Effect of Clearcutting Deciduous Forest on Radiation Exchange and Snowmelt in Pennsylvania

D. R. DeWalle, H. A. Parrott, and J. G. Peters

Associate Professor of Forest Hydrology, School of Forest Resources, The Pennsylvania State University, University Park, Pa., 16802; Former Graduate Assistant now with U.S. Forest Service, Cass Lake, Minnesota, 56633; and Graduate Assistant, School of Forest Resources, respectively.

Abstract

Radiation exchange and snowmelt were measured in Pennsylvania at a clearcut and adjacent deciduous forest site. Net radiation in the clearcut with snow cover averaged 16 percent less than net radiation above the deciduous canopy, but 86 percent more than below-canopy net radiation. Average clearcut to forest ratios for daily snowmelt volumes, peak melt rates and net radiation at the snowpack surface were 2.23, 2.35 and 1.86 respectively. Nearly all of the average difference in melt between the forest and clearcut could be attributed to a difference in net radiation at the snowpack surface.

Introduction

Clearcutting is a commonly used reproduction cutting method in the deciduous forests which cover 43 percent of the land area in the northeast and mid-Atlantic regions of the United States (U.S. Forest Service, 1965). Although not currently a hazard in abetting spring flooding because of the small fraction of land which is cut annually, clearcutting deciduous forest can substantially alter the snow hydrology of small basins. Differences in the snowmelt runoff between clearcut and forested areas can be attributed to differences in energy supplied to the snowpack. Generally radiation is the most important energy source for snowmelt, and differences in the net radiant energy supply between forest and clearcut sites should index melt rate differences. The net radiation energy supply is equivalent to the algebraic sum of incoming and outgoing solar and longwave radiation flux densities. Incoming solar and longwave radiation above a forest or clearcut should be similar for adjacent sites. However, differences in site albedo or solar reflectivity and surface temperature will cause differences in outgoing solar and outgoing longwave radiation respectively.

This paper presents a comparison of the winter radiation budgets and lysimeter snowmelt characteristics of a clearcut and adjacent deciduous hardwood forest as part of an evaluation of the effects of clearcutting on snowmelt in Pennsylvania. DeWalle and Lynch (1975) have reported on the effects of the clearcutting on basin snowmelt runoff in Pennsylvania and Lynch et al. (1973) reported the effects of clearcutting on stream water quality and quantity.

Study Area

The forest and clearcut sites were located on Leading Ridge Watersheds 1 and 2, respectively, at the Stone Valley Experimental Forest southwest of State College in central Pennsylvania. The latitude and longitude of the study area are 40.67°N and 77.75°W respectively. The ground at the sites, which are at the same elevation, is inclined at 5.5° with an azimuth of 155° (SSE).

The forest site was located in an uneven-aged mixed oak stand. The forest overstory was dominated by red oak (*Quercus rubra* Michx.f.) and white oak (*Q. alba* L.) with an understory of flowering dogwood (*Cornus florida* L.) and red maple (*Acer rubrum* L.). The basal area of the forest was 29.4 m^2ha^{-1} and the general canopy height was 29.5 m. The clearcut site was located in an area which was logged during the winter of 1971-72. Slash on the clearcut was lopped and scattered following logging. Vegetation regrowth at this site was primarily stump sprouts of white oak, red oak, and red maple plus blackberry (*Rubus alleghensis* Porter). By fall 1973 some stump sprouts were 2 m high. Herbicide was applied to the clearcut in summer 1974.

Methods

Two separate studies were conducted. During the winters of 1972-73 and 1973-74, data were collected for comparison of radiation budgets *above* the forest canopy and the clearcut. During the following two winters (1974-75 and 1975-76), net radiation and lysimeter snowmelt were measured in the clearcut and *below* the forest canopy.

