INTRODUCTION

Japan is located in the Asia monsoon zone and has an annual precipitation of 1,000 - 3,000 mm. In most of Japan, more than 50% of the annual precipitation is concentrated in the summer rainy season. Since about 70% of the land is hilly or mountainous, Japan has a long history of development and improvements for slopeland agriculture. Apart from persimmon, deciduous fruit-trees are mostly cultivated on slopes with a gradient of less than 10%. The situation is different with regard to evergreen fruit-trees such as citrus. Of these, 70% are cultivated on slopes with a gradient of more than 10%, and nearly half are cultivated on steep slopes with a gradient of more than 25%. (Table 1).

EFFECTIVENESS OF SOIL CONSERVATION MEASURES FOR SLOPELAND ORCHARDS

Many reports on the effectiveness of various soil conservation practices in controlling soil loss are available from all over the world. Unfortunately, however, there is little data on the effectiveness of soil conservation techniques in slopeland areas of Japan. The first part of this Bulletin discusses the results of field tests in Japan on the effect of mulching, grass cover and terracing on the rate of soil loss.

Effect of Mulching and Grass Planting

An experimental lysimeter to measure rates of run-off and soil loss was used by Hanano et al. (1996) to study soil loss from citrus orchards, and is shown in Fig. 1a. Sedimentation tanks were con-
structured at the lower end of the slope. Seedlings of Satsuma mandarin were planted along the slope in plots with straw mulch and grass cover. Observations were made over seven years (1987 to 1993).

Figs. 1b and 1c show the rate of soil loss and surface runoff, respectively, from each plot during this period. In the clean culture plot, soil loss was considerable until 1990, at about 30 mt/ha, but decreased sharply after that. The same tendency was found in the rate of surface runoff. Soil losses from plots with straw mulch or grass cover was relatively small throughout the whole study period. This result shows that when trees are young and their canopy is small, measures which cover the bare soil, such as straw mulch or grass cover, are quite effective in terms of soil conservation.

**Effect of Terracing**

Fig. 2 shows the layout of the plots which Hotta et al. (1967) used for their experiments. In each plot, 25 Satsuma* mandarin seedlings were planted.

As in the above-mentioned field tests, straw mulch and grass cover were effective in conserving soil. Grass strips were less effective, since more of the soil surface was left bare. In the plot with bench terraces, stone wall terraces were more effective than earth wall terraces, but both were comparable to the grass cover plot (Table 2). The risers of stone terraces can be constructed almost vertically so that the bench width is greater than that of earth terraces, leaving a broader planting space.

**SOIL CONSERVATION IN JAPAN**

Japan’s Agricultural Land Conservation Project was established in 1956. The aim of the project was to construct or repair drainage facilities, related waterways and farm roads in areas of steep slopeland, and to remove layers of locally distributed problem soils. (This is soil which extends over a limited area, and makes construction work and farming difficult because of its inferior quality). Currently, the project is proceeding in 310 locations nationwide.

**A Case Study**

This case study is from a small island in Hiroshima Prefecture, off the coast of western Honshu in the Seto Inland Sea. Orchards are laid out on the steep slopes of Mt. Ooyama, with an average gradient of 40%. The soil is derived from weathered granite. To prevent erosion, a network of drainage ditches has been constructed to remove runoff safely. Some of these are covered, so as to improve agricultural infrastructure (Fig. 3). The layout of ditches, roads which serve also as ditches, and sedimentation tanks is shown in Fig. 4. Basically, an interception ditch is constructed near the upper boundary of the orchard, to intercept run-off flowing downhill. Collection ditches and drainage ditches are in the valley.

When the gradient of a ditch is more than 20%, or when the design flow velocity exceeds the maximum allowable flow velocity of the ditch, a stepped ditch is constructed. (Stepped ditches are also utilized as paths in steep slopeland orchards). At

<table>
<thead>
<tr>
<th>Crop</th>
<th>Gradient of field</th>
<th>Growing area (1000 ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Less than 5°</td>
<td>5 - 15°</td>
</tr>
<tr>
<td>Satsuma mandarin</td>
<td>23</td>
<td>35</td>
</tr>
<tr>
<td>Other citrus fruits</td>
<td>27</td>
<td>31</td>
</tr>
<tr>
<td>Apple</td>
<td>65</td>
<td>28</td>
</tr>
<tr>
<td>Chestnut</td>
<td>48</td>
<td>30</td>
</tr>
<tr>
<td>Japanese persimmon</td>
<td>52</td>
<td>30</td>
</tr>
<tr>
<td>Grapes</td>
<td>65</td>
<td>26</td>
</tr>
</tbody>
</table>

Source: Ministry of Agriculture, Forestry and Fisheries, Japan. (1995)
Fig. 1a. Layout of the experimental lysimeter
Source: Hanano et al. (1996)

