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The impact of black cottonwood on soil fertility in coastal western hemlock forest

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F . 1. Geographic distribution of cottonwood in North America (modified from USDA Forest Services, 2004).

the genus Populus have been shown to enrich conifer forests, as

F . 2. Location of Malcolm Knapp Research Forest in southwest British Columbia.

as Gleyed Dystric Brunisol formed on morainal deposits (Tashe and Schmidt, 2001).

Six pairs of circular 0.008 ha plots were located within conifer-dominated stands of the MKRF. Five of the research sites were located within the dry maritime (dm) subzone of the CWH, while one site was within the very wet subzone of the CWH. Snow persists for about 4 months on one of the six pairs used in this study, but does not generally occur on the other five sites. Each pair of plots contained one plot centred on a dominant cottonwood bole and one plot centred on a dominant conifer. Cottonwood plots had one cottonwood individual surrounded by conifers. Douglas-fir trees were chosen for the centre of pure conifer plots whenever possible, however, one plot was centred around a western hemlock because an appropriate Douglas-fir tree could not be located.

Each pair of plots displayed similar site characteristics, including: slope, aspect, elevation, and age of stand. The soil moisture regime (SMR) did not differ by more than one unit and the soil textural class was adjacent on the textural triangle for each pair of plots. The SMR in the study area ranged from 2 to 6. The mean diameter for the central cottonwood stems classify humus form to the group level according to Green et al. (1993).

Three randomly selected forest floor samples were collected within each plot for further analysis. The moist forest floor samples were weighed before they were oven-dried at 70 °C for 24 h to determine dry weight of the forest floor (Kalra and Maynard, 1991). Water content and bulk density of each sample were calculated. A subsample of equal weight was removed from each oven-dried sample. Composite samples from each plot were sent to the BC Ministry of Forests and Range Laboratory for determination of the following properties: pH, total N, C, and S, mineralizable N, exchangeable cations, available P, cation exchange capacity (CEC), NH_4-N and NO_3-N. The pH was measured with a combination electrode and data acquisition system in a 1:1 forest floor to water solution (Kalra and Maynard, 1991). Total C, N, and S were determined by a dry combustion method using a Fisons NA-1500 Elemental Analyser.

Mineralizable N was measured using an anaerobic incubation method where soil samples were incubated under anaerobic conditions for 2 weeks at 30 °C, and N was determined colorimetrically by a Technicon Auto-analyzer II (Waring and Bremner, 1964a,b; Bremner, 1965). Mineralizable N was measured in a 1 M KCl extract and NH_4-N and NO_3-N were measured in a 2 M KCl extract. Exchangeable cations were measured using an ARL 3560 inductively coupled argon plasma (ICAP) spectrometer. The sum of cations reported by this method was used to determine effective CEC (Carter, 1993). Available phosphate was extracted using the Bray P1 method (Kalra and Maynard, 1991; John, 1970), while NH_4-N and NO_3-N were measured colorimetrically using an Alpkem Flow System IV analyzer (Carter, 1993).

The buried bag technique (Prescott et al., 2003; Prescott, 1992) was used to quantify differences in N mineralization rates between cottonwood and conifer plots. Bags were left to incubate at three random locations per plot for 40 days, from July 18 to August 27, 2007. The samples removed from each plot were composited and delivered, within 48 h, to Pacific Soils Analysis Laboratory in Richmond, BC for chemical analysis. Samples were analysed for NH_4-N and NO_3-N concentrations before and after incubation. Available NH

Table 3
Concentrations of elements ($\mu g\, g^{-1}$) in autumn litter from cottonwood plots (n = 6).

Element	Cottonwood litter		Fir/hemlock litter		Red cedar litter		ANOVA, P
C	507,530a	(3746)	542,373b	(6351)	543,258b	(10,963)	0.00
N	14,563a	(2093)	9772b	(1076)	5693c	(768)	0.00
P	643a	(61)	492b	(80)	362c	(85)	0.00
K	4885a	(1384)	1532b	(552)	1115b	(243)	0.00
Ca	19,215a	(1732)	9995b	(1832)	16,523a	(2545)	0.00
Mg	1993a	(351)	785b	(85)	603b	(124)	0.00
S	1385a	(229)	837b	(66)	543c	(38)	0.00
Mn	122a	(57)	300b	(207)	109a	(34)	0.01[a]
B	38a	(6)	15b	(4)	12b	(2)	0.00
Zn	339a	(112)	42b	(16)	19c	(7)	0.00
Fe	141	(25)	169	(68)	119	(21)	0.17
Cu	10a	(1)	8a	(3)	4b	(1)	0.00
Al	125	(22)	125	(22)	264	(349)	0.41

Single and double underlined values indicate significant differences at P < 0.1 and P < 0.05, respectively. Values in parentheses represent standard deviations. Different letters in the same rows indicate significant differences at P < 0.05.