In the first study, net radiation and reflected solar radiation were measured from towers above the clearcut and forest sites. Incoming solar radiation was measured at the clearcut site. Kipp pyranometers were used for solar radiation measurements, while Fritschen net pyrradiometers were used to obtain net radiation data. Solar radiation exchange was measured during 19 days with complete snow cover, two days with incomplete snow cover, and three days without snow. Net radiation above each site was measured concurrently with solar radiation on 11 of the days with complete snow cover and two of the snow-free days. The duration of each radiation measurement period was approximately 24 hours. Measurement periods typically started between 0830 and 0900 EST during the winter of 1972-73 and at 0700 EST during the winter of 1973-74. Snow depth was measured at three stakes at each site at the beginning and end of each measurement period. Details of the measurements are given by Parrott (1974).

Daily totals of radiation components were used to compute the albedo, net solar and net longwave radiation exchange. Albedo was calculated as the ratio of the reflected solar radiation measured at each site to the incoming solar radiation measured at the clearcut site. Net solar radiation was computed as the algebraic sum of incoming and reflected solar radiation. Finally, the net longwave radiation exchange was computed as the difference between measured net radiation and net solar radiation.

In the second study, net radiation was measured with a Funk net pyrradiometer over a snowmelt lysimeter in the clearcut and forest. Fifteen days of net radiation measurements with a variety of snow cover conditions were recorded. Radiation data for the forest was collected for an additional three days and the corresponding clearcut values estimated using regression equations. Each daily radiation period was taken as time interval between the points at which net radiation changed from positive to negative on two successive days. Characteristically, the measurement periods began and ended at about 1700 hrs. EST. These periods were subdivided into negative and positive radiation segments which generally coincided with night and day respectively.

Each snowmelt lysimeter was composed of a wooden frame which supported a 19 m^2 wire mesh covering. The frames were placed flush with the soil surface in shallow holes lined with sheets of plastic and covered with litter to represent a natural surface. A trough located at the bottom edge of each plastic sheet collected melt water which emptied into a metal drum placed in a pit further downslope. Plywood was placed over the pits and covered with snow to prevent freezing. Each drum was fitted with a 15° V-notch and FW-1 water-level recorder which provided a continuous stage-time hydrograph record. A stage-discharge curve was constructed for each 15° V-notch drum and incorporated into a computer program for hydrograph analysis. The program made computational adjustments for such problems as debris lodged in the notch and the separation of overlapping melt events.

Results and Discussion

Clearcut and above-canopy radiation comparisons. Measurements of solar radiation exchange above the leafless deciduous forest and clearcut during days with and without snow cover are summarized in Table 1. During periods with incomplete or no snow cover the mean albedo of the forest and clearcut were not significantly different ($P = 0.05$). The albedo of the forest with incomplete or no snow cover averaged 0.12 compared to 0.13 for the clearcut. The presence of a complete snow cover significantly increased the mean albedo of both the forest and clearcut to 0.22 and 0.44 respectively. Although the mean albedo for the clearcut was significantly greater than the mean albedo for the forest with snow, the difference in albedo between the sites varied with snow depth.

The relationship between albedo and snow depth for the clearcut and forest site is shown in Figure 1. The relationship appears linear over a broad range of snow depths with the albedo of the clearcut well over twice the forest albedo for deep snow. However, the albedo of each site converges rapidly as snow depth approaches zero. Albedo variations at a given snow depth were caused by fresh, light snowfalls.

A comparison of longwave radiation exchange between sites for 11 periods with snow cover and two snow-free periods is presented in Figure 2. Longwave exchange was negative representing an energy loss for both sites on all days. During snow-free dormant season periods there was little difference in the net longwave exchange of the clearcut and forest sites. However, for the 11 measurement periods with snow cover, net longwave radiation was 27 percent greater at the clearcut site.

Since longwave radiation received from the atmosphere by the adjacent forest and clearcut sites was equal, differences in net longwave radiation exchange can be related to surface temperature differences. Black-body radiation at 0°C varies about 0.0066 cal $(cm^2 \text{ min } °C)^{-1}$ or 9.5 cal

Table 1. Mean and Range of Daily Albedo for Leafless Deciduous Forest and Clearcut Sites with and without Snow Cover

	Number of Days	Forest		Clearcut	
		Mean	Range	Mean	Range
complete snow cover	19	0.22	0.15-0.30	0.44	0.26-0.65
partial cover or no snow	5	0.12	0.10-0.13	0.13	0.11-0.14

