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Regeneration and productivity of aspen [Populus tremuloides] grown on repeated short rotations [in Minnesota]

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REGENERATION AND PRODUCTIVITY OF ASPEN GROWN ON REPEATED SHORT ROTATIONS

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Because of the increasing demand for wood fiber, considerable research has been devoted to short rotation, full tree utilization systems, which are designed to produce the maximum amount of wood fiber in the shortest time. Quaking aspen (*Populus tremuloides* Michx.) is a likely candidate for these systems because it produces good quality wood fiber at a young age. However, the effects that repeated cropping would have on the aspen's coppicing ability have had little attention. Therefore, we conducted this study to decribe the productivity and other characteristics of repeatedly cropped aspen.

STUDY AREAS

The study areas are located within 13 km of each other on the Chippewa National Forest, Minnesota. The soils are well-drained Warba sandy to fine sandy loams and are considered good aspen sites. The climate is continental, averaging 20 °C in July and 64 cm annual precipitation. The topography is level to gently rolling and the elevation is 400 to 410 m. The areas had been commercially logged for aspen during spring and early summer 2, 4, and 8 years prior to study installation (table 1).

Table 1.–Parent stand summary

Rotation schedule (yr)	Site index[1]	Stand age	Aspen yield: Merchantable volume[2]	Aspen yield: Total tree[3]
	m	*yr*	*m*³/ha	*t/ha*
8	24.4	42	77	31
4	22.9	31	55	23
1	21.3	47	77	31

[1]At 50 years.

[2]To 10.2 cm top; from sale records.

[3]Oven-dry weight, except leaves, above 15 cm stump. Estimated from Schlaegel (1975). These figures are for merchantable trees and species only and probably underestimate total standing crop by at least 50 percent.

Treatment plots were located where suckers were uniformly dense and unimpeded by residual overstory.

METHODS

All woody stems on five circular 810 m^2 (16 m radius) treatment plots were clipped and removed on 1[1]-, 4-, and 8-year cycles beginning May 1970. Two plots were installed in each the 4- and 8-year cycles and one plot was installed in the 1-year cycle. Stems were clipped during the dormant season to maximize aspen suckering (Brinkman and Roe 1975). Five circular 16.2 m^2 (2.27 m radius) sample plots were systematically clustered at the center of each of the five treatment plots. The minimum distance between sample plots and treatment plot boundary was 8.4 m to exclude edge effects on sucker stocking and growth.

The aspen from the first clipping of the sample plots was used to develop stand equations for aerial dry weight of total trees (except leaves) and of wood based on stem diameter and height measurements (Perala 1973). Thereafter, these equations were applied to yearly diameter and height measurements, including the cropping years.[2] Other woody stems from the sample plots were weighed fresh by species at each cropping but were not measured during intervening years. Several stems of each of these other species of estimated mean size were subsampled to determine oven-dry weights (105°C oven) at each cropping. During the first 2 years, aspen coppice (ramets) was recorded as either root suckers or stump and root collar (S/RC) sprouts.

[1]*This sucker stand was 2 years old at first clipping but was clipped annually thereafter.*

[2]*Except for the 1-year rotation after the second cropping– it became more convenient to dry and weigh entire plot clippings.*

Curvilinear multiple regression analysis was performed on data from the 25 measurement plots to determine how stand characteristics influenced the sizes of both aspen S/RC sprouts and suckers (dependent variables).

The independent variables were:

X_1, ortet (parent) age (years);
X_2, ortet stem density (1,000's/ha);
X_3, ortet mean weight (g/stem);
X_4, sucker density (1,000's/ha);
X_5, S/RC sprout density (1,000's/ha); and
X_6, mean weight of suckers or S/RC sprouts, as appropriate, (g/stem).

All variables in both equations were significant at the 0.05 level.[3]

RESULTS AND DISCUSSION

Initial Sucker Stand Characteristics

If expressed as mean annual increment, the short rotation yields are much less than would be achieved on conventional (40 year) complete tree fiber rotations (table 2).

[3]*Coefficients and other statistics are not given here but are available from the author on request. Response to each variable was depicted graphically while holding all other variables at constant mean values.*

Table 2.—*Mean annual, increments of short rotations compared to conventional rotations*

Stand age, years	8	4	2
Site index, m	24	22.5	21
MAI (wood component) t/ha/yr	1.52	1.73	.47
MAI, conventional, t/ha/yr[1]	2.66	2.45	2.24
Ratio, short rotation ÷ conventional	.57	.71	.21

[1]From Perala (1977).

