SNOW INTERCEPTION AS INFLUENCED BY FOREST CANOPY VARIABLES

by

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INTRODUCTION

The interception of falling snow by forest trees is one of the significant effects of forests on supplies of snow water. Most forest trees offer a canopy on which a sizeable fraction of the falling snow becomes lodged and is kept from immediately reaching the ground or snowpack surface of the forest. This snow is exposed on all sides to evaporation losses. An understanding of the relationships between tree crown characteristics and the proportion of snow reaching the ground as throughfall and snowslide is essential to control such loss.

The primary objectives of this study were to determine whether forest treatments such as timber harvesting, tree planting, thinning, pruning, and type conversion affects the snow interception storage capacity of forests. Other objectives were to determine the effects of geometrical characteristics of the forest canopy on snow-interception storage. The forest itself may be characterized by such attributes as type, density, arrangement, and basal area.

The study was designed to determine the effects of crown geometric shape, density (leaf area index), and foliage distribution on snow-interception storage. On the other hand, it was also designed to evaluate the effects of stand arrangement and crown closure on snow catch.

LITERATURE REVIEW

Factors influencing the amount of snow lodging in a forest canopy include snow characteristics, air movement, and the geometry of the forest biomass (Jeffrey 1973). Hoover (1962) pointed out that trees with dense, stiff foliage, horizontal or upturned stiff branchlets, considerable vertical spacing between branches, and which are closely crowded together, hold a maximum of snow in their crowns.

CROWN SHAPE

Trees can take so many shapes that it would take an infinite number of parameters to express all of them accurately. Horn (1971) found a simple equation that can represent a wide variety of shapes in transverse vertical section, with only a few easily interpreted parameters; that is

$$X^a + (bY)^a = c^a$$

where X and Y are variable Cartesian coordinates and a, b, and c are constants (X and Y are position variables which describe the position of every point on the primeter of the vertical plane; a, b, and c depend on the characteristics of the specific "shape" of the crown). This equation behaves nicely in the quadrant where X and Y are positive. When a = 1, it is a straight line; when a = 2, it becomes convex and bows out from the origin to form part of an ellipse; if (a) is larger than 2, it is more convex, becoming rectangular as (a) approaches infinity. The ratio of height to width is measured by (b) and the absolute size by (c).

We can therefore represent the shape of a tree with only three parameters, each having a simple geometrical interpretation, size, ratio of height to width, and convexity.

The type of morphology of the vegetation cover affects the variation of interception loss. Delfs (1967) compared snow interception in spruce varieties with different crown shapes; it was least in "Kammfichte" (comb spruce) and greatest in "Burstenfichte" (brush spruce = spruce with side branches which rise sharply upward). A photographic report (Anonymous 1954 as cited by Miller, 1964) shows natural selection among races of spruce, particularly the contrasting "Kammfichte" and "Plattenfichte" (flat spruce). The flat spruce has spreading horizontal branches and is more vulnerable to snow break, but is strong in ice and rime loading.

Wide separation of branch whorls in Scotch pine is described by Miller (1966) as reducing the surface storage for snow, in spite of its long needles. Models of separated stacked boards show greater relative catch per board when they are separated, but the separations were not large, and this result may reflect transport of snow into the interior of the stack (Japan (1952) cited by Miller (1964)). Some idea of deposition of snow from an air stream can be gained by studying Japanese measurements of snow load on models and on a tree. The snow load on models was measured with reference to that received on a flat, elevated board, and it has been computed at zero and one meter per second wind speed (Miller 1964). Deposition of snow on flat, exposed boards decreased by 35 per cent and a stack of shelves or a pyramidal stack of shelves increased by 140 per cent, but on solid pyramid and crown of cryptomeria it decreased 30-40 per cent. The decrease of snow on the tree at a wind speed of 1 m/sec. is like that on the solid pyramid, where all snow accumulates on the outer surface.

FOLIAGE DENSITY

Crown depth, crown volume, and crown density are more undefined characteristics than are crown coverage or crown closure, the first group can characterize the three dimensional nature of a forest canopy. These characteristics can be used as an index of interception of precipitation or radiation (Miller 1961), both of which bear certain analogies to each other. Horn (1971) used a method to measure the proportion of unobscured sky directly above each sapling in the forest by photographs, and he constructed histograms of the amount of shade cast by each species of canopy tree. Satterlund and Haupt (1967) used the leaf-area-index (ratio of leaf surface area to projected area) as a factor to compare snowfall interception storage of lower vegetation and that of trees and shrubs.