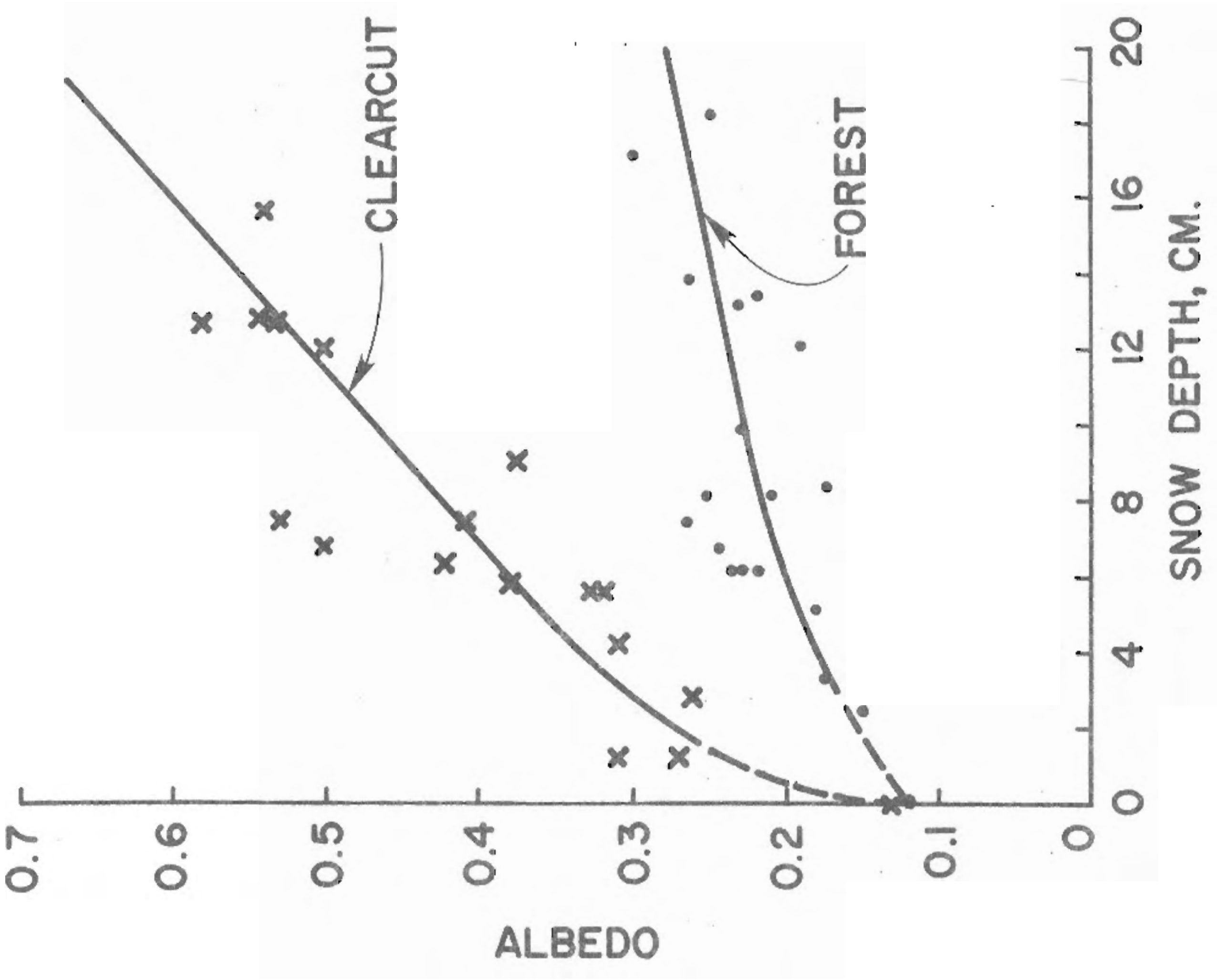


Figure 1. Albedo of the deciduous forest and clearcut sites as a function of snow depth.

