The Effects of Elevation on Productivity of *Betula papyrifera* Growing on Mount Mansfield in Underhill, Vermont

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ABSTRACT

This study intended to demonstrate patterns in growth production of *Betula papyrifera* growing at elevations of 730, 820, 910, and 1000 meters in Underhill, Vermont. *Betula papyrifera* competes well at upper elevations on mountains, and is tolerant to cold weather and extreme conditions while intolerant to light limitations. Production, calculated as dbh/age, was therefore hypothesized to decrease with increasing elevation because less favorable growing conditions, such as high wind, short growing season, and low temperatures, exist at upper sites. Alternatively, age specific productivity, or production within dbh size classes, was hypothesized to show maximum production levels decrease in age as elevation increased due to the need of younger trees at high elevations to establish themselves quicker to compete in a harsh environment. Two trees in each in each of five dbh classes were randomly sampled along horizontal transects at each elevation to obtain increment cores and dbh measurements. Age was determined from the number of rings observed from the increment cores. Results suggested mean production did not decrease with increasing elevation but rather demonstrated production across elevations varying around an overall mean of 0.285 cm/yr. Age specific production did not decrease with increased elevation and demonstrated maximum production levels at different ages for each elevation with no noticeable pattern. This was speculated to be due to *Betula papyrifera's* response to random gap disturbances instead of elevation-caused environmental factors. Highest production occurred in a 48 year old tree in the highest dbh class, growing at 1000m. Lowest production occurred in an 85 year old tree in the second dbh class growing at 910m.

INTRODUCTION:

Paper birch, *Betula papyrifera,* is a northern species adapted to cold climates. Its range is bound by the 13C July isotherm. In general the climate where paper birch is found has short cold summers and long cold winters during which the ground is covered with snow for long periods (Grant, 1975). Paper birch grows in almost any soil and topographic situation ranging from steep, rocky outcrops of the mountains, to flat muskegs of the boreal forest. Best development and growth are on the deeper well drained sandy loam on drier that average conditions (Whitney, 1988). In New England, paper birch tends to be more abundant on the dry sites than on the wet or poorly drained soils (Hutnik, 1965). Paper birch is extremely tolerant to cold and competes best in colonizing newly opened forested sites (Tang & Kozowski, 1982). Paper birch is commonly found in the mixed hardwood-conifer forests but may form nearly pure stands where they pioneer areas disturbed by fire or logging (Burns, 1990). Paper birch is very intolerant to shade and is usually replaced by other species as a canopy develops and light becomes limited (McClure & Lee, 1992). Life span rarely exceeds 140 years for this short lived species. The diameter at breast height (dbh) ranges from 17.2cm to 25.5cm: with the greatest mean diameter occurring at 1000m elevation (Whitney, 1988). Above ground net primary production commonly reaches a maximum in young forest stands and decreases by 0-76% as stands mature (Gower et all, 1996).

Paper birch leaf litter contributes to the nutrient status of the forest floor (Burns, 1990). Litter under birch was found to be enriched with calcium, potassium, magnesium, phosphorus, and boron, and reduced in manganese, aluminum, iron and zinc. Enrichment extended into the top 3cm of the mineral soil, where concentrations of calcium, nitrogen, phosphorous, magnesium, potassium, volatile and pH were increased (Tappeiner, 1975). These increases result from the rapid rate of decomposition under birch stands. Paper birch tolerates fairly high levels (up to 80mg/l) of aluminum in nutrient solution with no reduction in root growth (Mc Cormick, 1978).

Precipitation increases linearly with increasing elevation at a rate of 2.9cm/100m (Whitney, 1988). Mineral horizons are thicker at lower elevations where organic horizons increase in thickness with elevation (Whitney, 1988).

Additionally, high elevation forests are subject to severe environmental conditions associated with exposed sites. These conditions may include fluctuating temperatures and moisture regimes, high wind speeds, and ice storms (Whitney, 1988). Reduction in annual diameter growth of paper birch occurs when growing seasons and moisture availability are lower than normal (Jones, 1992). At mid-to-high elevation montane forests of northeastern North America, severe weather, high winds, shallow soils, and other factors interact to produce frequent tree fall disturbance (Easter, 1991). This frequent tree fall disturbance creates a favorable niche for paper birch because it is best adapted to colonization of open sites (Tang & Kozolwski, 1982).

Mount Mansfield in Underhill, Vermont provides a favorable niche for paper birch over a variety of elevations. As one gains elevation on a mountain, especially at elevations above 715m. the forest begins to take on a more northern character. Generally, the cause for montane zonation is ascribed to a complex gradient of soil depth, annual precipitation, snow accumulation, and length and warmth of the growing season; of which all are associated with elevation (Whittaker, 1960). On the average, air and soil temperatures decrease by about 0.6C for every 100m increase in elevation in the mountains of the Northeast (Marchand, 1987). Along with this decrease there is an increase in precipitation of about 2.9cm per 100m increase in elevation (Whitney, 1988). All of this has a telling influence on tree growth. On Mount Mansfield it is hypothesized that overall productivity of *Betula papyrifera* across size classes will decrease with elevation. This is expected because with an increase in elevation environmental factors become harsher. The most obvious effect of lower temperature is a reduction of chemical and biological reaction rates that slow all life processes, even for organisms adapted to growing in cold places (Marchand, 1987). Also respiration increases linearly with temperature up to some optimum and then remains constant, hence the decrease in temperature with elevation will cause a decrease in productivity (Gower, 1996).

It is also hypothesized that age specific productivity of *Betula papyrifera* will change with elevation. Age of maximum productivity will decrease with an increase in elevation (Gower, 1996). This is speculated as being related to reduced nutrient availability in older stands. Also, as elevation increases soils become less nutrient rich (Marchand, 1987). At higher elevations and lower temperatures soils have slower chemical reactions of mineral nutrients, and reduced microbial activity in the colder soils means slower decomposition and nutrient turnover. On top of these conditions, the increased precipitation at higher elevations, while it contributes some nutrients to the soil, also leaches the soil of its more soluble elements and carries them down into the lower forests, leaving the higher forests nutrient poor.

Thus, overall production of *Betula papyrifera* across dbh size classes, along with age specific production within dbh size classes is expected to decrease with increased elevation.