Miller (1964) commented that surface area and volume of foliage play a role in interception storage but their exact importance is not well defined. Love (1955) observed that insect-killed lodgepole pine and Engelmann spruce, which had lost needles and finer branches, intercepted less snow than live trees but he was unable to estimate the relative importance of the remaining branches which still intercepted some snowfall.

FOLIAGE DISTRIBUTION

Horn (1971) defined two different spatial distributions of leaves in a plant community. His distributions were stated as: 1) monolayer and 2) multilayer, or leaves loosely scattered among many layers. A monolayer can obviously expose no more than one unit of self-sustaining leaf area for each unit of ground area. A multilayer, however, can expose much more leaf area, and its leaves pay for themselves if they are small and far enough apart so that no leaf completely eclipses the sun from any leaf in the next layer.

Zinke (1967) summarized the results of the American interception studies and pointed out that:

1. Interception storage is greater for trees in forests than for isolated trees, because of leaf distribution and other factors.

2. Interception losses vary with species and forest types because of thickness and density of foliage and crown. Generally, tolerant species intercept more than intolerant, climax more than preclimax.

Miller (1964) believed that the ratio between branchwood and stem size is an important factor in interception storage. He said that the stands damaged worst in a severe storm in 1916 were in an age class in which dense stocking produced slender, high-crowned trees. Molnau (1973) showed that branch angle does have an effect on snow-interception and that this effect is represented by more interception by trees with smaller angle. Hoover (1962) believed that the vertical spacing between branches is an important factor in snow deposition on crown canopy.

CROWN CLOSURE

Observations made by Morey (1942) in central Vermont indicated that a correlation may exist between the degree of snow-interception and crown density, stem density, and stem size. He compared crown depth and closure and concluded that a stand with more trees per acre and thinner canopy intercepts less snow than one with fewer trees and deeper canopy.

Johnson (1942) concluded that, under specific condition, an average of 81.4 per cent of the total precipitation reached the ground under the ponderosa pine tree-crown. Yet this amount varied significantly among the watersheds, probably because of a variation in density of the crown closure.

Snow depth and water equivalent were measured in each of the vegetation types in Tuolumne County, California by Kittredge (1953). The total depth of snow was found to be greatest in the open areas or in the stands with large openings. The smallest water equivalents were found in the dense white fir type and ponderosa pine stands.

Twelve measurements of the canopy density were obtained at each sampling station in the Upper Columbia River Basin with a "ceptometer," a type of spherical densiometer by Packer (1962). The amount of water in the snowpack increased 4.2 inches as the vertical density of the forest canopy was reduced from 100 per cent in density stocked stands to zero in clear-cut and natural openings. Because the forest canopy effect was uniform in all aspects, the effect on snowpack water is inferred to be due primarily to interception losses rather than differential melting during the snow accumulation period.

CROWN DISTRIBUTION

Canopy interception is a function of biomass and spatial arrangement of vegetation cover, in addition to other factors. Cover modification or removal, influences the amount of precipitation reaching the earth's surfaces, and accordingly the magnitude of interception loss (Gray 1973).

Results of research on managing forest snowpacks by Anderson (1969) have indicated that forest cutting patterns and forest-terrain interaction have a major impact on snow accumulation, snowmelt, and water yield.

Snow accumulation as affected by three types of logging in a red fir forest was studied by Anderson and Gleason (1959) in the snow zone of the Cascade-Sierra Nevada mountains of California. First year results show that all three methods of logging-- strip cutting, block cutting, and commercial selection cutting-- increased maximum snow accumulation and decreased annual water losses by interception. At maximum snowpack there was an average of 8 to 10 inches more water in strip cutting area than in the adjacent uncut forest; the block-cut and commercial diameter-limit cut areas had 5 to 7 inches more than the uncut forest.