Wood specific gravity was similar to mature stands (Schlaegel 1975) but moisture content (mainly because of seasonal variation) and bark percent were considerably higher and bark specific gravity was lower (table 3). Bark percent decreased as stand age increased but the other physical properties did not vary significantly with age.

Repeated Crop Yields

Regeneration and yield of aspen decreased as cropping frequency increased. Regeneration and yield on the 1-year rotation declined steadily through the fourth crop and precipitously thereafter (fig. 1). The decline in yield through the fourth crop was a function of both a reduction in number of stems regenerated and mean stem size. After the fourth cropping, mean stem size remained essentially unchanged. After 7 annual croppings, aspen regeneration ceased.

Table 3.—*Yield and properties of young aspen sucker stands*

Stand age (yr)	Dominant height	Mean dbh	Basal area	Number of stems	Total fresh weight	Oven dry weight: Total	Oven dry weight: Wood	Oven dry weight: Bark	Moisture	Bark	Specific gravity: Wood	Specific gravity: Bark
	m	*cm*	*m²/ha*	*1,000's/ha*		*....t/ha....*			*...Percent...*			
8	6.7	2.8	8.99	14.9	36.2	16.3	12.2	4.18	121	25.5	0.391	0.509
4	4.4	1.4	6.46	44.0	22.4	9.55	6.91	2.64	135	27.6	0.378	0.451
2	2.3	—	—	73.1	3.41	1.50	0.94	0.56	128	37.6	0.386	0.449
[1]1	1.3	—	—	75.2	0.87	0.40	0.22	0.18	120	44.5	0.415	[2]

[1]First 1-year cropping of the original age 2 stand.
[2]Not determined.

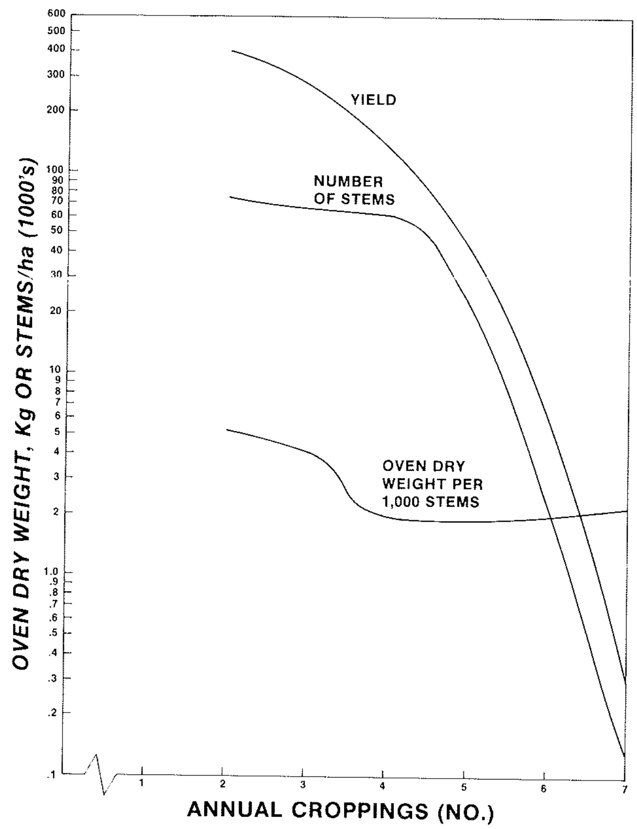

Figure 1.— *Regeneration and oven-dry above-ground yield of aspen coppice (except leaves) on successive 1-year croppings. The first cropping was omitted because it was at age 2.*

The 4-year rotation tended toward the same results— number, vigor, and total yield declined with each cycle (figs. 2 and 3). However, it would take at least several more cycles to completely eliminate aspen.

The 8-year rotation produced two-thirds less sprouts and one-third less total yield on the second cycle (figs. 2 and 3), but the results are confounded by feeding damage by hares (*Lepus americanus*) during the winters following the fifth and sixth growing seasons. Hares girdled some of the smaller stems, which died a year or two later without resprouting. However, even if the hare damage had not occurred, the estimated total yield of the second cycle was still 10 percent less than the first cycle (Perala 1973). Because the largest stems survived, the average size of three dominant stems was compared at the end of each cycle as well as between dominant regenerated stems (table 4).