METHODS AND MATERIALS

Betula papyrifera was sampled on the western slope of Mount Mansfield (Underhill, Vermont) at four elevations working off the Teardrop trail. These elevations were 730m, 820m, 910m, 1000m. These elevations were determined by using an altimeter. A compass was used to determine the direction of each transect traveled. The 730m transect followed the direction of N80E, the 820m transect followed a direction of N80E, the 910m transect followed a direction of N72E, and the 1000m transect followed a direction N74E. To ensure sampling a range of different aged trees, diameter at breast height (dbh) was measured and stratified into five dbh classes (dbh < 10.16cm, 10.16cm < dbh < 15.24cm, 15.24cm < dbh < 20.32cm, 20.32cm < dbh < 25.40cm, dbh > 25.40cm). Dbh was measured using a dbh tape measure in inches, to the nearest tenth of an inch then converted to centimeters by multiplying by 2.54. Trees were selected using a belt transect (Brower and Zar, 1984). The width of the transect was 3 meters. A horizontal distance of 150m was traveled along each elevation in which all paper birch trees were measured for dbh and marked. Observing the availability within dbh classes at each horizontal belt transect, a random number generator was used to select two trees to be cored. In the lab, tree core rings were counted using a dissection microscope to obtain age. Results were analyzed using statistical analyzing software which calculated productivity as a ratio of dbh/age and an average productivity for each elevation. Comparisons were made between elevation and production, production and age, and production and dbh class.

At each of the four elevations, three soil samples were taken for an analysis of soil chemistry. These samples were obtained across the 150m transect from the top 3cm of soil where maximum enrichment extends in the mineral soil under paper birch stands (Tappiner, 1975). These data were analyzed by the University of Vermont lab to see what differences there were between sites. Results included comparisons of pH, available phosphorus, reserve phosphorus, potassium, calcium, and aluminum at each elevation and are represented by bar graphs. Any differences will give insight as to the available nutrients on each site which could relate to growth productivity.

RESULTS

Overall mean production for all cored trees growing at each of four elevations, along with the grand mean for all trees regardless of elevation were graphed (Figure 1). The overall mean production (Figure 1) was 0.28 cm/yr. (SD +/- 0.11 cm/yr). Highest overall production occurred at 730m which demonstrated 0.40 cm/yr (SD +/- 0.20cm/yr). Lowest production occurred at 910m and demonstrated 0.22 cm/yr (SD +/- 0.05 cm/yr). Birch trees at 1000m demonstrated a higher production rate than 910m and 820m but not 730m. Birch trees at 730m appear to show the highest production rate of 0.39 cm/yr.

Age specific production (Figure 2) was graphed as production vs age. Tree number 1 (Table 1) exhibited abnormally high production (0.82 cm/yr) for such a young age (28 years) and therefore was deleted from the data range (Figure 3). The two graphs are identical except for the deletion of tree 1. No patterns of age specific production declining with increased elevation were demonstrated (Figure 3). It is apparent that trees of the same age produce at very different rates at the same elevation (Figure 3). For example at 820m, 50 year old trees demonstrate production levels of 0.38 cm/yr. and 0.18 cm/yr. Production levels for older trees at the same elevation follow no downward or upward trends but rather a scattering of production rates. This scattering of production rates is observed for all the other elevations showing no trends of maximum production for any aged tree at any elevation.

Age specific production was evaluated in a different way by graphing production vs dbh size classes (Figure 4). Again, maximum production levels are observed to act independently of dbh size classes or elevation (Figure 4). At 820m and 1000m maximum production occurs at the third dbh class. At 910m the third dbh class demonstrates the lowest production rate. Other dbh classes show no patterns in production in relation to elevation.

Soil data shows levels of calcium (Figure 6) and phosphorus (Figure 5) following a similar pattern as overall mean production (Figure 1). Soil pH (Figure 7) was variable across elevations and had a maximum of 3.9 at 910m and a maximum of 3.4 at 820m. Levels of reserve phosphorus, potassium, aluminum, and magnesium do not show any unique or relevant patterns (appendix).

DISCUSSION

The hypothesis that overall production across size class will decrease with elevation was disproved. Although it appears that there is some downward trend in production, at least for the lowest three elevations, we believe it is ellusive because of the data used to achieve the overall production mean at 730m. At this elevation there were only large trees to be sampled. No trees in the first 3 dbh classes were present therefore no young trees were sampled. This restricted the mean production by not including young tree production rates at that elevation whereas all other elevations did. Additionally there was tree #1 that could possibly be a measurement error or some other factor that was not present for any other trees. All of this combined for a high mean production rate that may or may not represent the real production rate at that elevation. Thus we can not accurately assume production went down for the first three elevations.

There are some possible explanations as to why overall production (Figure 1) responded the way it did. One explanation could be attributed to the soil conditions at each site. The amount of calcium (figure 6) and available phosphorus (Figure 7) showed patterns similar to that of the overall production rates. Both calcium and phosphorus are highest at 730m and decrease until 910m, then rises again at 1000m. If production of *Betula papyrifera* is linked to available calcium and phosphorus reserves then that could account for the production pattern observed. In this scenario the next question would be: why are levels of calcium and phosphorus present in this pattern?

Another reason production did not decrease with increasing elevation lies in *Betula papyrifera's* life history traits. It has been shown that *Betula papyrifera* is an aggressive pioneer species that is well adapted to colonizing gap disturbances (Tang & Kozlowski, 1982). Additionally, this species competes well at upper elevations and extreme conditions (Burns, 1990). Therefore, high production rates may occur for this species when there is a disturbance and light becomes plentiful. Thus, production rates would occur independent of elevation but rather in response to gaps in the canopy.

The pattern noted in production rates disproves the second hypothesis that age specific production will decrease with increasing elevation. No patterns in age specific production were observed. If gap disturbance or high light situations are what cause the tree to suddenly produce quickly then age might be irrelevant to production. In other words, a blow down, or any other gap disturbance occurs randomly in the forest, regardless of how old a near by *Betula papyrifera* may be and it is then that high production occurs. These gap disturbances can and do occur at any elevation and because *Betula papyrifera* competes well at high elevation and in harsh conditions, production would increase in response to new light regimes. An interesting study that comes from this scenario would be to determine if trees responding to gap disturbances of similar nature produce better at higher elevations than low elevation. This would be similar to the experiment performed with the addition of accounting for available light at each stage of the trees growth.

Mount Mansfield provides a range of conditions for plant growth, and two of these, altitude and moisture, may be particularly important in determining the distribution of the various tree species. There is an overlap in the abundance of different species with elevation. There are no sharp boundaries. Various tree species can be strung out over a gradient with the tails of their distributions overlapping (Whittaker, 1956). The results of gradient analysis show that the limits of the distribution of each species "ends not with a bang but with a whimper." (Whittaker, 1956).