METHODS

MODELS AND VARIABLES

To evaluate the effects of crown shape and foliage density on snow-interception storage, 32 tree models with identical projected area and different shape and foliage density (leaf area index) were employed in this study. The tree models were constructed of artificial dwarf-juniper-like branchlets made of plastic (composition unknown) which were obtained from a floral supply firm, and 3 mm diameter aluminum wire. Eight stand models with different arrangement and spacing were used to determine the effects of stand closure and crown distribution on snow-interception storage. The stand models were made of tree models hanging from 76 by 76 cm wire frame.

Shredded polyethelene film was used to simulate falling snow in this study. Molnau (1973) tested sawdust, soap flakes, and shredded polyethelene as artificial snow. The shredded polyethelene film was suitable for modeling interception of dry light snow on trees because of the manner in which it accumulates on the tree, the mounding effect as it is caught, and the manner in which the individual particles are caught by the needles.

A single module of a snowfall apparatus designed and reported by Molnau (1973) was used in this study. The screen was made of 0.5 mm polyester sheet by punching 6 mm in diameter circular holes in a grid pattern (2.5 x 5.0 cm) attached to an 80 x 80 cm wooden frame. It allowed all but the coarser material to pass through the screen. The module was connected to an electric shaker by a special type of spring to fix the screen vibration speed.

The trial runs were made on all stand models and individual tree models for durations of 30, 60, and 120 seconds, yielding consistently 0.4, 0.8, and 1.6 grams per 100 square centimeters of snowfall.

Tests were also conducted to determine the uniformity of snow coverage of the net area (76 X 76) within the snowfall simulator. Nine cylindrical shaped snow gages were placed on the floor in both a grid pattern and irregular positions. The first part of this test resulted in a mean of 2.7 grams per gage and a standard deviation of 0.6 grams. The range was from 2.0 to 3.5 grams. The second part of this test resulted in a mean 2.65 grams per gage and a standard deviation of 0.65 grams. The range was from 1.8 to 3.7 grams.

PROCEDURE

The trials were conducted in the following fixed sequence to insure consistency of any procedural errors or bias.

1. Evaluating the effects of tree crown characteristics on snow-interception storage.

A system for automatically recording weight changes was designed and used in this study. The stem of the tree model was passed through the middle of a circular hole on a small plastic table and stuck to a piece of sponge mounted on a very sensitive electronic scale. The small plastic table covered all parts of the electronic scale. In this position the balance was showing the mass of the tree model and any snow deposition on it. All tree models were used to measure snow-interception in this procedure.

Snow depositions on each tree model crown were measured at three levels of storm duration; 30, 60, and 120 seconds. The snowfall depths and masses were checked during the trials with a cylindrical snow gage mounted under the snowfall simulator. This snow gage had a cross-sectional area precisely equal to projected area of tree models (123.33 cm^2).

2. Evaluating the effects of stand characteristics on snow-interception storage.

For simulating different stands of trees, 18 to 42 tree models were hung in different patterns from a thin wire screen fixed solidly to a 76 by 76 cm wooden frame. For example, 42 tree models were hung in grid pattern (12.7 by 10.9 cm) from wire screen to yield 92.61 per cent crown closure.

The amount of intercepted snow by the stand canopies was calculated by subtracting throughfall (accumulated snow under the stand canopy) from total snowfall. Snow accumulation under the stand canopies was measured automatically by a 76 by 76 cm cardboard sheet mounted on an electronic scale.

RESULTS

Snow-interception tests were conducted on both single tree and stand models to enable some comparison between the forest and the isolated tree. Each type will be discussed separately and a general conclusion will be made.

Even though the simply-designed snowfall simulator and other elements of the experiment did not allow control over all appropriate variables, relatively useful results were obtained. These results show the effect of tree and stand geometrical characteristics on the rate of snow-interception storage. They further show some effects of storm size on snow deposition over the tree and stand canopy. The results indicate that the potential amount of snow interception loss in forest stands can be estimated from basic characteristics of the precipitation and the forest.

The amount of snow-interception storage on ellipsoidal-shaped tree crowns was more than storage on conic-shaped tree crowns when the leaf area index (LAI) was 3 for all levels of foliage distribution. For the other LAI values (2, 4, and 5) responses were less striking and limited to the trees with H/D value of 1.5 and 2.0.