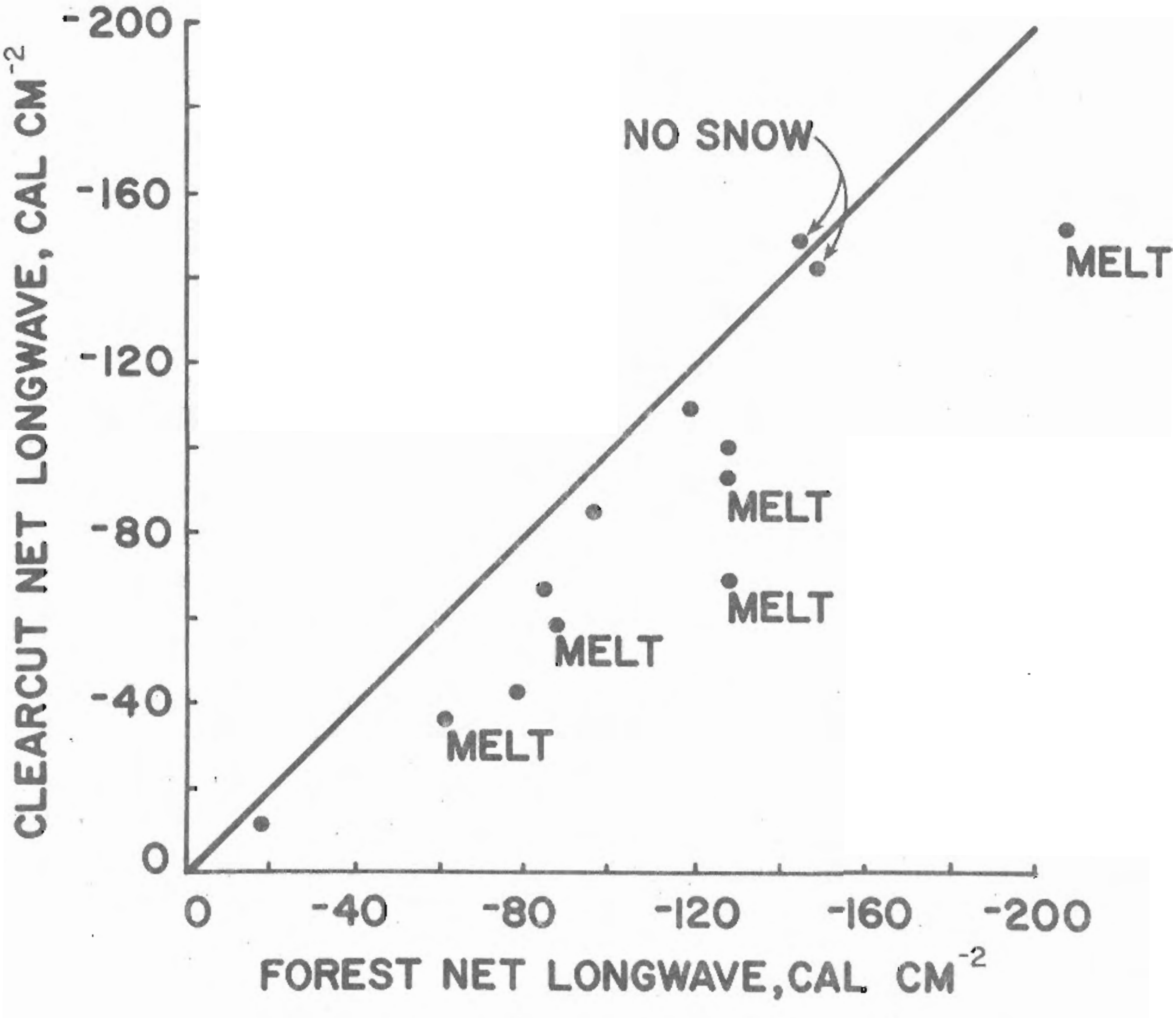


Figure 2. Comparison of net longwave radiation above the deciduous forest to that in the clearcut for 11 days with complete snow cover and 2 days with no snow. Days with snowmelt are indicated.