Paper birch can be divided into two varieties, *Betula papyrifera var. papyrifera* and *Betula papyrifera var. cordifolia.* In the east the variety *cordifolia* generally grows in the cooler habitats-upper elevations on mountains near tree line (Burns, 1990). Another speculative analysis of the data begins in Figure 1. Figure 1 shows a decrease in productivity with increasing elevation until 1000m which is near tree line. This data may be showing an overlap of ranges of the two varieties of paper birch. The sudden increase in productivity may suggest the variety *cordifolia* is more productive at higher elevations than the variety *papyrifera.* An interesting place for future study would be to investigate the elevation of maximum productivity of the two varieties to see if this variety overlap really does occur due to a response to an elevation gradient.

This study disproves the hypothesis that *Betula papyrifera's* productivity across size classes will decrease with elevation. The hypothesis that age specific productivity of *Betula papyrifera* will change with elevation was also disproved. Disproving these hypotheses has shown interesting patterns in paper birch life history characteristics and opened doors for intriguing future studies.

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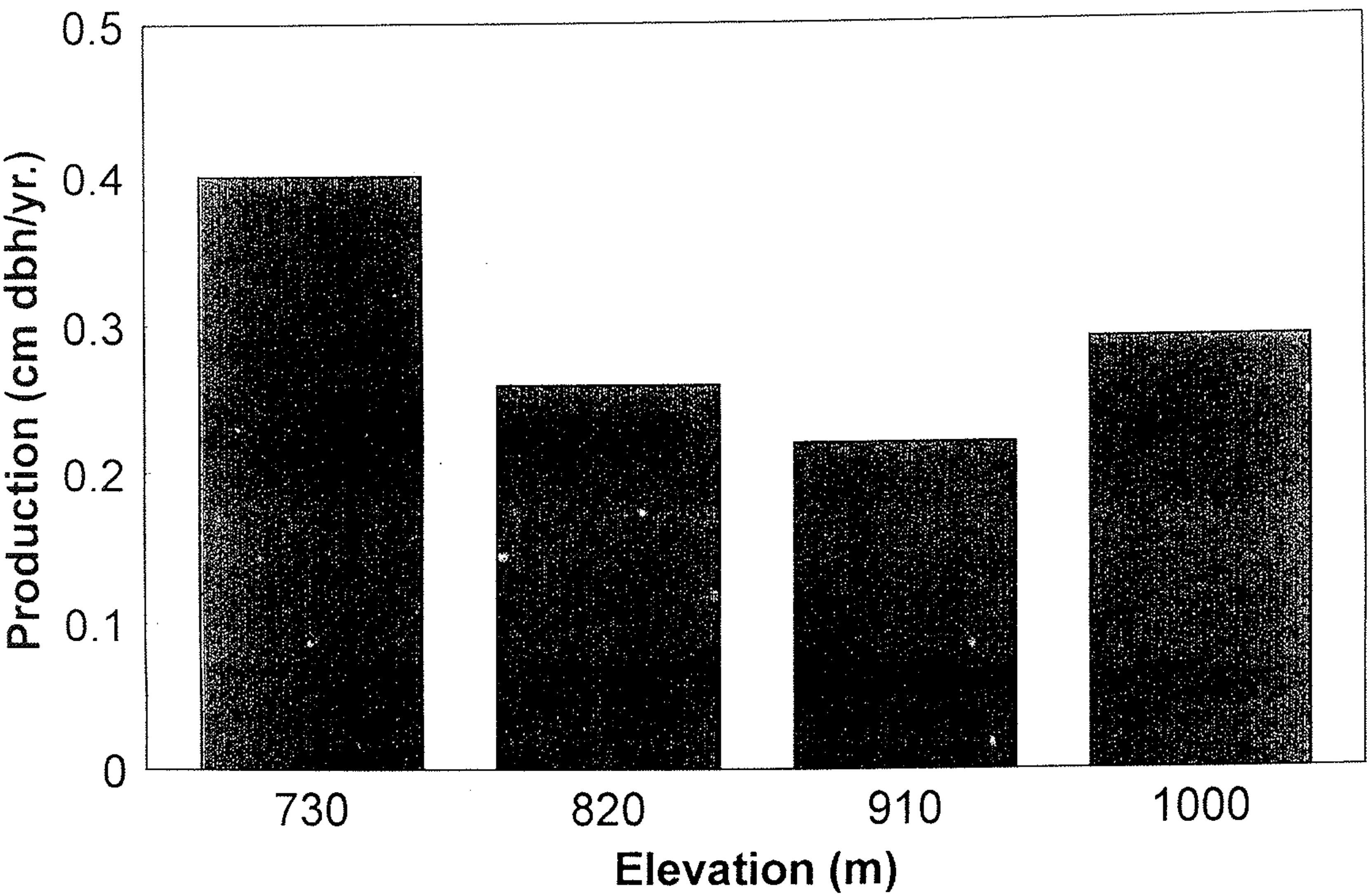


Figure 1. Bar graph showing mean production levels of *Betula papyrifera* at four different elevations. Horizontal line at 0.28 cm/yr. shows mean production across all elevations