Fig. 1b. Yearly changes in soil loss
Source: Hanano et al. (1996)

Fig. 1c. Yearly changes in runoff rate
Source: Hanano et al. (1996)
Interception ditches and collection ditches on slopelands often take the form of U-shaped concrete ditches. Sometimes surface runoff from slopes and roads does not flow into the ditches, but flows downhill beside the ditch, eroding the soil at the edge of the ditch. The large rills which can form in this way damage the ditch, destroy roads and slopes, and accelerate soil erosion from the orchard. To solve the problem, Nakao et al. (1996) developed a method of controlling water erosion using the Geonet, a plastic net made from high-density polyethylene. The Geonet is cut into a trapezoid shape (Fig. 5a), and the pieces laid at right angles to the ditch, as shown in Fig. 5b.

Fig. 6 shows the results of the test conducted at the site. In the graph, the relation between the horizontal distance from a datum point to another point downstream, and the height of the maximum erosion depth before, immediately after, and one year after the construction, are indicated. It is evident that Geonet is very effective in controlling erosion along the side of the ditch, and since the Geonet material is not corrosive, we can expect the effect to be a long-term one. Furthermore, since it is made of flexible material, it is not damaged by the traffic of farm machinery.
EFFECT OF INTERCEPTION DITCHES ON EROSION CONTROL

Shortening the length of a slope by constructing an interception ditch can be a very effective soil conservation measure. However, there is as yet no method of estimating the relation between the interval between interception ditches and the rate of soil loss. Thus, the intervals between interception ditches are based on experience, and the effect of the ditches on soil conservation is unclear. In orchards, ridge culture is sometimes adopted to produce fruit of high quality. The effect of interception ditches on soil conservation in orchards of this type were studied. To simulate the relation between the arrangement of interception ditches and the rate of soil loss, “A model of predicting sediment yield from sloping ridged cropland” developed by Nakao et al. (1996), was adopted, (Fig. 7).

Outline of the Model

Soil loss from fields laid out in ridges, furrows, and interception ditches can be predicted from this model.

The rate of soil loss Qf(g/s) from a furrow is calculated by the following equation, (see Formula 1).

\[ Qf = Tf (Pf \cdot Tf), \quad Qf = Pf (Pf - Tf) \quad \ldots (1) \]

where

Tf : Sediment transport capacity of the flow at the end of a furrow
θf : Total erosion rate in a ridge and furrow
Pf (g/s) : The sum of the erosion by raindrops on a ridge, and by the flow along the furrow.

The equation can be described as

\[ Pf = K_r \cdot r_L \cdot L_f \cdot \frac{1}{3600} \]

\[ + a f \cdot \beta \left\{ B f \cdot \cos (\theta f) \cdot \cos (\theta c) \right\}^b \]

\[ \left\{ \tan (\theta f) \right\}^{1/2} \cdot L_f \cdot b^{1/2}(b+1)^{1/2} \cdot \text{Re}^b \quad \ldots (2) \]

where

Kr : Parameter of soil erodibility of ridge (g*hr/m)

rL : Side slope length of ridge (m)
Fig. 4. Cross-section of drainage facilities
Source: Onomichi Agriculture and Forestry Office, Hiroshima Pref., Japan (1988)
Fig. 5a. Geonet used in the experiment
Source: Nakao et al. (1994)

Fig. 5b. How the Geonet is applied
Fig. 6. Effect of Geonet on the control of erosion
Source: Nakao et al. (1994)

Fig. 7. Orchard model for simulation
Lf : Ridge length (m)
lj : Hourly precipitation in a rainfall event (mm/h)
Bf : Ridge width (the distance between the tops of the ridges (m))
af : Coefficient of erodibility of soil in a furrow
θf : Ridge slope (°)
θc : Interception ditch slope (°)
Re : Effective rainfall (mm/h)
ß : Unit transformation coefficient (=10^{b+c})
b,c : Exponent (b = 0.8, c = 1.3)

Tf (g/s) is estimated by the following equation which applies Yalin’s transport equation (Yalin 1963)

\[ Tf = p \cdot Wf \cdot 10^2 \] ………(3)

where
\[ p : \text{Rate of sediment transport compared to the dry mass of sediment (dry soil mass per width unit and time unit) \quad \text{[g/(cm*s)]},} \]
\[ Wf: \text{furrow width (m)} \]

The rate of soil loss from the interception ditch is found in the same way as with a ridge and furrow. As for the interception ditch, the relation of a ridge to a furrow is the same as the relation of the total ridges and furrows to the interception ditch. Thus, in the case of the interception ditch, the first term of the right side of the second equation corresponds to the total sum of the rate of soil loss Qf (g/s), from each furrow in the first equation. The rate of soil loss from the interception ditch Qc (g/s), sediment transport capacity at the end of the interception ditch Tc (g/s) and erosion rate in the interception ditch Pc (g/s), respectively, can be expressed by the following equation.

