EFFECT OF FIRE ON WATER AND MAJOR NUTRIENT BUDGETS IN FOREST ECOSYSTEMS

III. RAINFALL INTERCEPTION BY FOREST CANOPY

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Synopsis


Precipitation, throughfall, stemflow and stream discharge were measured simultaneously throughout a year from middle April of 1981 till early April of 1982 in both a natural and burnt red pine forest on Etajima Island, Hiroshima Prefecture, west Japan, where a forest fire occurred in June of 1978. Little difference in precipitation between these two forests was found, however, throughfall in the burnt forest was always larger than that in the natural forest due to the loss of the canopy by fire, the annual ratio of throughfall to precipitation was estimated at 94.4% and 83.0%, respectively. There was no significant difference in stemflow between the two forests, because stemflow was promoted by smoothing out the thick and rugged bark by fire in spite of the loss of most of the canopy (leaves and fine branches). Consequently, the annual interception storage, which is estimated as the balance between precipitation and the sum of throughfall and stemflow, was 3.6% and 14.0% of the annual precipitation in the burnt and natural forests, respectively. The difference in interception storage between these two forests (10.4% of annual precipitation) corresponded closely to difference of stream discharge, especially that of the direct flow between them.

Introduction

Fire directly changes a forest structure (for example, it consumes the foliages of over- and under-stories, leaving only charred timbers), and destroys the important functions of the forest ecosystem.

Many authors have reported on the subjects of forest fire damage to the water cycle and increased stream discharge from the burnt watershed (HoYT & TroxELL, 1932; Sinclair & Hamilton, 1955; Helvey, 1973; Campbell et al., 1977; Wright, 1976; Anderson et al., 1976). Recently Kusaka et al. (1983) showed that annual discharge increased in proportion to the ratio of

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the burnt area to its watershed area, based on the data observed at three watershed-ecosystems (strongly burnt, moderately burnt and natural red pine forests), located on Etajima Island in Hiroshima Prefecture, west Japan.

The change of water balance after fire is mainly the result of destruction to the forest structure. In particular, loss of the forest canopy seems to be one of the most influential factors causing the increase of discharge from the watershed after fire, since interception by the forest canopy, which is the process whereby vegetation intercepts the fall of precipitation onto the soil surface, is estimated at 15–30% of the annual gross precipitation in many types of forests (including red pine forests) as summarized by Zinke (1967) and Nakano (1976). Although the percentage of gross precipitation lost to interception varies directly with the type and density of forest vegetation and foliage coverage, and indirectly with the amount of precipitation and rainfall duration (Tiedemann et al., 1979), interception storage seems to be roughly comparable in amount to the increase of the discharge after fire.

However, no studies have been published concerning the direct changes in interception storage caused by fire (Tiedemann et al., 1979).

Thus in the present study, interception storage was measured at every rainfall throughout a year (middle April of 1981–early April of 1982) simultaneously at both burnt and natural pine forest stands located on Etajima Island, where observations of water budget as the balance between precipitation and discharge have been carried out since 1979 by the authors (Kusaka et al., 1983).

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**Study Sites and Methods**

The interception of rainfall by the forest canopy was investigated in both a natural Japanese red pine forest (Plot A) and a burnt forest (Plot B) stand located on Etajima Island (34° 16' N, 132° 29' E) in southern Hiroshima Prefecture, west Japan, where about 90% (1005 ha) of the forest area was burnt in June of 1978. These two forest stands (Plots A and B) were set up in April of 1981 in the undamaged watershed (E-12) and the strongly burnt watershed (E-5) respectively, which are the same watersheds in which the authors researched the water budget (Kusaka et al., 1983).

The climate of this region belongs to the warm temperate, monsoon zone. Average of annual mean temperature and annual precipitation during the last three decades were 15.9°C and 1575 mm, respectively. The rocks of Etajima Island consist mainly of granite. The vegetation existing before the fire was a 40–70 years old red pine (Pinus densiflora Sieb. et Zucc.). For a detailed description of the climate, geology and vegetation before the fire on Etajima Island, refer to Kusaka et al. (1983) and Nakane et al. (1983). A description of the watersheds at the forest stands studied was also given by the authors.