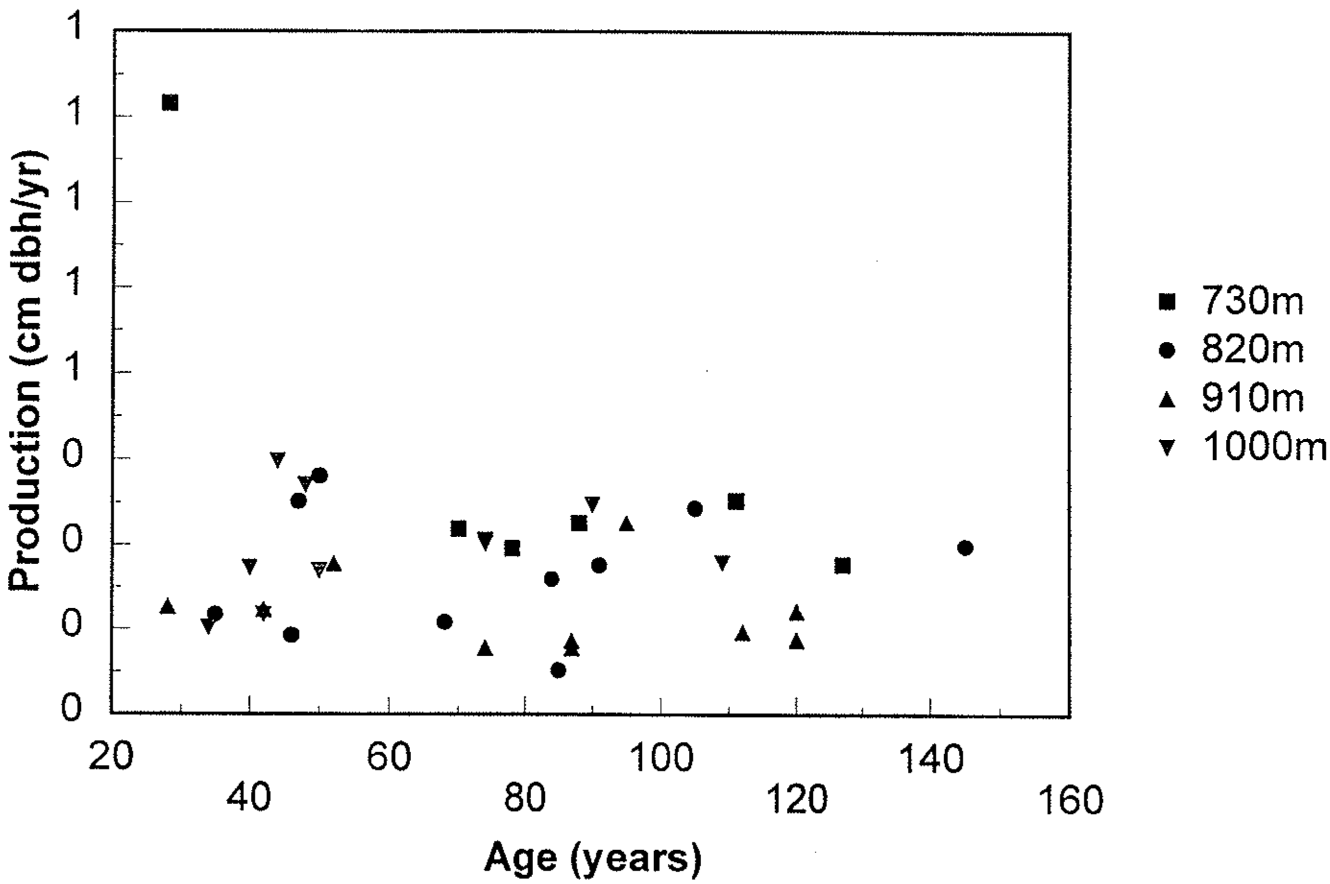


Figure 2. Scatter plot showing Age specific production of all *Betula papyrifera* trees growing at four elevations.

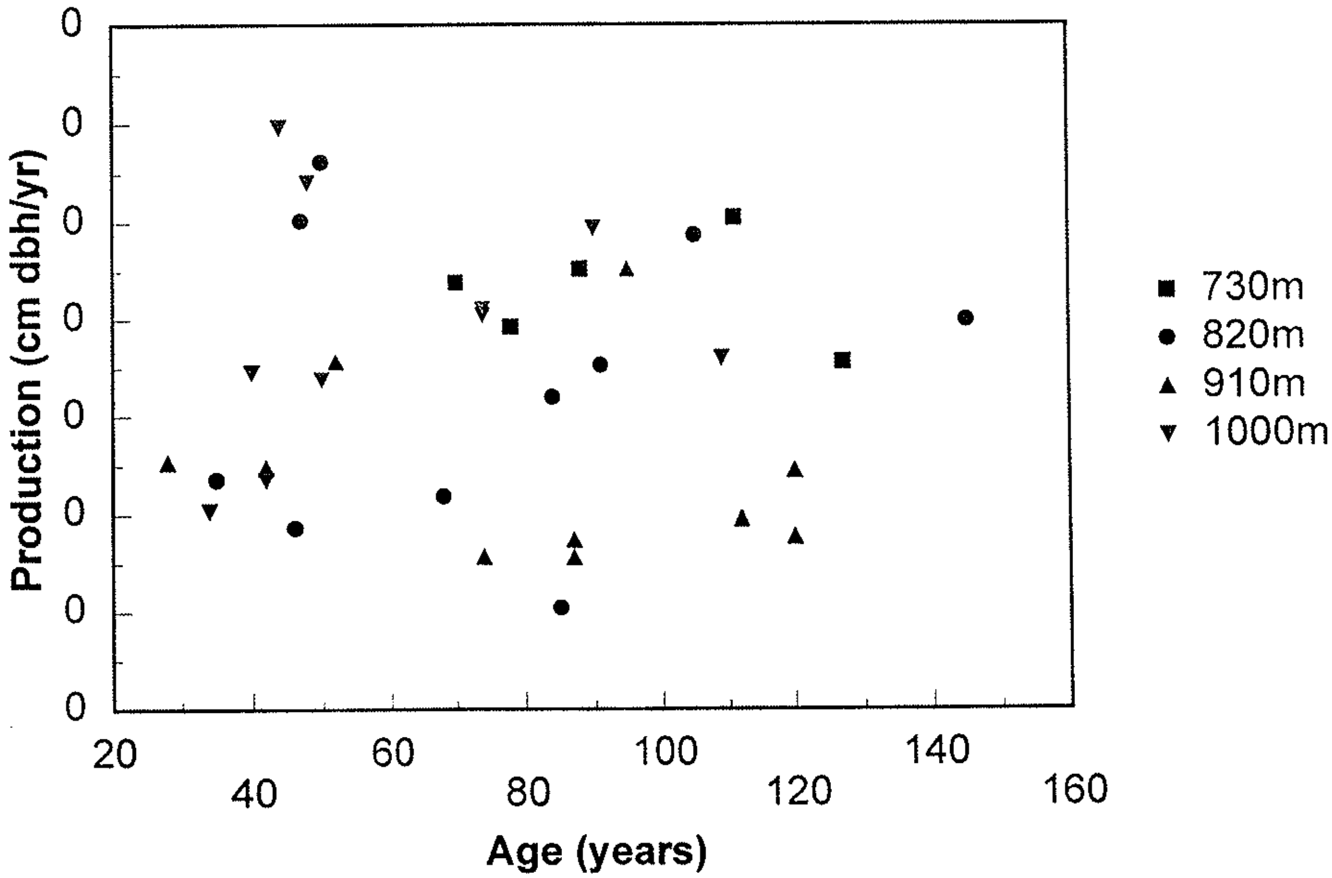


Figure 3. Scatter plot showing Age specific production of all *Betula papyrifera* trees growing at four elevations excluding an outlyer (tree #1).