$(cm^2 \text{ day } °C)^{-1}$. On 16 January 1974 when the greatest difference (forest minus clearcut) in net longwave radiation exchange of -59 cal cm^{-2} day^{-1} occurred between sites, the average surface temperature of the forest was apparently 6.2°C greater than the clearcut surface temperature. On other days with snowcover, the surface temperature of the forest was also greater than the surface temperature for the clearcut, but differences were not as great. The snowpack with an upper temperature limit of 0°C dominates longwave radiation emitted from the clearcut, while longwave radiation emitted from the forest is dominated by the canopy which can be heated to considerably higher temperatures. This is especially noticeable in Figure 3 for the warmer snowmelt days when snowpack temperatures were limited to 0°C. Differences in apparent surface temperature for the five melt days averaged 4.2°C, compared to 1.9°C for non-melt days.

Net radiation differences between the forest and clearcut sites were due to the combined effects of clearcutting on net solar and net longwave radiation. During periods with snow cover the mean net radiation of the clearcut site was 16 percent less than the mean net radiation measured above the forest site. The lower net radiant energy supply at the clearcut site can be traced to lower absorbed solar radiation caused by a higher albedo. In contrast, during the two snow-free periods, net radiation at the clearcut and forest sites was nearly equal.

Clearcut and below-canopy radiation comparisons. Total net radiation over the entire measurement period is the algebraic sum of radiation for the positive and negative radiation periods. Ratios of clearcut to below-canopy forest net radiation for the total period averaged 1.86. On two occasions total net radiation was negative in both the clearcut and forest. On these days nocturnal longwave losses were more than sufficient to offset the meager amounts of daytime solar. Such a condition occurred when clear nights were followed by cloudy days. On one of these two days, nocturnal loss and daytime gain of radiation in the clearcut produced net radiation nearly equal to that in the forest.

At night the forest canopy radiates energy stored as the result of solar radiation absorption on the previous day. Part of this radiant energy is directed downward, thereby minimizing net surface heat losses. During the 15 periods for which net radiation was measured at both sites, clearcut nocturnal net radiant heat losses averaged 1.94 times greater than losses measured beneath the canopy.

During daylight periods, a significant portion of the incoming solar is absorbed by the canopy increasing the temperature of tree stems and boles. Though part of this energy reaches the surface as longwave radiation, it does not compensate for the decrease in incoming solar during the day. Thus, measured net radiation averaged 2.10 times greater at the clearcut site than in the forest during daylight.

Average net radiation at forested and clearcut sites was affected by cloud cover. Ratios of clearcut to below-canopy forest net radiation for positive radiation periods were 2.27, 2.09, and 1.78 under clear, partly-cloudy, and overcast skies, respectively, illustrating the tendency of increasing cloud cover to reduce daylight net radiation differences between the two sites. No measure of cloud cover was available for nocturnal periods.