Table 4.— *Comparison of dominant stems at end and beginning of successive 8-year rotations*

	End of 8-year rotation		Beginning of 8-year rotation	
Cycle	Mean dbh	Mean height	Mean basal diameter	Mean height
	cm	*m*	*cm*	*m*
1	4.7	6.7	—	—
2	4.6	6.5	1.1	1.52
3	—	—	1.1	1.43

None of these comparisons were statistically different. Furthermore, of the 10 plots, 5 had larger dominants at the end of the first cycle and 5 at the end of the second. All in all, the results for the 8-year rotation do not suggest significant physiological impairment to aspen productivity.

Character of Regeneration

In contrast to mature stands which produce suckers almost exclusively, most of the aspen regeneration in all rotations were stump and root collar sprouts (table 5).

Table 5.—*Stump and rootcollar sprouts regenerated on short rotations*

	Stump and root collar sprouts		
Ortet age	Percent by weight	Percent by number	Per stump
8	58	57	3.9
4	88	82	1.6
2	60	63	0.6
1	58	59	0.5

S/RC sprouts did not differ significantly in growth and survival from suckers during the first 2 years when this data was gathered.

S/RC sprouting in aspen has rarely been reported before. Maini (1968) reports they are occasionally found on aspen up to sapling size in Canada and Baker (1925) found that S/RC sprouts accounted for 9 percent of the sprout regeneration after mature Utah aspen were felled. In this present stand, the stumps were cut so low that stump and root collar sprouts could not be differentiated. The propensity to regenerate S/RC sprouts is probably related to the strong tendency for suckers to