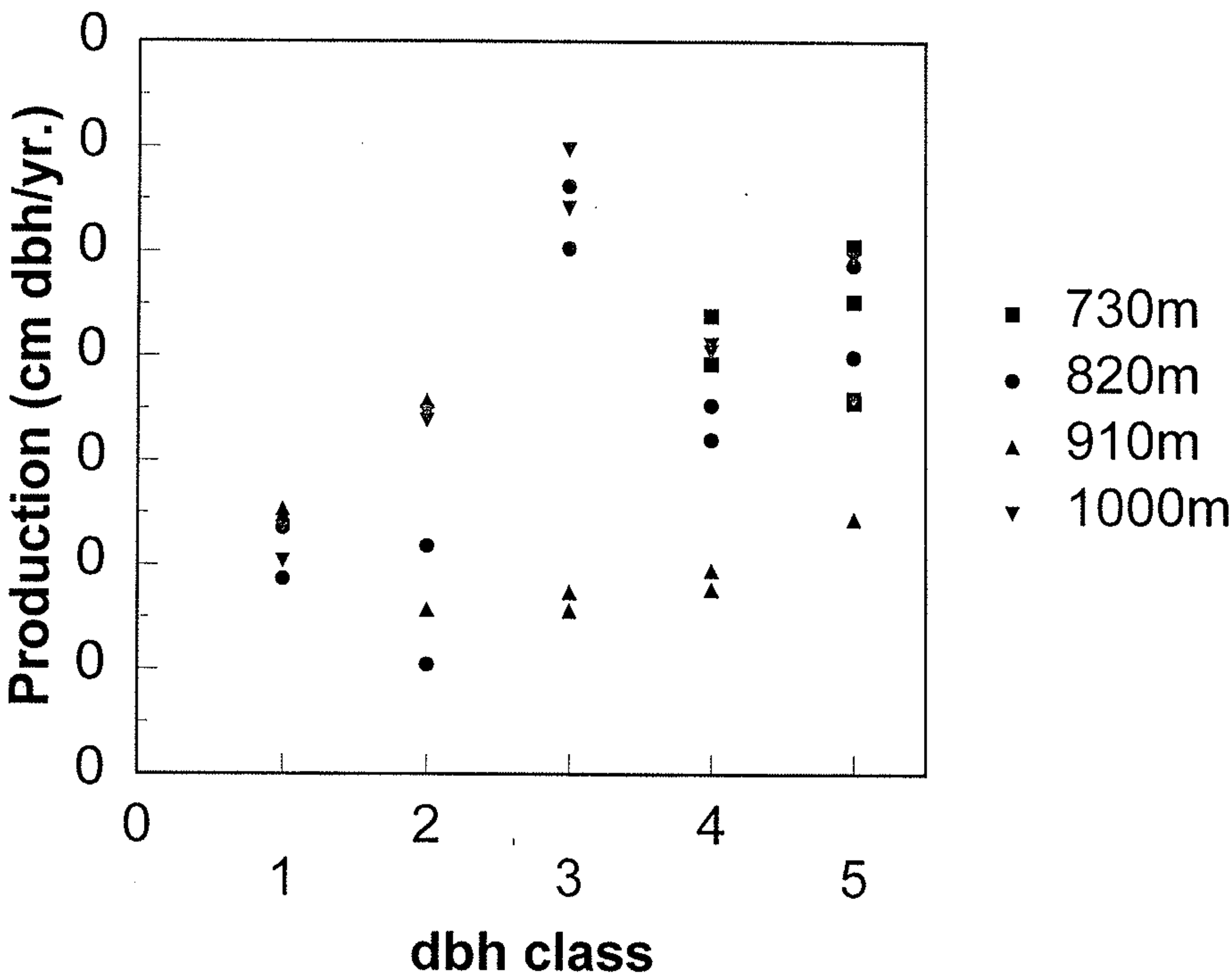


Figure 4. A scatter plot showing *Betula papyrifera* production levels for each of five dbh classes at four elevations.