There was a highly significant difference between trees with different leaf area indices, trees with dense foliage (LAI = 5) showing the greatest snow-interception storage and trees with sparse foliage having the smallest snow loads. These differences were not so large on trees with low vertical spacing (H/D = 0.5) especially on conic-shaped trees because of snow sliding from crown surfaces.

The extremely high interception storage value for the dense ellipsoidal tree crowns led to a highly significant interaction between crown shape and leaf area index.

Trees with ratio of crown height to diameter equal to two (H/D = 2) had the maximum intercepted snow when the leaf area index was greater than 3 for both shapes. Only the trees with sparse crowns (LAI = 2) and ellipsoidal shape responded to change in the H/D ratio. The interactions between foliage distribution and leaf area index and also foliage distribution and crown shape were significant and there was a significant difference for interaction between crown shape, foliage distribution, and leaf area index. This significant difference points out clearly that ellipsoidal trees with dense foliage and considerable vertical spacing had the maximum snow interception storage.

There was a significant difference between different storm sizes for conic and ellipsoidal trees with sparse foliage (LAI = 2) but for dense and intermediate dense trees (LAI = 3, 4, 5) there was no significant difference between storm sizes.

EFFECT ON SNOW-INTERCEPTION STORAGE BY FOREST STAND

There were highly significant differences between pooled means for crown distribution, crown closure, and storm size. The stand with regular crown distribution (grid pattern) had higher snow-interception storage than the stand with random crown distribution in all closures for any storm size. The extremely high snow deposition over the regular stand with high crown closure led to a highly significant interaction between stand density and crown arrangement.

Snow-interception storage increased with the percentage of crown closure in all storm sizes and crown arrangements. There was a positive linear relationship between crown closure and interception storage with coefficient of determination between 0.88 and 0.98.

There was no significant difference between both regular and random crown distribution for different storm sizes in low and intermediate crown closure values (up to 66.15 per cent). Conversely the difference between storm sizes was highly significant for high crown closure values (79.38 and 92.61 per cent). In regularly distributed stands maximum snow was intercepted in the intermediate storm size because in big storms overloaded branches shed their snow loads.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

The model studies on snow-interception storage provide numerous detailed conclusions that are useful to watershed managers and silviculturists. Some of the most significant are:

1. The amount of snow catch by tree crown is related to the geometric shape of crown; species with ellipsoidal or spherical crown catch more snow than those with conical crowns. The difference is more significant for dense foliage trees.

2. The leaf area index is an important parameter in the rate of snow-interception storage and it can be described as a function of foliage density (trees with high leaf area index value have larger interception storage capacity than those with lower leaf area index).

3. The ratio between crown height and crown diameter reflects the type of foliage distribution and the rate of vertical spacing within foliage. Tall crown trees with considerable vertical spacing catch more snow than short crowns with closely crowded branch whorls.

4. The amount of intercepted snow varies by storm size in a manner similar to that reported by Satterlund and Haupt (1967). It appears that heavy snow loads on flexible branches bend them downward, and at some point trees can hold no more snow.

5. Snow storage in the stand canopy is related to the arrangement of the crowns in the forest stand. The stands with regular crown distribution catch more snow than those with irregular crown distribution and variable opening sizes.

6. In the forest stand the increase in snow-interception storage appears to be directly proportional to the percentage of crown closure.

Snow accumulation beneath a forest canopy can be increased by silvicultural treatments of the tree crowns. Replacing ellipsoidal species with "conical" species in the forest stand would probably decrease snow-interception storage about 15 per cent. Shortening tree crown by pruning lower branches to reduce the crown height ratio or thinning out the tree crown by removing branches to reduce leaf area index would probably decrease intercepted snow by about 21 to 43 per cent.

After planting in a clearcut area (afforestation) the amount of accumulated snow would be related to the pattern of tree plantation. The provision of openings sharply increases snow accumulation; conversely stands with uniform sapling distribution and closely crowded together catch most of the snowflakes and accumulate minimum snow on forest floor. The effects of other silvicultural treatments such as timber harvesting, thinning, road constructing, and prescribed burning on the size of snow accumulation are related to the intensity and severity of the treatments.

It is further concluded that physical models of trees and stands can be used to study the effect of various forest and climate parameters on interception loss, especially on snow accumulation and water yield.

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