that the amounts of soil transported by rivers of the Okinawa Islands were, on the average, 700 to 1200 tons/Km^2/year, increasing as the ratio of bare land to catchmant area, the precipitation and the discharge become larger. The value obtained is approximately 10 to 100 times larger than the ordinary amounts caluculated from other rivers in Japan. If we use the standard equation generally used for the caluculating the amounts of soil transported by rivers, the calculated value in Okinawa Island is far lower than the measured value of Tokuyama (1980). This suggests that applying the standard equation for Japanese rivers is not valid in Okinawa Prefecture. The same suggestion can be made for the amounts of soil eroded by slope failure. The engineers in charge of various construction projects insist that another suitable equation should be applied in the Okinawa Islands, to determine the

amounts of transported and eroded soil carried by rivers.

Damages by Soil Erosion and Transportation of Eroded Soils

I. Decrease in the functions of the forests and rivers, and also that of constructed dams and roads.

A large number of projects, such as farm reclamation, forest development and road construction, have been carried out on the hillside slopes on Okinawa Island. Enormous amounts of soils have been eroded by the surface run-off flowing along the hillside slopes, causing hillside failures. Due to the soil erosion, especially gully erosion, forests have become denuded and have lost the ability to hold the soils, to maintain and work as the water source, sand prevention and wind break. Due to the transportation of soils into dams, water sources have become polluted. The functions of dams have also decreased because of the excess sedimests that flow to the reservoir shorten their designed utilization time. Furthermore, the functions of rivers, such as carrying run-off into ocean, supplying drinking and industrial water, and production of fresh-water fisheries, have been reduced. The functions of rivers in controlling discharge and in cleaning of the natural environments have also decreased. Rock and mud slides onto roads, resulting in blockage and other damages, interfere with vehicular traffic.

The following is an example of the damages by the construction of forest roads (Okinawa Prefectural Office, 1975). In 1968 and 1969, Omoto forest roads of 860 and 787 m long were constructed on Ishigaki Island. These construction works caused soil erosion, resulting in the pollution of drinking water in Kabira Village. Paddy fields extending both along the Nagura Bay (60 ha) and Kabira Bay (30 ha) were buried by the transported soils and the bays were subjected to the pollution. These damages were due to the lack of soil conservation practices during the construction works. Consequently, these works were held up due to complaints from the inhabitants of Kabira Village, voiced through a petition to the municipal authorities. The buried paddy fields were then bought by the minicipal authorities, or new fields were supplied to the farmers.

II. Damages to agriculture

The loss of fertile surface soils causes severe damage to agriculture. When the fertile surface soils have had organic manure applied to them for many years, and they have been eroded,a severe decrease in productivity of the cultivated lands occur. In Japan, reclamation and enlargement projects have been done as follows ; truncation of the surface soils, leveling of the underlying parts of soils, and re-covering with the previouly truncated surface soils. All these steps are carried out with no concern directed towards the unfavorable affects of raising infertile sub-soils to the surface on the farm lands. In Okinawa Prefecture, enlargement projects should proceed with strong consideration shown for the conservation of fertile surface soils.

There have been a decrease in the efficiency of agricultural works caused by soil erosion. Gully erosion which occurs on the land surface causes direct problems in mechanized works and also in weed control, application of fertilizers and mechanized application of pesticides. The extensive and continuous soil erosion and transportation of eroded soils in the river-side areas cause the abandonment of some agriculture due to burial of fields and agricultural facilities. Limitations in excuting new plans for land development in agriculture is often due to soil erosion. Soil erosion sometimes forces changes in new plans for the development of areas, due to the unfavorable conditions in agricultural environments.

III. Damages to fisheries

Okinawa Prefectural Fisheries Experimental Station (Department of Agriculture, Forestry and Fishery, Okinawa Prefectural Office, 1978 and 1979a) performed detailed investigation on the influence of red soils transported into the ocean on local fisheries in 1977-1980. The coastal areas of Yataka, Onna-son, Kushi coast of Nago City, Ishikawa coast of Ishikawa city, and Haneji coast of Nago city on Okinawa Island were investigated. The term "red soils" mentioned above is synonymous with fine sand, silt and clay (less thas 0.2 mm) of Red and Yellow Soils and Reddish Brown Soils. The results obtained were summarized as follows : Soils transported from land were mainly deposited on the deep marine bed where sea water movement was less than in the intertidal zone. In the intertidal zone, red soils were sometimes re-suspended in high density (more than 200 g per liter of water) because of the water movment caused by wind and wave. The degree of re-suspension and the amount of deposited red soils differed from area to area depending the characteristics of each area.