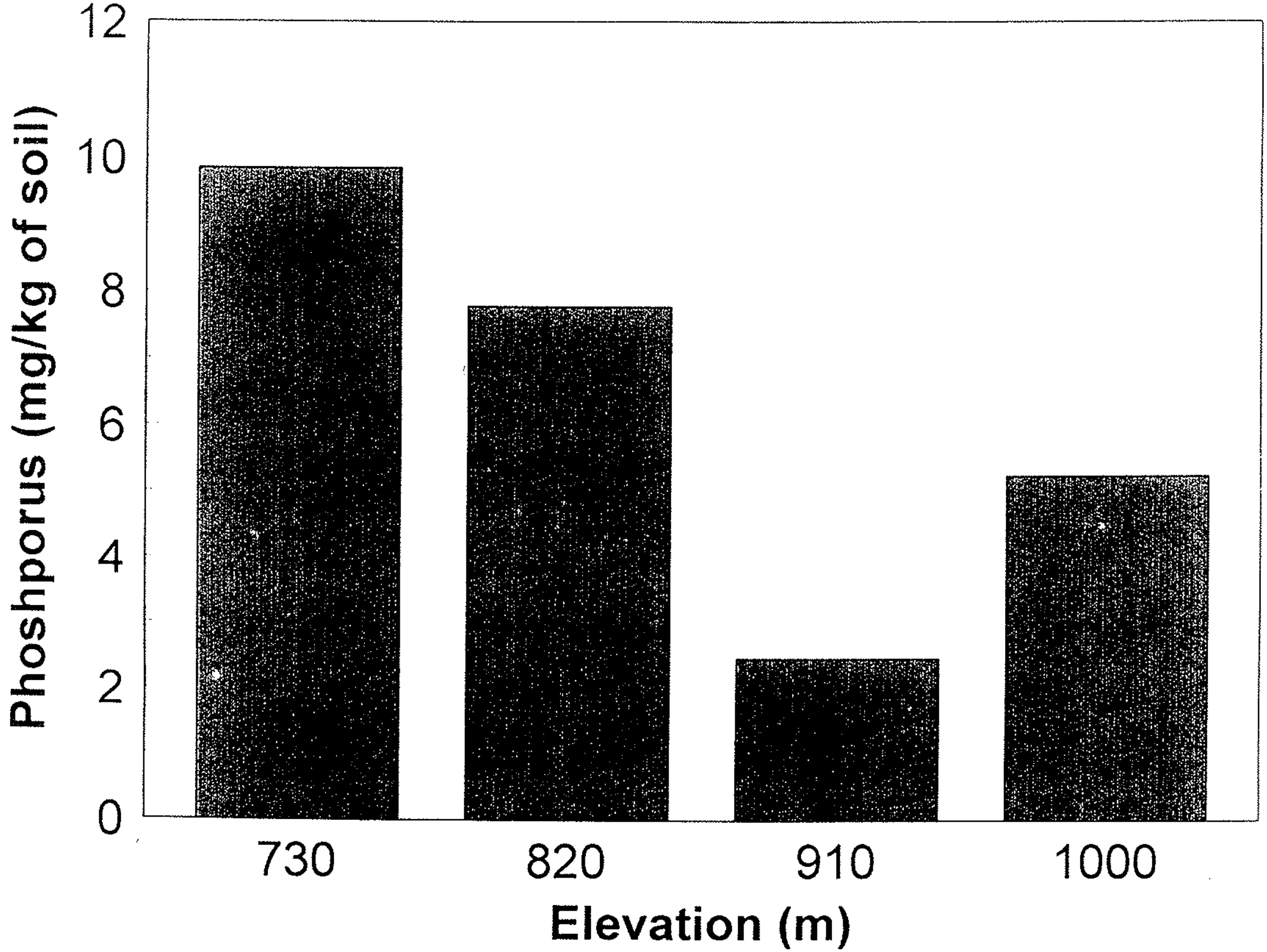


Figure 5. A bar graph showing available phosphorus in soil collected at different elevations.

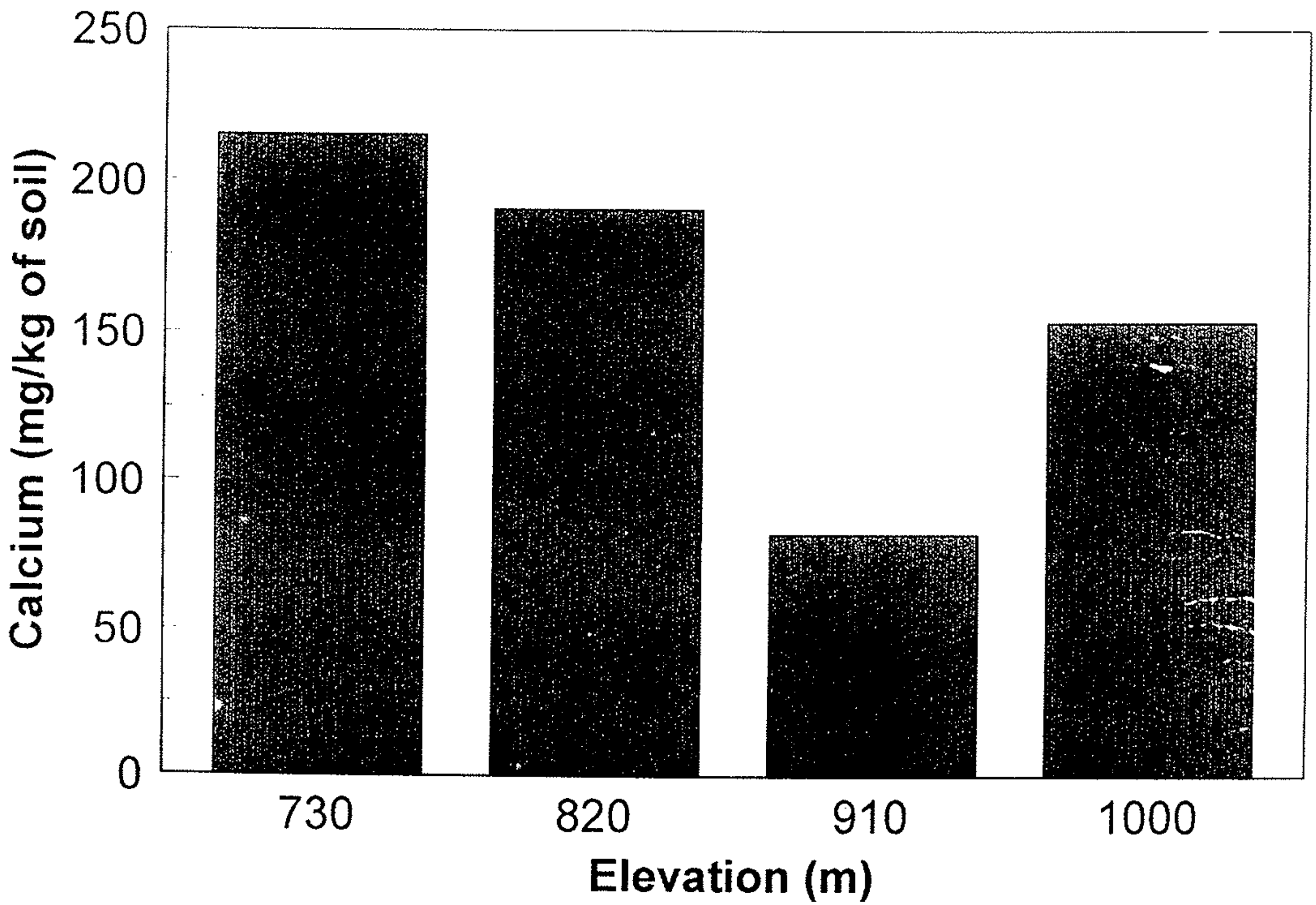


Figure 6. A bar graph showing calcium in soil collected at different elevations.