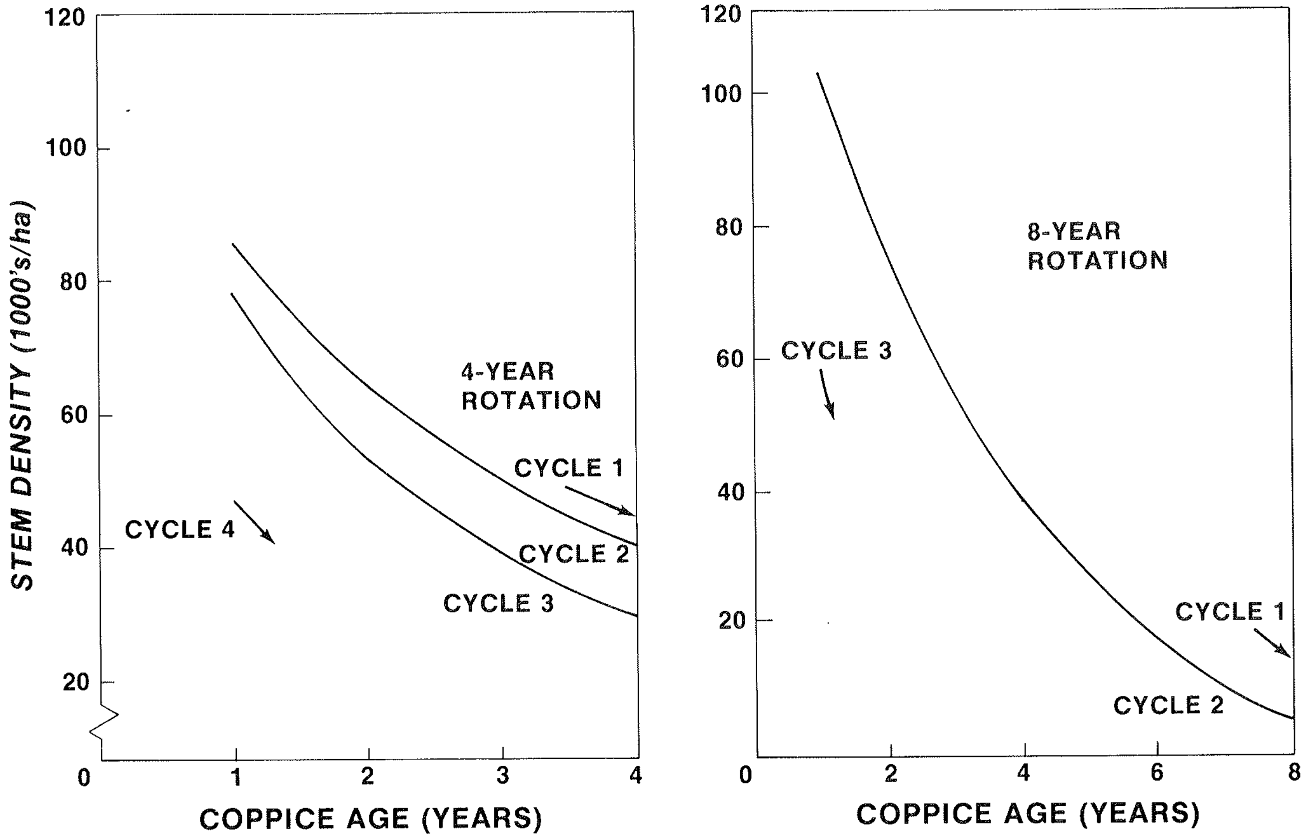

Figure 2.—*Regeneration and survival of aspen coppice on 4- and 8-year rotations. Arrows indicate expected trends.*

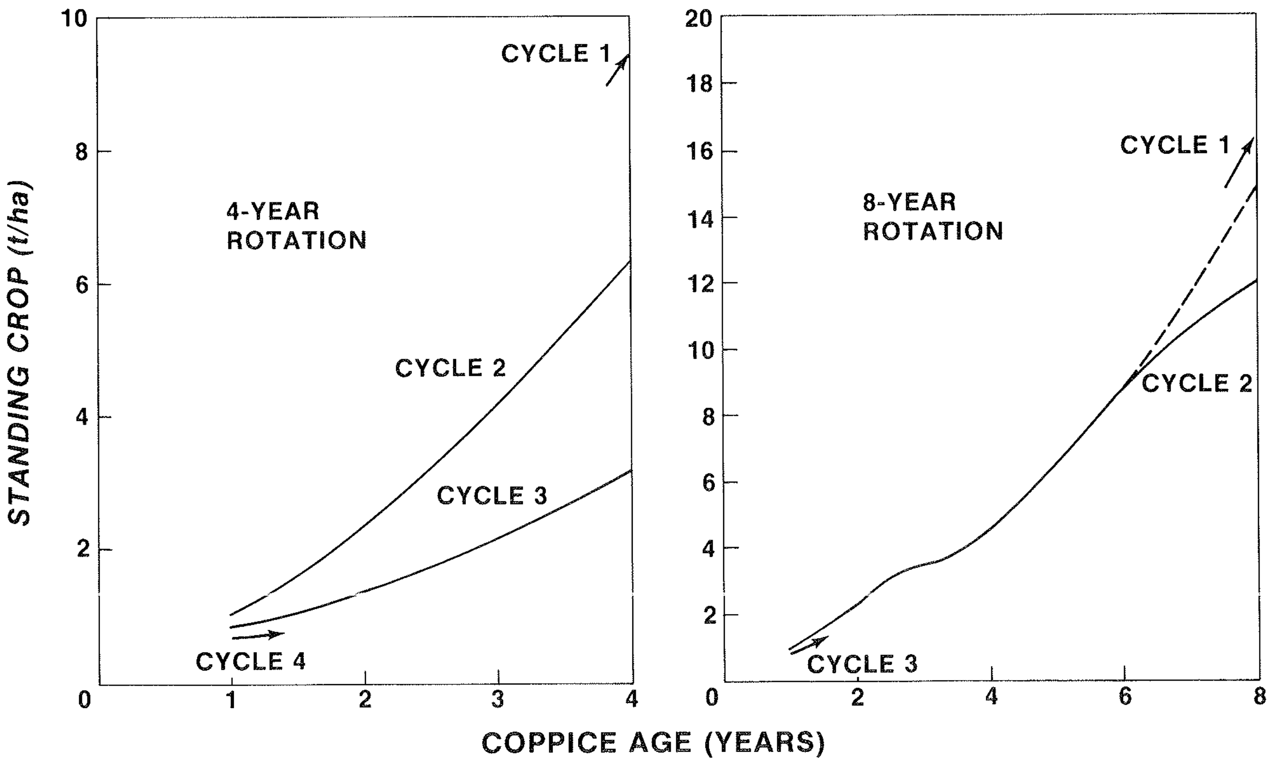

Figure 3.—*Standing crop (total stem oven-dry weight) of aspen coppice on 4- and 8-year rotations. Arrows indicate expected trends. Dashed line indicates the expected trend without hare damage (Perala 1973).*

regenerate in groups from localized areas about 6 cm in length along the aspen root (Sandberg and Schneider 1953). Usually only single stems survive but apparently these localized areas can continue to dominate sprout reproduction.