Most of the coral fish as *Balistes comspicilum, Siganus guttatus, Siganus fuscescens, Chrysipters assimilis, Chaetodon auriga, Prionurus microlipidotus* and *Parapriacanthus besyformus* avoided turbidity having a concentration of more than 50 mg per liter. At fishing grounds where turbidity occurred often, evasion by fish, a decrease of feeding activity, and a decrease in growth by damage to their respiratory function are to be expected. According to the results of a fisheries invetigation using nets, very few of the following fish were found in water with high turbidity : *Lethrinus choerorhynchus, Upeneus bensasi, Labridae, Chalotomus japonicus, Serranidae, Sepioteuthis lessoniana.*

It is difficult to remove the red soils which stick to the edible brown algae, *Nematocystis decipines*. The commercial value of the algae contaminated with red soils decreases. On May 14, 1978 cultured *Nematocystis decipines* was coverd with red soils. Fisherman expected the movement of sea water to clean the algae but that did not occur. Two weeks later, about 1.7 g of red soils was still sticking to each 100 g of algae. During the rainy seanon from May to June, the harvesting season for this algae, large amounts of red soils are transported into the marine bed, frequently damaging the culture of this algae. The development of zoospora by this algae is also hampered by the suspension of over 50 mg per liter of red soils.

The deposition and the suspension of transported red soils caused both sedimanta-

tion of fish foods such as planktonic diatoms and the loss of the seaweed bed, which supplied a living environment to adult and immature fishes. Consequently, the productivity of fishes and seaweed decreased considerably. The amounts of transported red soils which had stuck to fishing nets increased remarkably in 3 to 8 days after the setting and fish catch decreased with the increased contamination of fishing nets. Fisherman also have the added expense of washing the muddy red soils from the fishing nets. Since the mucilage secreted from becteria and planktonic diatoms tend to mix with the red soils and stick to the nets, this job becomes more difficult.

IV. Damages to coastal and marine environments

Coral reefs are often destroyed by the transported soils. In the Amami Islands of Kagoshima Prefecture (Hirate, K., 1980) on January 15 and 16, 1975 the coral reefs at the marine park at the eastern part of Amami Oshima were completely destroyed by the transported soils.

Yamazato (1978) studied the influence of red soil (crushed to 200 mesh) on the growth of coral under different concentrations of soil (from 0.024 to 3.33 g per liter of sea water) under a constant temperature of 26°C and illumination of 3000 to 5000 Lux. The results obtained by Yamazato (1978) and by the Okinawa Prefectural Fisheries Experimental Station (Department of Agriculture, Forestry and Fishery, Okinawa Prefectural Office, 1978 and 1979a) are as follows: The concentration of red soils harmuful to the growth of coral is 0.49 to 1.23 g per liter, though various species are influenced to different degrees. *Ascrospora* was very weak. Under low concentrations of red soils in shallow seas, it is assumed that the coral is being starved, a condition which is accelerated by the red soil's shading effect on the photosynthesis of *zooxanthella* (symbiotic algae with coral). In addition to this, sticky red soils on the surface of coral cause suffocation by blocking the interchange between the coral and the sea water. These phenomena occur in a sea area where large amounts of red soils are eroded into a sea with a moderate current.

Counter-measures for Soil Erosion

Measures to counter soil erosion being planned and already practiced in Okinawa Prefecture are as follows (Department of Agriculture, Forestry and Fishery, Okinawa Prefectural Office, 1979c):

I. Fundamental concepts

1) To promote the infiltration of water into the soils and to reduce the surface run-off.

2) To minimize the velocity of surface run-off on the slopes.

3) To arrange drainage canals suitable for controlling the accumulated water discharge.

4) To decrease the erodability of soils.