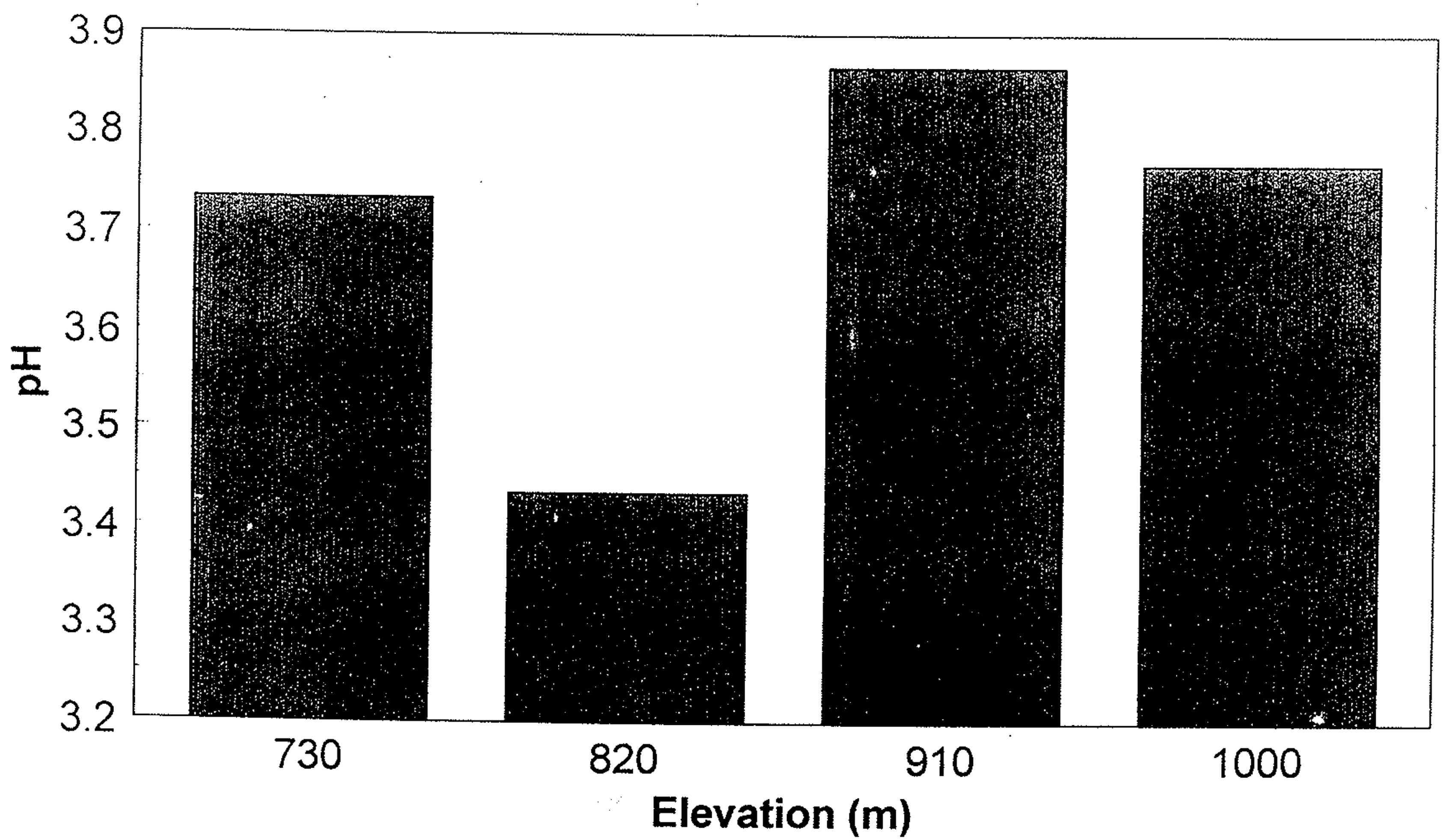
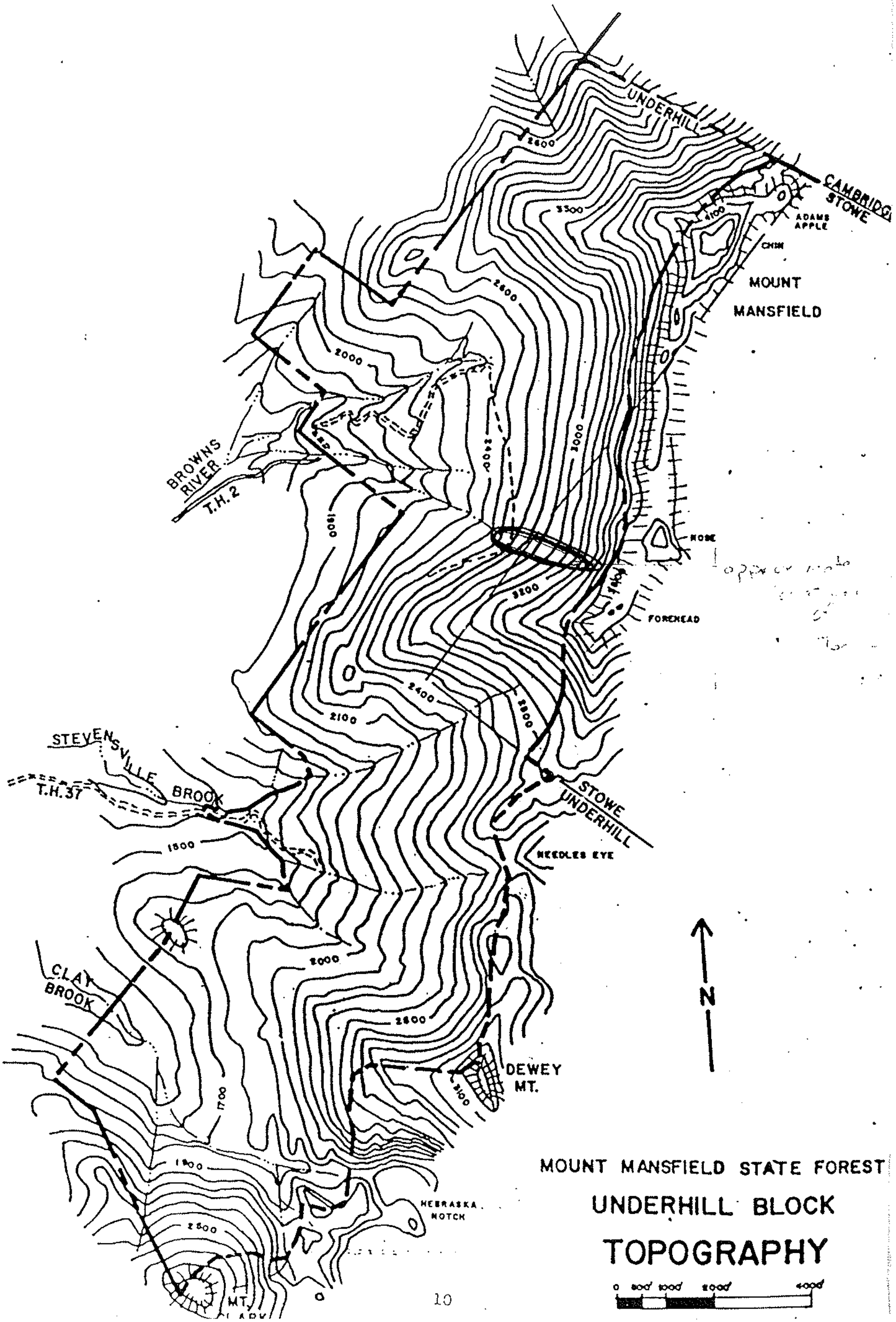


Figure 7. A bar graph showing pH values of soil collected at different elevations.