The most striking results of the regression analysis were that sucker and S/RC sprout mean weights (MW) responded in opposite sign to 4 of the 6 independent variables :

Independent variable	Sucker MW	S/RC sprout MW
Ortet age	increased	maximum at age 4
Ortet number	decreased	increased
Ortet mean weight	decreased	increased
Sucker density	increased	decreased
Stump/root collar sprout density	increased	decreased
Other ramet mean weight	increased	increased
R_2	.92	.97
Sy.x, percent of arithmetic Y	15	12

One exception was ortet age where sucker mean weight (MW) rose asymptotically to age 8 while S/RC sprout MW peaked at age 4, and then began to decline. This indicates that S/RC sprouting capacity decreases with age and with the approach to full suckering capacity.

The positive S/RC responses probably reflect a direct relation of general ramet-ortet vigor; i.e., vigor begets vigor. The negative responses may reflect competition. For example, S/RC sprout MW declined with both sucker and S/RC density while, in contrast, sucker MW increased with both sucker and S/RC density. This suggests that suckers dominate S/RC sprouts.

Clearly, the physiology of aspen S/RC sprouts and root suckers differ, most importantly in the culmination of S/RC sprouting at about age 4, followed by the increasing dominance of suckers. This may, in turn, reflect the rate of aspen root system development. Because of carbohydrate depletion, the parent root system in age 4 stands may be less able to produce suckers than it is in age 2 stands, and new roots for sucker production likely are not as extensive in age 4 as in age 8 stands. Thus, the total amount of roots capable of producing suckers may be at their lowest level at about age 4.

Nutrient Limitations

Nutrients were not studied but the magnitude of nutrients removed can be estimated from exisitng data (Einspahr 1977) and compared to nutrient reserves for a Warba soil (Alban *et al.* 1978) similar to this study. The total biomass removals in the 1-year rotation over 9 cycles would extract no more than 2 percent of the available soil nutrients (or total N). The estimated removals in three cycles of the 4-year rotation ranged from 2 percent of total N to 13 percent of exchangeable K. Corresponding values for two cycles of the 8-year rotation are 2 percent N to 17 percent K. Thus, the relatively greater reductions in yield with shorter rotations are *inversely* related to nutrient removals. Therefore, the only reasonable conclusion is the declines in yield can be almost wholly ascribed to regenerative stress.

The magnitude of nutrients removed on longer aspen rotations can also be estimated from existing data. Generally, the concentration of aboveground nutrients excluding leaves declines with age (Einspahr 1977). However, when the values for tree nutrient concentrations are multiplied by mean annual biomass increment (Perala 1973), mean annual accumulation of nutrients approximately parallels the accumulation of biomass and both culminate at nearly the same age (fig. 4).

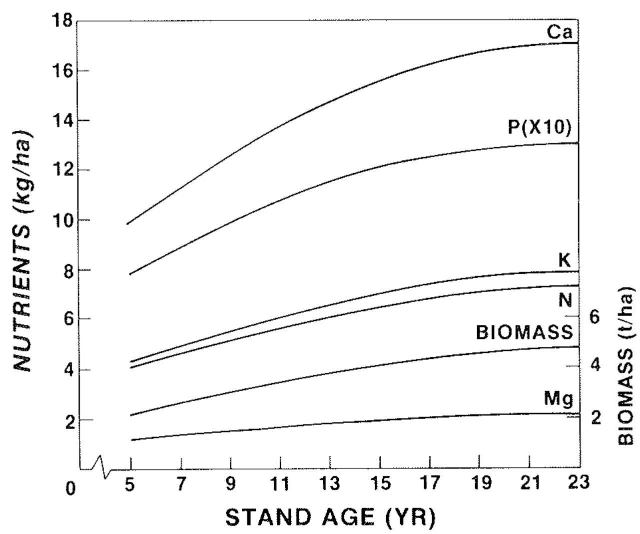

Figure 4.– Mean annual above-ground accumulation of nutrients and biomass in aspen (except leaves). Integrated from Einspahr (1977) and Perala (1973).