II. Counter-measures for soil erosion in civil engineering

In case of the enlargement and reclamation of farm land, or lands for housing, the following items must be considered to reduce soil erosion to a minimum.

1) To adjust the scale of the project, to which counter-measures are to be provided.

2) To set an allowable 'grade of slope.

3) To arrange for catch drains and drainage canals for the control of surface run-off.

4) To set a proper grade of the catch drain with consideration for limiting velocity.

5) To grow cover plants immediately after diking is set to reduce the duration of bare land to a minimum.

6) To arrange and manage the forested areas properly.

7) Not to proceed with engineering works during periods of heavy rainfalls.

8) To use effective sedimentation tanks, debris barriers, sedimentation basins, wire covered dikes and fence structures.

III. Counter-measures for soil erosion in agriculture practices

Important counter-measures by farmers are as follows:

1) The following management is recommended for pineapple cultivation. When re-planting pineapples, the truncation of surface soil is not to be done. Plowing old stocks into the soils should be done. The following farm work must be practiced as counter-measures for the prevention of injury attributable to continuous cropping: To cut old stocks by a rotary cutter, into small chips to be left for more than one month in the field to attain complete decomposition. Deep tillaging and plowing of old stocks deep into the soils and crushing clods after the soil becomes soft. In steep sloping fields, where cutting of old stocks is virtually impossible, old stocks are to be plowed in and buried by means of power shovels, when plowing to replace surface soil with sub-soil is done. Sterilization of soils with chemicals should be done at least two weeks before planting. In fields of continuous cropping, where heart rot often occurs, pesticides are to be sprayed and drainage must be sufficient. To take counter-measures against the wilt-disease caused by pine mealybugs. To control the scarabaeid beetles (*Anonalo albopilosa*). Grass mulching and contour cropping should be done.

2) Contour strip cropping on hillside farms.

3) Grass mulching in orchards.

4) To assist the formation of stable aggregates with the application of organic manures.

5) To practice mixed cropping when it is possible.

6) To plow the soils before planting in the period when it is safty to prevent soil erosion.

7) Flattening of the rills and gullies in the farm lands.

8) Ridging for proper drainage.

9) Arrangement of green belts and suitable protection of slope with bench terraces.

10) Removal of transported soils in the sedimentation tanks, drainage canals and grassed water-ways.

IV. Other counter-measures for soil erosion

1) Mutual cooperation studies on counter-measures for soil erosion by Agricultural, Forestry and Fishery Experimental stations.

2) Development of new, effective and cheap engineering methods for the prevention of soil erosion.

3) Complete control of pest and disease due to continuous cropping of pineapples.

4) Studies on suitable methods for removing the eroded and sedimented soils in the marine environment and in the sedimentation basins.

5) To find a rapid aggregation accelerator, which is harmless to natural ecosystem, for the dispersive soil clays.

6) Limit scale of development in harmony with the environmental conditions of the area.

7) Education concerning soil conservation for farmers and inhabitants in the districts.

8) Issuing municipal ordinence concerning the prevention of soil erosion, i. e. as in the case of Higashi-son, previously mentioned in the introduction of this report.

V. Examples of actual counter-measures for soil erosion in Okinawa Prefecture

1) "Sutera sheet" works. In the grass land reclamation works on hillside slopes, a mesh net made of reinforcing bars of 10 cm in length, and of 3 m in height, is buried along the slope of the bench terrace. A synthetic fiber ("Sutera sheet") is packed between the each terrace and the reinforcing bar net to prevent soil erosion. Three years later, at the time when the grass is fully grown on the sloping lands, the net is removed. "Sutera sheet" work was planned around 1975 and was put into practice around 1977. The cost of this work was apporximately 300 yen ($ 1.50) per one meter at the time of 1975.

2) Sedimentation basins in the reclaimed grass land. About 220 ha of livestock area is now constructed on a hillside and upstream watershed of the Nagura River on Ishigaki Island. The sedimentation basins in this area occupy 1 % of the total reclaimed grass land. From these basins, only the clear supernatants are intended to drain.