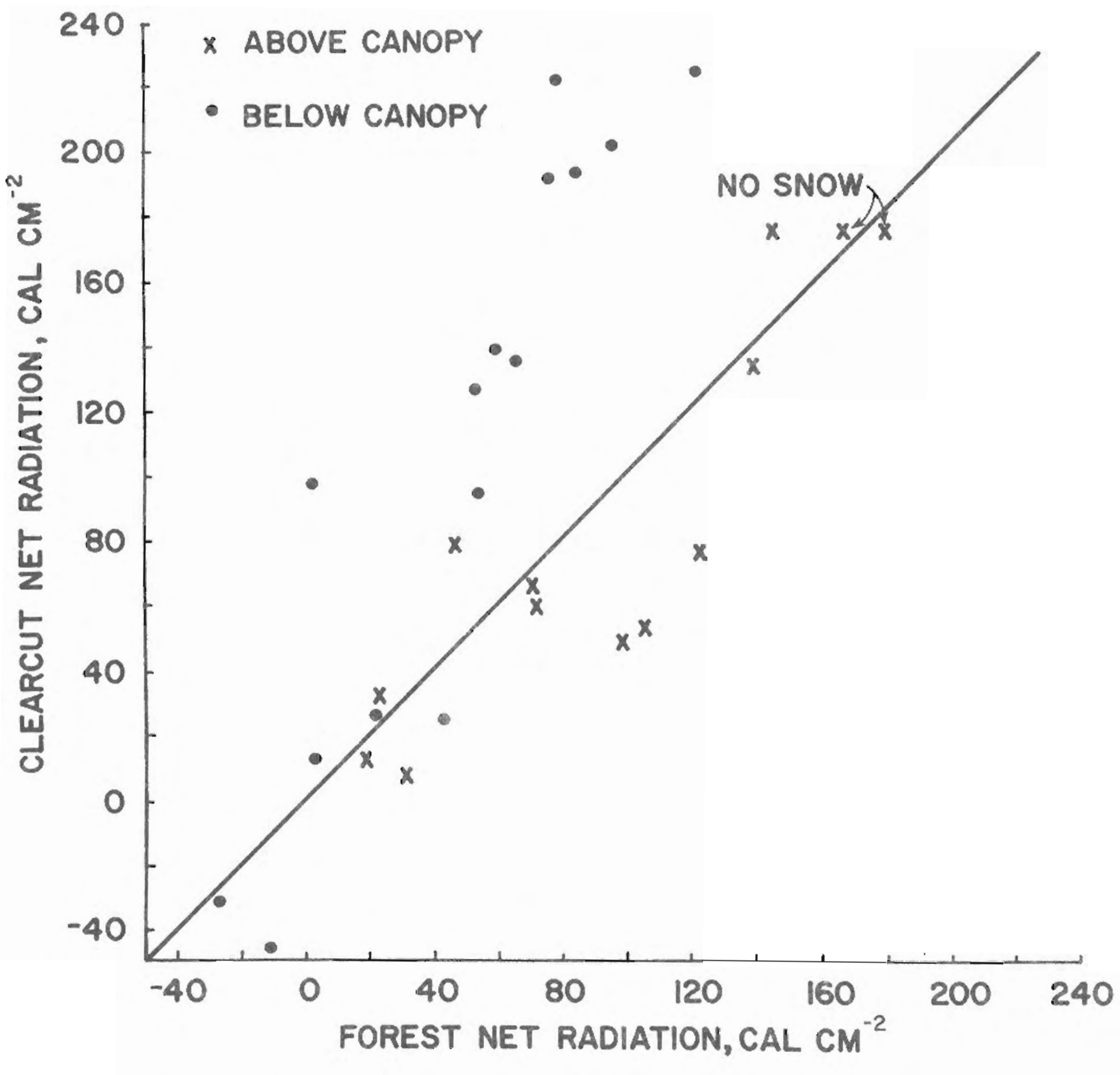


Figure 3. Net radiation at the clearcut site and above and below the deciduous forest canopy.

Table 2. Lysimeter Snowmelt Comparisons at the Deciduous Forest and Clearcut Sites

	Total Melt, mm			Peak Melt Rate, mm min^{-1}		
Date	Forest	Clearcut	Ratio	Forest	Clearcut	Ratio
2-10-76	0.9	1.7	1.89	70	107	1.53
2-11-76	8.6	15.0	1.74	415	699	1.68
2-11-76	3.7	6.6	1.78	238	572	2.40
2-12-76	1.4	5.7	4.07	100	324	3.24
2-13-76	12.5	14.7	1.18	339	457	1.35
3-10-76	2.2	6.0	2.73	158	613	3.88
Mean Ratio			2.23			2.35

Ratios of clearcut to forest net radiation were not well-correlated with areal extent of snow cover. A comparison of average clearcut to below-canopy net radiation ratios on days with complete, partial and depleted snow cover revealed no significant difference ($P = .05$). As the melting snowpack exposed more bare surface, albedo decreased but longwave emission tended to increase because of higher surface temperatures. The two effects had opposite and apparently offsetting influences on net radiation. Thus, net radiation ratios remained essentially the same.

In Figure 3 net radiation data from above and below the canopy and in the clearcut are compared to illustrate the effect of the forest canopy. On days with snow cover, net radiation was consistently greater above the canopy than it was in the clearcut, but the reverse was true on four days with shallow or absent snow cover. Daily net radiation was generally higher in the clearcut than beneath the canopy. In the clearcut net radiation averaged 16 percent less than above-canopy net radiation but 86 percent more than below-canopy net radiation. Net radiation above the canopy was approximately 2.22 times greater than that below the canopy.