Therefore, nutrient removals are largely proportional to biomass removals and little adjustment can be made in rotation length to minimize nutrient removals without reducing fiber yields.

Other Species

The yield of other woody species was not altered as dramatically by repeated cropping as was aspen (table 6). The total yield of other woody species in the 1-year rotation was reduced by about 60 percent at the third cropping and remained stable thereafter. In the first crop, these species comprised about 20 percent of the total yield; by the seventh crop, their percentage increased to almost 100!

Total yield of these other species under the longer rotations was stable. However, species differed greatly in their ability to withstand repeated cropping. It appears that red oak, mountain maple, red maple, and green alder are decreasers and the juneberry-cherry group, red-osier dogwood, and possibly bur oak are increasers. Hazel was persistent and maintained high productivity. The drop in hazel yield on the second 8-year cycle can be almost wholly attributed to hare feeding damage.

These other woody species added about one-fourth more to the total yield at the first 4- and 8-year rotation and up to two-thirds more to the third crop of the 4-year rotation.

CONCLUSIONS

The failure of aspen to withstand rotations of 4 years or less confirms the findings of Berry and Stiell (1978). Furthermore, their conclusion that aspen productivity cannot be sustained on rotations of up to about 10 years is also largely substantiated by this study. Considering that (1) Berry and Stiell's second 8-year rotation regenerated 80 percent of the biomass regenerated in the first cycle; (2) that my study at the beginning of the third cycle of the 8-year rotation regenerated 93 percent of the second cycle regeneration biomass; and (3) that in both studies productivity of 8-year

Table 6.—*Yield of other hardwoods and shrubs*

		Hardwoods					Shrubs				
Rotation	Cycle	*Betula papyrifera*	*Quercus macrocarpa*	*Quercus rubra*	*Acer rubrum*	Other	*Corylus* sp.	Juneberry, cherry[1]	*Cornus stolonifera*	Other	Total
		kg ha^{-1}									
8	1	242	135	—	—	—	3,234	362	172	[2]	4,291
	2	352	669	—	—	—	2,137	909	155	[3]	4,229
4	1	—	100	50	15	—	1,368	43	3	[4]	2,053
	2	—	88	37	35	—	1,682	80	14	[4]	2,484
	3	—	84	11	0	—	1,356	107	22	[4]	1,992
		presence (x)									kg ha^{-1}
1	1		x	x	x	([5])	x	x	x	([6])	166
	2	x	x	x	x	([5])	x	x	x	([6])	147
	3		x	x	x		x	x	x	([6])	56
	4		x	x		([5])	x	x	x	([6])	68
	5		x	x		([5])	x	x	x	([6])	74
	6		x	x			x	x	x		69
	7		x	x			x	x	x		71

[1]*Amelanchier* sp., *Prunus pensylvanica*, *P. virginiana*.

[2]*Alnus crispa*, 97 kg ha; *Acer spicatum*, 32; *Dirca palustrus* and *Crataegus* sp., 17.

[3]*Salix* sp., 6; *Acer spicatum*, 1.

[4]*Salix* sp. - 90, 276, 256; *Alnus crispa* - 384, 272, 155; cycles 1 - 3 in order.

[5]*Tilia americana*, *Acer saccharum*, *Fraxinus nigra*.

[6]*Salix* sp., *Acer spicatum*.

rotations was diminished much less than in 3-, 4-, and 5-year rotations, it seems reasonable to conclude, as did Berry and Stiell, that rotations of at least 15 years are unlikely to impair aspen regenerative and productive capacity. Because short rotation yields are at least 25 percent less than can be gained under longer rotations approaching culmination of MAI, it seems unlikely that financial rotations would be prescribed that approach these limits imposed by regeneration requirements.

Rotation length is not a factor in reducing nutrient losses in cropped aspen because nutrient extraction is directly a function of biomass extraction (leaves not considered). This is not to say, however, that nutrient management is not important in short rotation systems. On the contrary, short rotations timed to coincide with maximum mean annual increment will maximize nutrient extraction. Whether fertilization will be required to maintain productivity under such systems still remains a question.

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