Table 1 shows the slope degree, position on the slope, area and vegetation of the stands.

Gross precipitation (P) was measured by precipitation gauges at two points in a nearby open field in both the burnt and natural forests, and throughfall (Tf) and stemflow (Sf) were collected at every rainfall in both Plots A and B throughout the year from middle April, 1981 till early April, 1982. Throughfall in the burnt forest was tentatively defined as the rain which falls through the charred branches and stems, or touches them before reaching the ground surface and drops.

Ten (five pairs) of the collectors for throughfall, consisting of a 30 cm diameter funnel and a 10 liter reservoir, were randomly placed on the forest floor fixed by iron frames at 60 cm height in Plot A, and six (three pairs) of the same collectors were arranged in Plot B in the same way as in Plot A.

Amount of stemflow was measured at five and at three trees of different diameter size classes of DBH at Plots A and B, respectively, using gutterings made of synthetic resin attached spirally to the stem in the conventional way.

Discharge from each watershed (E-5 or E-12) was measured continuously at the stream-gauging station, which includes a gauging weir, using the relation established between water level and flow rate of discharge (refer to Kusaka et al., 1983). On the other hand, the crown projection area of all trees (tree height ≥ 60 cm) was measured in Plots A and B as shown in Fig. 1, where the crown pro-
Table 1. Description of research stands at a natural forest (Plot A) and burnt forest (Plot B) on Etajima Island, Hiroshima Prefecture, west Japan.

<table>
<thead>
<tr>
<th></th>
<th>Plot A</th>
<th>Plot B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position of the slope</td>
<td>Middle</td>
<td>Middle</td>
</tr>
<tr>
<td>Slope [degree]</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Rocks</td>
<td>Granite</td>
<td>Granite</td>
</tr>
<tr>
<td>Area [m²]</td>
<td>152.4</td>
<td>104.8</td>
</tr>
<tr>
<td>Vegetation*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dominant species of overstory</td>
<td>Pinus densiflora</td>
<td>Pinus densiflora</td>
</tr>
<tr>
<td>Dominant species of understory</td>
<td>Rhododendron reticulatum</td>
<td>Eurya japonica</td>
</tr>
<tr>
<td>Number of trees** [No./ha]</td>
<td>1575</td>
<td>2290</td>
</tr>
<tr>
<td>Mean tree height*** [m]</td>
<td>7.0</td>
<td>6.8</td>
</tr>
<tr>
<td>Mean DBH** [cm]</td>
<td>12.4</td>
<td>10.1</td>
</tr>
<tr>
<td>Crown projection area [ha/ha]</td>
<td>1.986</td>
<td>1.076</td>
</tr>
</tbody>
</table>

*Represents vegetation in Plot B (burnt forest) before the fire, except for the crown projection area, which was estimated by a tree census after the fire; **Tree height ≥ 60 cm; ***DBH ≥ 4.5 cm

Fig. 1. Crown projection maps in a natural (Plot A) and a burnt (Plot B) Japanese red pine forest stand on Etajima Island, Hiroshima Prefecture, west Japan. Crown projection area in the burnt forest stand is tentatively defined as the horizontal extent of the lost leaves of the charred branches. A, B: Collectors of throughfall, SA, SB: Sample trees for collection of stemflow

The precipitation, throughfall, stemflow, interception and stream discharge are all expressed in mm of water depth.

**Results and Discussion**

**Gross precipitation**

The relationship of the precipitation between the natural forest, Plot A ($P_a$), and the burnt forest, Plot B ($P_b$), shown in Fig. 2, indicates that there was little difference in the amount of each rainfall between the two plots throughout the year studied. Table 2 shows also the close relation in monthly precipitation between these plots. Ku-
Fig. 2. Relationship of precipitation between the natural ($P_a$) and burnt ($P_b$) forests on Etajima Island observed from April 1981 till April 1982. Solid line (---): $P_b = P_a$.