MOUNT MANSFIELD STATE FOREST

UNDERHILL BLOCK

TOPOGRAPHY

SOIL DATA FROM 4 ELEVATIONS on MOUNT MANSFIELD (data of Landis & Lee, 1996)

730m	A	B	C	Average
pH	3.8	3.6	3.8	3.73
P(avaliable)	9.9	17.3	2.3	9.83
K	182	150	122	151.33
Mg	57	51	39	49.00
P(reserve)	27	24	28	26.33
Al	15	8	239	87.33
Ca	265	266	116	215.67

820m	A	B	C	Average
pH	3.4	3.5	3.4	3.43
P(avaliable)	7.6	9.2	6.5	7.77
K	130	126	137	131.00
Mg	49	65	56	56.67
P(reserve)	12	15	9	12.00
Al	9	7	8	8.00
Ca	180	135	257	190.67

910m	A	B	C	Average
pH	4	3.9	3.7	3.87
P(avaliable)	2.6	2.8	2	2.47
K	180	98	103	127.00
Mg	41	49	57	49.00
P(reserve)	22	6	13	13.67
Al	194	207	96	165.67
Ca	69	64	113	82.00

1000m	A	B	C	Average
pH	3.6	4.2	3.5	3.77
P(avaliable)	4.4	5.9	5.4	5.23
K	93	90	83	88.67
Mg	36	130	40	68.67
P(reserve)	23	23	25	23.67
Al	53	16	19	29.33
Ca	66	303	91	153.33

730m	A	B	C	Average
pH	3.8	3.6	3.8	3.733333
P(avaliable)	9.9	17.3	2.3	9.833333
K	182	150	122	151.3333
Mg	57	51	39	49
P(reserve)	27	24	28	26.33333
Al	15	8	239	87.33333
Ca	265	266	116	215.6667

820m	A	B	C	Average
pH	3.4	3.5	3.4	3.433333
P(avaliable)	7.6	9.2	6.5	7.766667
K	130	126	137	131
Mg	49	65	56	56.66667
P(reserve)	12	15	9	12
Al	9	7	8	8
Ca	180	135	257	190.6667

910m	A	B	C	Average
pH	4	3.9	3.7	3.866667
P(avaliable)	2.6	2.8	2	2.466667
K	180	98	103	127
Mg	41	49	57	49
P(reserve)	22	6	13	13.66667
Al	194	207	96	165.6667
Ca	69	64	113	82

1000m	A	B	C	Average
pH	3.6	4.2	3.5	3.766667
P(avaliable)	4.4	5.9	5.4	5.233333
K	93	90	83	88.66667
Mg	36	130	40	68.66667
P(reserve)	23	23	25	23.66667
Al	53	16	19	29.33333
Ca	66	303	91	153.3333

Botany 160 Fall 1996 Birch data

	C1	C2	C3	C4	C5
	Elevatio	DBH	Age	dbh clas	dbh/age
56	4	20.57	*	4	*
57	4	30.48	109	5	0.279633
58	4	10.92	40	2	0.273000
59	4	22.60	74	4	0.305405
60	4	29.72	*	5	*
61	4	31.50	*	5	*
62	4	16.00	*	3	*
63	4	13.46	50	2	0.269200
64	4	29.21	*	5	*
65	4	22.10	*	4	*
66	4	10.16	*	1	*
67	4	17.78	48	3	0.370417
68	4	21.08	*	4	*
69	4	17.53	44	3	0.398409
70	4	12.70	*	2	*
71	4	32.51	*	5	*
72	4	29.21	*	5	*
73	4	6.86	34	1	0.201765
74	4	9.14	42	1	0.217619

Botany 160 Fall 1996 Birch data

	C1	C2	C3	C4	C5
	Elevatio	DBH	Age	dbh clas	dbh/age
1	1	22.86	28	4	0.816429
2	1	28.70	88	5	0.326136
3	1	39.12	111	5	0.352432
4	1	35.31	127	5	0.278031
5	1	30.99	*	5	*
6	1	23.11	78	4	0.296282
7	1	39.37	*	5	*
8	1	22.35	70	4	0.319286
9	2	8.89	46	1	0.193261
10	2	7.62	35	1	0.217714
11	2	19.05	50	3	0.381000
12	2	10.41	*	2	*
13	2	43.43	145	5	0.299517
14	2	15.49	*	3	*
15	2	16.51	47	3	0.351277
16	2	21.84	84	4	0.260000
17	2	16.00	*	3	*
18	2	25.15	91	4	0.276374
19	2	12.95	85	2	0.152353
20	2	16.76	*	3	*
21	2	15.75	*	3	*
22	2	32.51	*	5	*
23	2	36.07	105	5	0.343524
24	2	14.22	68	2	0.209118
25	2	17.53	*	3	*
26	2	29.46	*	5	*
27	2	29.72	*	5	*
28	2	22.61	*	4	*
29	2	12.95	*	2	*
30	3	16.26	87	3	0.186897
31	3	12.95	*	2	*
32	3	16.75	*	3	*
33	3	30.99	95	5	0.326211
34	3	13.21	74	2	0.178514
35	3	6.35	28	1	0.226786
36	3	18.80	*	3	*
37	3	11.18	*	2	*
38	3	26.67	120	5	0.222250
39	3	31.75	*	5	*
40	3	14.48	52	2	0.278462
41	3	14.73	*	2	*
42	3	22.61	120	4	0.188417
43	3	32.51	*	5	*
44	3	18.54	*	3	*
45	3	15.49	87	3	0.178046
46	3	28.70	*	5	*
47	3	9.40	42	1	0.223810
48	3	22.10	112	4	0.197321
49	3	26.16	*	5	*
50	3	25.65	*	5	*
51	4	9.14	*	1	*
52	4	6.60	*	1	*
53	4	22.35	74	4	0.302027
54	4	12.19	*	2	*
55	4	31.24	90	5	0.347111