3) Gentle longitudinal slopes of drainage canals. An agricultural dam with an expected reservoir capacity of 2,350,000 tons is now under construction upstream on the Nagura River on Ishigaki Island. The drainage canla from the benefited area is intended to be wide and shallow to minimize the run-off of soils. The

longitudinal slope of this canal is 1/1660.

Summary

Okinawa prefecture has a subtropical climate and is one of the heaviest rainfall regions in Japan. Various development projects, especially the enlargement of agricultural fields on sloping lands, causes extensive soil erosion which produces unfavorable effects on the lands, rivers and marine ecosystems. The projects also cause considerable damage to the fisheries and tourist industries, the function of roads, rivers and forests, etc. . It is assumed that soil erosion will also have negative effects on future agriculture. These hasty developmental projects have been carried out without the practice of any counter-measures against soil erosion. At the present time, large funds and much research on soil conservation is needed to recover from wide spread damage, although the agricultural developmental projects have already obtained excellent results.

Developmental projects in the heavy rainfall areas of subtropical and tropical regions, especially on sloping lands, should be planned with careful attention paid to the prevention of soil erosion, irrespective of the scale of the development projects.

Acknowledgement

The authors's profound thanks are expressed to M. K. Oshiro, Chief of the Soil Conservation Laboratory of Okinawa Prefectural Agricultural Experimental Station, who offered helpful suggestions concerning the present conditions of the soil erosion on the Okinawa Island and its counter-measures in the future.

The authors are also indebt to Mr. M. Yokota, Chief of the Chemistry Section at Okinawa Prefectural Agricultural Experimental Station (now Director of the branch of the same Agricultural Station at Ishigaki Island, Okinawa Prefecture), Dr. K. Fukunaka, Associate Professor at Ryukyu University, Mr. H. Ichiki, Chief of the Soil Laboratory at Tropical Agricultural Research Center, Ministry of Agriculture, Forestry and Fishery (now at Tōhoku Agricultural Experimental Station, Morioka, Japan), and Dr. N. Nanba and Dr. H. Hirata, professors at Kagoshima University. They gave us many valuable suggestions and aided the authors in improving this manuscript.

References

Department of Agriculture, Forestry and Fishery, Okinawa Prefectural Office. 1978 (March). Influence of eroded and transported soils into the fishing area in Okinawa. pp. 162. (inJapanese).

Ibid (1979a, March). the same title as above. pp. 52. (in Japanese).

Ibid (1979b, September). Forestry of Okinawa. pp. 54. (in Japanese).

Idid (1979c, October). Counter-measures for soil erosion. pp. 27. (in Japanese).

Hirata, K. 1980 (March). Damages to coral-reef of marine parks at Amami Island by Starfish. Sature Conservation Society of Kagoshima Prefecture. (in Japanese).

Kadomura, H. and Yamamoto, H. 1978. Man induced erosion, the rete of erosion and an example from Okinawa Island, southern Japan. J. Geogr. 87: 1-15. (in Japanese).

Municipal ordinance concerning the prevention of soil erosion issued by Higashi-son. 1979 (october). pp. 4. (in Japanese).

Nago City Office, 1979 (September). Tomorrow in Nago City. 14: Catchment area of the Yabu River. pp. 96. (in Japanese).

Okinawa Development Agency. Budget data of Okinawa General Bureau. 1980.

Okinawa Prefectural Office. 1975. Nature of Okinawa. pp 161.

Tokuyama, A. 1980. Amounts of transported soils by rivers in Okinawa Island. Annual Conference of Geochemical Society of Japan. Summaries of presented papers. pp 97-98. (in Japanese).

Yamada, Y., Motoyama, S., Matsusaka, Y. and Kato, Y. 1973. Soils of Ishigaki, Miyako and Yonaguni Islands. Bull. National Inst. Agr. Science (Japan) 24B: 266-335. (in Japanese).

Yamamoto, H. 1976. Slope processes and sediment yield on bare land in the northern part of Okinawa Island., southwestern Japan. Geor. Reps. Tokyo Metropol. Univ. 11: 87-96.

Yamazato, K. 1978. (March). Influence of suspended red soils to the coral reefs. River Section, Okinawa General Bureau, Okinawa Development Agency.

(Received April 30, 1985)