SAKA et al. (1983) reported the same relation based on the data observed in 1979–1980. The annual precipitation (middle April, 1981 – early April, 1982) was estimated at 1513.1 mm in Plot A and at 1555.1 mm in Plot B, and the difference between them was only 3% of their values. Comparing the annual and monthly precipitation rates of the period studied with those recorded during the last three decades on Etajima Island, it becomes clear that the precipitation records of the period were closely similar to those of a usual year (Table 2).

On the other hand, Table 1 shows that the topography and rocks of Plots A and B are closely similar to each other, and that the vegetation (including its structure) was also similar between them before the fire. These facts suggest that it is reasonable to compare the water cycle, especially the throughfall and stemflow or interception between Plots A and B, based on the data of the period studied, and that the result of the comparison can be accepted as that of a usual year.

**Throughfall**

Several examples of the relation between gross precipitation ($P$) and throughfall ($T_f$), which was measured by each throughfall-collector, were shown in Fig. 3. There was fluctuation of the amounts of throughfall between collectors in the two stands, especially in the natural forest stand, due to the variety and complexity of the crown structure. However, individual and mean values of

<table>
<thead>
<tr>
<th>Table 2: Monthly and annual precipitation [mm] on Etajima Island from 1941–1971 and from April 1981–March 1982</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural forest (Plot A)</td>
</tr>
</tbody>
</table>
throughfall increased in proportion to the increase of precipitation whether the forest was burnt or not (Figs. 3 and 4). These relations could be approximated by the following linear equation as reported by many authors,

$$T_f = a_t(P - b_t)$$  \hspace{1cm} (2)

where $a_t$ and $b_t$ are coefficients and take specific values for each forest stand. The value of coefficient $b_t$ is regarded as the amount of rain water needed to wet the canopy. Eq. (2) suggests that no throughfall ($T_f$) precipitates on the forest floor when $P$ is less than $b_t$. However, in burnt or natural forests having sparse crowns, $T_f$ can be expected even in the case of little rainfall, because a considerable amount of rain water falls directly on the floor without touching the canopy. In such cases, the relation between $P$ and $T_f$ can be described as follows:

when $P$ is slight ($P \leq b_t/\alpha$),

$$T_f = (1 - \alpha) \cdot P$$ \hspace{1cm} (3)

and when $P$ increases more than the amount required to wet the canopy ($P > b_t/\alpha$),

$$T_f = (1 - \alpha) \cdot P + (\alpha \cdot P - b_t) \cdot (1 - \alpha + \alpha \cdot n_t)$$

$$= (1 - \alpha^t - 1 + \alpha^t \cdot n_t) \cdot P - b_t$$

$$= a_t \cdot (P - b_t)$$ \hspace{1cm} (4)

where $\alpha$ is the probability of rain water touching the canopy, $b_t$ is the amount of water required to wet the canopy, and $n_t$ stands for the ratio of the amount of water which falls from the canopy onto the floor as throughfall to the total amount of rain water caught by the canopy after it becomes wet. Eq. (4) apparently coincides with Eq. (2)
Table 3. Values of coefficients of Eqs. (3) and (4), representing the relationship between throughfall ($T_f$) and precipitation ($P$).

<table>
<thead>
<tr>
<th>Coefficients</th>
<th>Plot A</th>
<th>Plot B</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$: Probability of rain water which will touch the canopy</td>
<td>0.76</td>
<td>0.11</td>
</tr>
<tr>
<td>$\beta$: Amount of water to wet the canopy [mm]</td>
<td>2.1</td>
<td>0.5</td>
</tr>
<tr>
<td>$n$: Ratio of amount of throughfall to that caught by the canopy</td>
<td>0.838</td>
<td>0.555</td>
</tr>
<tr>
<td>$a' (=1-a+\alpha n)$</td>
<td>0.877</td>
<td>0.951</td>
</tr>
<tr>
<td>$b' (=n; \beta/a')$ [mm]</td>
<td>2.0</td>
<td>0.3</td>
</tr>
</tbody>
</table>