\[ Qc = Tc \cdot \text{Pc - Tc}, \quad Qc = P \cdot (Pc - Tc) \] ………(4)

\[ P \cdot c = n \cdot Qf + a \cdot \beta \cdot \{Lf \cdot \cos (\theta _f) \cdot \cos (\theta _c)\} \cdot \{\tan (\theta )\} \cdot Lc^{b+1} \cdot (b+1)^{-1} \cdot \Re^b \] ………(5)

\[ Tc = p \cdot Wc \cdot 10^2 \] ………(6)

where
\[ Lc : \text{Length of interception ditch (m)}, \quad a : \text{Erodibility coefficient of soil in interception ditch}, \]
\[ n : \text{The number of furrows}, \quad Wc: \text{Width of interception ditch (m)} \]

Pf and Pc are derived from the rill erosion model proposed by Takagi et al. (1996), and the equation of interrill erosion rate (e.g. Liebenow et al. 1990). Each of the above equations is described according to the rate of rainfall. Thus, when the amount of soil loss in a rainfall event is estimated, soil loss rate during each rainfall event should be calculated, and these values added to give a total.

Simulation

A ridged orchard with a slope length of 50 m and with an interception ditch 28 m long, was simulated (Fig. 7).

Soil loss from the end of the field where 1, 2, 3, 4, 5, 7 and 10 interception ditches with equal intervals were constructed, was calculated according to the slope. The conditions necessary for the calculation and the precipitation are shown in Table 3. The precipitation data was obtained from the AMeDAS (Automated Meteorological Data Acquisition System) system of the Japan Meteorological Agency. The maximum daily precipitation from 1979-1990 in Saita-cho, Kagawa Prefecture, was adopted for the calculation.

The results of the simulation are shown in Fig. 8. Regardless of the gradient of the furrows, soil loss sharply decreases as the number of interception ditches increases. On gentle slopes with four ditches, no major change in the rate of soil loss was observed if more ditches were constructed. Provided enough interception ditches are constructed, it is evident that such ditches give effective erosion control.

CONCLUSION

In Japan, as in most other countries, there is widespread use of mulching, grass cover and terracing for soil conservation. Surface drainage of rainfall by means of ditches is another important soil conservation measure. This Bulletin discusses the effect of these practices on soil and water loss, and comes to the following conclusions.

- Straw mulch and grass cover are both extremely effective in controlling soil losses from slopeland orchards, particularly when the trees are young.
- Bench terracing is as effective as grass cover as a soil conservation practice.
- In orchards on steep slopes, a conservation project emphasizing drainage is being implemented in many parts of Japan, and giving good erosion control.
- The use of Geonet along the sides of ditches for erosion control is extremely
Fig. 8. Relationship between number of interception ditches and soil loss

Table 3. Computational conditions

<table>
<thead>
<tr>
<th>Items</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity of soil: Gs</td>
<td>2.518</td>
</tr>
<tr>
<td>Median particle size (mm): $d_{50}$</td>
<td>2.782</td>
</tr>
<tr>
<td>Precipitation (mm/day)</td>
<td>202</td>
</tr>
<tr>
<td>Runoff ratio: $f$</td>
<td>0.5</td>
</tr>
<tr>
<td>Coefficient: $a_f$</td>
<td>0.00002</td>
</tr>
<tr>
<td>Coefficient: $a_c$</td>
<td></td>
</tr>
<tr>
<td>Sediment deposited in the ditch &gt; 0</td>
<td>0.00002</td>
</tr>
<tr>
<td>Sediment deposited in the ditch = 0</td>
<td>0</td>
</tr>
<tr>
<td>Exponent: $b$</td>
<td>0.8</td>
</tr>
<tr>
<td>Exponent: $c$</td>
<td>1.3</td>
</tr>
<tr>
<td>Width of interception ditch (cm)</td>
<td>24</td>
</tr>
<tr>
<td>Width of collection ditch (cm)</td>
<td>30</td>
</tr>
</tbody>
</table>
effective.

- The use of a simulation model for predicting sediment yield indicated that the construction of interception ditches has a considerable effect on soil conservation.

For the future, we need to develop methods of constructing ditches which give the best soil conservation. We also need to develop more effective soil conservation practices which combine ditches with other conservation measures.

REFERENCES


DISCUSSION

Mr. Nakao was asked about the cost of using Geonet for erosion control. He answered that the cost of Geonet (in Japan) is US$13 per square meter. In the test described, each Geonet insertion used 0.25m² at a cost of around US$3-4 each. Mr. Nakao added that most conservation projects in Japan enjoy a government subsidy, so that farmers pay only around 7% of the total investment cost. Even that payment of c.7% is in the form of a long-term, low-interest loan.