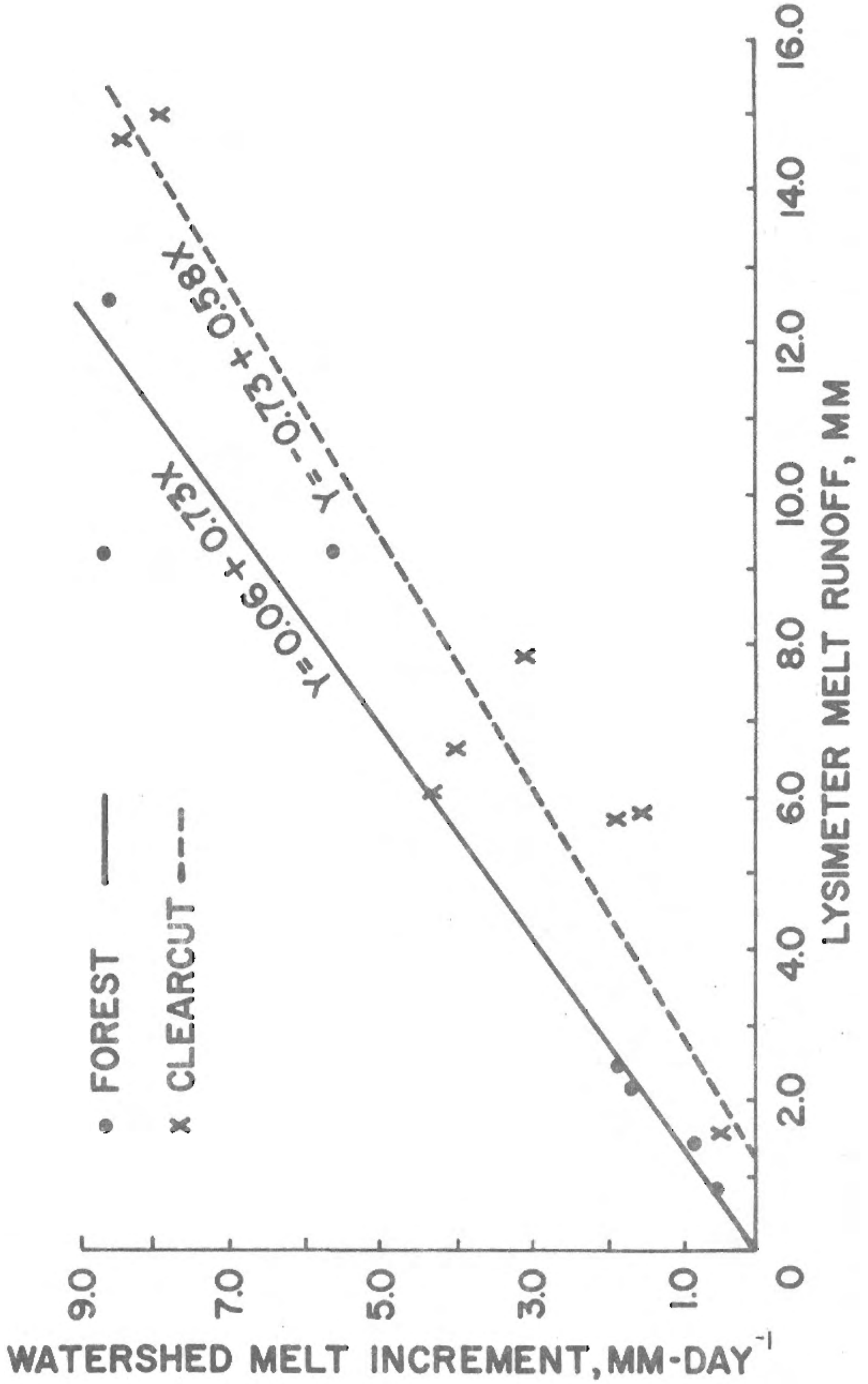
Snowmelt and net radiation in forest and clearcut. During the winter of 1975-76 six melt events were recorded with complete snow cover at both forest and clearcut sites. In Table 2 total melt and peak melt rates are compared for the six events. Daily melt totals and peak melt rates in the clearcut were greater by an average of 123 and 135 percent respectively. Greater melt increases tended to occur on clear days when net radiation differences between sites were greater.