when $P$ is larger than $\beta/\alpha$. Eqs. (3) and (4) suggest that the ratio of $T_f$ to $P(T_f/P)$ will converge to $(1-\alpha)$ when $P$ decreases to $\beta/\alpha$. Based on the smallest amount of rainfall (1.7 mm for the natural forest, or 1.5 mm for the burnt forest) collected during the period studied, the value of $(1-\alpha)$ was assumed to be 0.24 for the natural forest stand and 0.89 for the burnt one. As shown in Fig. 4, a linear regression (Eq. 4) of throughfall ($T_f$) to gross precipitation ($P$) was applied to the data ($P>2$ mm) observed in both stands to obtain the following equations,

$$T_f(b) = 0.877(P-2.0)$$

(5)

$$T_f(b) = 0.951(P-0.3)$$

(6)

where $T_f(b)$ represents the throughfall in the natural forest and $T_f(b)$ stands for that in the burnt one. The value of coefficient $a'$ of Eq. (5), 0.877, closely coincided with that reported by ROGERSON & BYRNE (1968), who measured throughfall in a red pine forest in the US, but it is somewhat larger than that observed in a pine/hinoki (Chamaecyparis obtusa Endl.) mixed forest in Kyoto, Japan (NISHIMURA, 1973; SUZUKI et al., 1979). From Eqs. (4) and (6) and the value of $(1-\alpha)$, we could transform Eqs. (5) and (6) to, respectively,

$$T_f(f) = 0.24 P + (0.76 P-2.1) \times 0.838$$

(7)

$$T_f(b) = 0.89 P + (0.11 P-0.5) \times 0.555$$

(8)

when $P$ is less than 2.8 (2.1/0.76) mm or 4.6 ($=0.5/0.11$) mm, Eqs. (7) and (8) are expressed as

$$T_f(f) = 0.24 P$$

(9)

$$T_f(b) = 0.89 P$$

(10)

The values of the coefficients of Eqs. (3) and (4) are given in order in Table 3.

The amount of rain water required to wet the canopy in the burnt forest (0.5 mm) was smaller than that in the natural forest (2.1 mm), owing to the loss of most of the canopy (leaves and fine branches). The ratio of the amount of rain water which dropped from the canopy to that caught by the canopy ($n_2$) was larger in the natural forest than in the burnt forest. It appears that the living pine tree readily loses the rain water it catches because of the needle shape of its leaves and its rugged bark. The ratio of $T_f$ to $P$ shown in Fig. 5 suggests that it was always higher in the natural forest than in the burnt one, particularly when rainfall was scant, and that it converged to about 88% in the former, or 95% in the latter, with the increase of rainfall. The annual ratio of $T_f$ to $P$ was estimated at 83.0% and 94.4% in the natural and burnt forests, respectively. This means that the annual ratio of throughfall to precipitation increased 11.4% above the value shown before the fire.
On the other hand, Murai (1970) reported that the annual ratio of $T_f$ to $P$ ranged from 78 to 82% during his four years of observations at a 43-year-old pine forest in Iwate Prefecture, north Japan, which had a mean DBH and tree height of 20 cm and 15 m, respectively. The value of the ratio obtained in this study was slightly higher than that reported by Murai (1970). This may be due to the difference in leaf biomass and structure between them, as indicated by the mean DBH and tree height (refer to Table 1). Actually, the ratio ($T_f/P$) observed in a second growth ponderosa pine by Rowe & Hendrix (1951) was 82.8%, which agreed well with that obtained in this study.

**Stemflow**

Examples of the linear relation between gross precipitation ($P$) and stemflow observed at an individual sample tree ($S_f$) were shown in Fig. 6. There was not such a significant correlation between stemflow per tree ($S_f'$) and tree dimensions such as crown area, DBH, tree height, etc., in these pine forest stands, as indicated by Iwatsubo & Nishimura (1978). However, for convenience, stemflow per plot area ($S_f$) was estimated by using the ratio of the sum of crown area of each sample tree ($\sum A_r$) to the total crown area in the plot ($A_s$) as follows:

$$S_f = \left( \sum S_f' \times \frac{A_e}{\sum A_r} \right) / A_s$$

(11)

where $\sum S_f'$ and $A_s$ are the sum of stemflow of sample trees and the plot area, respectively.

Linear regression of stemflow ($S_f$) on gross precipitation ($P$) was applied to the data observed in both Plots A and B to obtain

$$S_f(f) = 0.034 (P - 4.8)$$

(12)

$$S_f(b) = 0.027 (P - 9.3)$$

(13)

where $S_f(f)$ and $S_f(b)$ are stemflow in the natural and burnt forest, respectively. The coefficient values of Eq. (12) were close to those reported by Murai (1970), Nishimura (1973) and Suzuki et al. (1979). Stemflow can be described theoretically as

$$S_f = (\alpha P - \beta_t)n_s$$

$$= \alpha n_z(P - \beta_s/\alpha) = a_f(P - b_s)$$

(14)

where $\beta_s$ corresponds to the amount of rain water required to wet the canopy and stems, and $n_s$ stands for the ratio of the amount of rain water flowing along the stem as stemflow to that caught once by the canopy or stem. From the value of $\alpha$ and Eqs. (12) and (13), the values of coefficients of Eq. (14) were calculated and given in Table 4. The results of the calculation show that in the burnt pine forest, only 1.0 mm of rainfall was needed to wet its “canopy” and stems; moreover, about one-fourth of the amount caught once by itself flowed along the stem, while the undamaged forest required 3.7 mm for wetting itself, and a relatively smaller percent of rain water caught by itself flowed as stemflow owing to interference by the thick bark.

The summary by Nakano (1976) indicates that the value of $\beta_s$ ranged from 0.5 to 3.0 mm for a pine or fir forest, which was a somewhat lower than that obtained in this study. However, total stemflow in the natural forest was larger than that in the burnt forest because the crown area per unit area in the former was 2-fold in the latter.

The ratio of stemflow to gross precipitation was
Table 4. Values of the coefficients of Eq. (14), representing the relationship between stemflow ($S_f$) and precipitation ($P$).

<table>
<thead>
<tr>
<th>Coefficients</th>
<th>Plot A (Natural forest)</th>
<th>Plot B (Burnt forest)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_1$: Amount of rain water to wet the canopy [mm]</td>
<td>3.6</td>
<td>1.0</td>
</tr>
<tr>
<td>$n_t$: Ratio of amount of stemflow to that caught by the canopy</td>
<td>0.045</td>
<td>0.245</td>
</tr>
<tr>
<td>$\alpha_t = a_t n_t$</td>
<td>0.034</td>
<td>0.027</td>
</tr>
<tr>
<td>$b_t = \beta_t n_t + \beta_s n_s$ [mm]</td>
<td>4.8</td>
<td>9.3</td>
</tr>
</tbody>
</table>

Fig. 7. Comparison of the ratio of stemflow ($S_f$) to precipitation ($P$) between the natural (○) and burnt (●) forests.

Fig. 8. Comparison of the ratio of interception ($I_c$) to precipitation ($P$) between the natural (○) and burnt (●) forests.

Fig. 9. Relationship between interception ($I_c$) and precipitation ($P$) in the natural (○) and burnt (●) forests, fitted by the curves (Eq. 19).

Consistently less than 4% and 3% (Fig. 7), and the annual mean ratio was estimated at 3.0% and 2.0% in the natural and burnt forests, respectively.

**Interception**

The ratio of interception ($I_c$), which is the balance between gross precipitation ($P$) and the sum of throughfall ($T_f$) and stemflow ($S_f$), to precipitation ($P$) is shown in Fig. 8 in relation to precipitation. From $T_f-P$ relation (Eqs. 3 and 4) and $S_f-P$ relation (Eq. 14), $I_c$ can be described as follows:

when $P$ is less than $\beta_t/\alpha$,

$$I_c = \alpha' P$$  \hspace{1cm} (15)

when $P$ ranges from $\beta_t/\alpha$ to $\beta_t/\alpha$,

$$I_c = \alpha'(1 - n_t)P + \beta_t n_t$$  \hspace{1cm} (16)

and when $P$ increases more than $\beta_t/\alpha$,

$$I_c = \alpha'(1 - n_t - n_s)P + (\beta_t n_t + \beta_s n_s)$$  \hspace{1cm} (17)

where

$$a_t = \alpha'(1 - n_t - n_s), b_t = \beta_t n_t + \beta_s n_s$$  \hspace{1cm} (18)