Based upon average net radiation and melt measurements, the fraction of the increase in snowmelt in the clearcut caused by increased net radiation was estimated. Beginning with daily snowmelt in the forest of 0.5 cm, the melt in the clearcut was estimated to be 1.1 cm. using the average melt ratio of 2.23. For the average daily net radiation in the forest of 50 cal cm^{-2}, daily net radiation in the clearcut was estimated to be 93 cal cm^{-2} using the average net radiation ratio of 1.86. The average net radiation difference of 43 cal cm^{-2} between forest and clearcut is equivalent to about 0.54 cm melt or 90 percent of the estimated melt difference. Thus, nearly all of the increased melt in the clearcut can be attributed to increased net radiation.

Although nearly all of the melt difference between sites may be due to net radiation, net radiation alone is not a good index to daily melt at each site. For days when concurrent measurements of melt and net radiation data were available (four days in the forest and one in the clearcut), net radiation melt equivalent ranged from 9 to 90 percent of daily melt in the forest and 22 percent of daily melt for one day in the clearcut. Estimates of other heat exchange components, especially latent and sensible heat exchange, are also needed to predict melt.

Comparisons were made between various lysimeter and watershed hydrograph parameters. DeWalle and Lynch (1975) determined after testing five basin hydrograph parameters at Leading Ridge that discharge increment, the daily peak snowmelt discharge minus initial discharge, demonstrated a good response to clearcutting and was best correlated with meteorological variables. Figure 4 presents a comparison of forest and clearcut lysimeter melt volumes

Figure 4. Relationship between watershed runoff melt increment and total lysimeter melt runoff for the forest and clearcut. Melt increment is defined as the difference between daily peak melt runoff rate and the runoff rate before melt began.



and watershed discharge increments for days with complete and partial snow cover. The coefficients of determination (adjusted for degrees of freedom) are 0.89 for the forest and 0.88 for the clearcut. They suggest that snowmelt lysimeters can be a useful tool in predicting responses to snowmelt on Leading Ridge Watersheds.

Summary

During periods with snow cover the clearcut exhibited a higher albedo but lower surface temperature than adjacent deciduous forest. Differences in albedo between the sites usually prevailed producing net radiation at the clearcut which averaged 16 percent less than for the forest. Without snow cover, the radiation budgets of the forest and clearcut were remarkably similar.

Clearcutting increased net radiation at the snowpack surface by 86 percent with greatest increases occurring on clear days. Increases in net radiation occurred during daylight, since nocturnal net radiation was consistently greater in the forest.

Daily snowmelt volumes and peak melt rates were 123 and 135 percent greater, respectively, in the clearcut with the greatest melt increases occurring on clear days. Nearly all of the average differences in lysimeter melt between forest and clearcut was attributed to net radiation differences between sites. Lysimeter melt was also found to correlate well with watershed snowmelt runoff.

Acknowledgments

Support for this study was provided by the School of Forest Resources, McIntire-Stennis Project 1991 and the Institute for Research on Land and Water Resources of The Pennsylvania State University. Published with the approval of the Director, Pennsylvania Agricultural Experiment Station, Journal Series No. 5264. Authorized for publication 3/22/77.

Literature Cited

DeWalle, D.R. and J.A. Lynch, 1975. Partial forest clearing effects on snowmelt runoff. ASCE, Irrigation and Drainage Div., Proc., Symp. Watershed Management, Logan, Utah, pp. 337-346.

Lynch, J.A., et al., 1973. Effects of management practices on water quality and quantity, Penn State Experimental Watersheds. Symposium on Management of Municipal Watersheds, U.S. Forest Service, Northeast Forest Exp. Sta., Tech. Report NE-13, 1973.

Parrott, [illegible] A., 1974. Radiation exchange and snowmelt characteristics at deciduous forest and clearcut sites in central Pennsylvania. M.S. Thesis, The Pennsylvania State University, 132 pp.

U.S. Forest Service, 1965. Timber resources for America's future. U.S. Forest Service Report No. 14, 713 pp.