Eqs. (15) and (17) suggest that $I_c$ coincides with $\alpha'P$ (Eq. 15) when $P$ is slight, but when $P$ is sufficiently large, $I_c$ is equal to Eq. (17). As KIRA (1976) stated, these separate linear equations can be described approximately using the following equa-
Table 5. Values of the coefficients of Eqs. (17) and (19), representing the relationship between interception ($I_e$) and precipitation ($P$).

<table>
<thead>
<tr>
<th>Coefficients</th>
<th>Plot A (Natural forest)</th>
<th>Plot B (Burnt forest)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_i$ ($= \alpha (1-n_i-n_s)$)</td>
<td>0.089</td>
<td>0.022</td>
</tr>
<tr>
<td>$b_i$ ($= \beta_i n_i + \beta_s n_s$) [mm]</td>
<td>1.9</td>
<td>0.52</td>
</tr>
<tr>
<td>$\alpha'$</td>
<td>0.79</td>
<td>0.18</td>
</tr>
<tr>
<td>$a_i'$ [mm]</td>
<td>0.095</td>
<td>0.019</td>
</tr>
<tr>
<td>$b_i'$ [mm]</td>
<td>3.2</td>
<td>1.3</td>
</tr>
</tbody>
</table>

\[ 1/I_e = 1/\left(\alpha'P\right) + 1/\left(\alpha'P + b_i'\right) \]  
(19)

where

\[ \alpha' \approx a_i, a_i' \approx a_i, b_i' \approx b_i \]  
(20)

Curves of Eq. (19) fitted to the data were shown in Fig. 9. The values of $\alpha'$, $a_i'$ and $b_i'$ used for fitting were calculated by the non-linear least square method and given in Table 5 with $a_i$ and $b_i$. MURAI (1970) and ROGERSON & BYRNES (1968) also reported nearly the same values of $a_i$ and $b_i$ in the red pine forests as mentioned before, but the values of $a_i$ estimated in the red pine/hinoki mixed forest by NISHIMURA (1973) were somewhat higher (0.18) than those of the present study.

Comparing the results of analysis of $I_e-P$ relation between the two plots, it is clear that interception storage was almost completely lost after the fire; for example, only several percent of gross precipitation ($P>10$ mm) was intercepted in the burnt forest, in contrast to more than 10\% in the natural forest. Annual interception storage was estimated at 14.0\% and 3.6\% in the natural and burnt forests, respectively, suggesting that 10\% of the annual precipitation was added to the forest floor after the fire. Taking into consideration the two extremely heavy rainfalls (216 and 218 mm) of the period studied and the poor forest stand, the value of annual interception in the natural forest (14.0\%) estimated herein was reasonable and regarded as being within the range of the interception (14.2–19\%) rate of other pine forests reported by several other authors (MURAI, 1970; ROWE & HENDRIX, 1951; ROGERSON & BYRNES, 1968).

Fig. 10. Annual water cycle in the natural (E-12) and burnt (E-5) forest watersheds. $S_1$: Water storage in soil layers, $S_2$: Water storage on bedrock.

*These water storages are assumed to change little on an annual basis.
Table 6. Comparison of annual water cycle between the burnt (E-5) and undamaged (E-12) watersheds at Etajima Island.

<table>
<thead>
<tr>
<th></th>
<th>Undamaged watershed (E-12)</th>
<th>Burnt watershed (E-5)</th>
<th>Balance (E12 - E5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_e$: Interception [mm]</td>
<td>212.2</td>
<td>55.8</td>
<td>156.4</td>
</tr>
<tr>
<td>$I_e/P$: Ratio of interception to precipitation [%]</td>
<td>14.0</td>
<td>3.6</td>
<td>10.4</td>
</tr>
<tr>
<td>$T_f + S_f$: Sum of throughfall and stemflow [mm]</td>
<td>1300.9</td>
<td>1499.3</td>
<td>-198.4</td>
</tr>
<tr>
<td>$(T_f + S_f)/P$: Ratio of sum of throughfall and stemflow to precipitation [%]</td>
<td>86.0</td>
<td>96.4</td>
<td>-10.4</td>
</tr>
<tr>
<td>$Q_d$: Direct flow [mm]</td>
<td>211.2</td>
<td>379.7</td>
<td>-168.5</td>
</tr>
<tr>
<td>$Q_d/P$: Ratio of direct flow to precipitation [%]</td>
<td>14.0</td>
<td>24.4</td>
<td>-10.4</td>
</tr>
</tbody>
</table>

Relation between interception and discharge

The annual water cycles of both the burnt (E-5) and undamaged (E-12) watersheds by fire were shown in Fig. 10. The stream discharge ($Q$), which was observed continuously throughout the year studied at the stream-gauging stations, was separated into two flows, that is, direct flow ($Q_d$) and base flow ($Q_b$) (the results and a discussion of these stream discharges will be reported in a subsequent paper).

Annual difference of discharge ($\Delta Q$) between the two watersheds was estimated at 12.4% of the annual gross precipitation, most of which, 10.4%, was due to that of direct flow ($\Delta Q_d$) (Fig. 10). After fire, transpiration by the forest canopy ($T_f$) ceases, except for $T_r$ by the regeneration, which may be comparatively small; on the contrary, evaporation from the ground surface ($E_{ev}$) may be promoted with the increasing of direct sunshine; therefore, in the present study, $T_r + E_{ev}$ varied only slightly (-2.0% of $P$) in spite of the drastic change which occurred to the forest ecosystem. Consequently, the difference of interception ($\Delta I$) or net precipitation ($\Delta (T_f + S_f)$) between E-5 and E-12 corresponded closely to that of the direct flow ($\Delta Q_d$) (Table 6). This indicates that interception by the forest canopy contributes significantly to regulation of the water cycle, especially direct flow. However, interception by herbaceous layer in the natural forest or by regeneration in the burnt forest, and the change of soil structure after the fire were not taken into consideration in this study. Thus more discussion concerning the relation between interception and discharge is warranted in order to gain further insights into subject.

References


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摘 要

1978年6月の山火によって島の森林の大半を焼失した広島県江田島において、アカマツ林が完全に焼失した集水域（完焼区）と延焼を逃された集水域（森林区）にそれぞれ調査区を設置した。そこで、林外雨、林内雨、樹幹流を一降雨ごとに、また河川流出量を連続的に測定した。測定期間は1981年4月中旬から翌年4月初旬までの1年間であった。

1. 完焼区と森林区の林外雨量には差異がみられず、ほぼ1:1の対応がみられた。また、両区の地形、母岩、焼失前の植物は良く類似していた。したがって、両区の調査結果の比較から山火が水収支、特に樹冠による降水遮断量及び河川流出量へ及ぼす影響を評価できるものと思われた。

2. 林内雨量は、樹冠の焼失した完焼区が森林区より常に多く、10 mm以上の雨量では降水量の90～97%であるのに対して、森林区では75～87%にとどまった。年間量としては、完焼区で林外雨量の94.4%、森林区で83.0%と推定された。

3. 一方、樹幹流は両区の差異は小さく樹冠を焼失していないにもかかわらず、焼失区が生じた集水域であったのがみられた。これは、アカマツに特徴的な厚い樹皮が山火でなくならなかったことが原因している。年間量としては、完焼区で林外雨量の2.0%、森林区で3.0%と推定された。

4. 結局、林外雨量から林床到達量を差し引いた遮断量は森林区で常に多く、年間量で林外雨量の14.0%であったのに対して、完焼区で3.6%にすぎなかった。

5. 完焼区と森林区の遮断量の差（林外雨量の10.4％）は、結果的には河川流出量、特に直接流出量の差に対応し、完焼区では森林区よりも林外雨量の12.4％の河川流出量の増加がみられた。このうち、10.4％が直接流出量の増加であった。