[a] Data were log transformed to meet underlying statistical assumptions.

Table 4
Element contents ($kg\, ha^{-1}$) of autumn litter (composite of all litter types) in cottonwood and conifer plots (n = 6).

Element	Cottonwood plots		Conifer plots		P	Power
C	1578	(569)	1437	(432)	0.28	0.12
N	28.02	(9.97)	23.34	(6.47)	0.10	0.23
P	1.57	(0.70)	1.30	(0.54)	0.25	0.17
K	6.74	(3.93)	4.77	(2.83)	0.08	
Ca	44.14	(22.54)	33.59	(14.77)	0.13	0.23
Mg	3.12	(1.59)	2.29	(1.04)	0.07	
S	2.49	(0.91)	2.02	(0.49)	0.11	0.27
Mn	0.45	(0.21)	0.56	(0.13)	0.24	0.27
B	0.05	(0.03)	0.04	(0.01)	0.04	
Zn	0.38	(0.37)	0.14	(0.06)	0.13	0.43
Fe	0.70	(0.31)	0.97	(0.84)	0.30	0.17
Cu	0.022	(0.007)	0.018	(0.005)	0.03	
Al	0.79	(0.35)	1.15	(1.02)	0.31	0.19

Values in parentheses represent standard deviations. Single and double underlined values indicate significant differences at P < 0.1 and P < 0.05, respectively.

cottonwood plots, there was significantly more conifer litter (fir/hemlock + cedar) than cottonwood litter (P = 0.096).

Cottonwood litter that fell in autumn had significantly higher concentrations of N, P, K, Ca, Mg, S, B, and Zn, and lower concentrations of Mn than fir/hemlock litter (Table 3). Cottonwood plots had higher contents of K, Mg, B, and Cu in autumn litterfall (composite of all litter types) than conifer plots (Table 4). There were no significant differences in nutrient concentrations within fir/hemlock litter between cottonwood and conifer plots. No differences were found in lignin concentration or the lignin:N ratio between cottonwood and fir/hemlock litter (Table 5).

After 18 months of decomposition, mass loss did not differ between cottonwood and fir/hemlock litter within cottonwood plots, however, mass loss was lower for cottonwood litter when

Table 5
Properties of cottonwood and fir/hemlock litter (n = 4).

Property	Concentrations ($\mu g\, g^{-1}$)					
	Cottonwood litter		fir/hemlock litter		P	Power
Fibre (total)	664,912	(102,715)	574,955	(47,523)	0.13	0.41
Cellulose	320,432	(17,317)	307,089	(21,107)	0.43	0.22
Lignin	338,274	(91,506)	260,898	(50,242)	0.11	0.37
Lignin:N ratio	24	(6.30)	25	(4.73)	0.87	0.07

Values in parentheses represent standard deviations.

Table 6
Percentage of original litter remaining after 18 months decomposition period (n = 6).

	Post 18 month incubation					
	Cottonwood plot		Conifer plot		P (t-test)	Power ($1-\beta$)
Cottonwood litter	64.7	(3.10)	66.2	(4.09)	0.374	0.11
Fir/hemlock litter	60.6	(7.11)	62.7	(4.58)	0.465	0.09

	Post 18 month incubation					
	Cottonwood litter		Fir/hemlock litter		P (t-test)	Power ($1-\beta$)
Cottonwood plot	64.7	(3.10)	60.6	(7.11)	0.157	0.25
Conifer plot	66.2	(4.09)	62.7	(4.58)	0.071	0.29

Values in parentheses represent standard deviations.

F . 3. Mean thickness of forest floor horizons and Ah horizons for cottonwood and conifer plots (n = 6). None of the horizon depths are significantly different between plot types.

compared to fir/hemlock litter within conifer plots (Table 6). Mass loss did not differ for cottonwood litter decomposing in cottonwood plots when compared to conifer plots, or for fir/hemlock litter decomposing in cottonwood as compared to conifer plots.

3.2. Forest floor, mineral soil and N mineralization

None of the forest floor or upper mineral horizon depths were significantly different between plot types (Fig. 3). The same six humus forms were identified in both cottonwood and conifer plots: humimor, mormoder, vermimull, leptomoder, and mullmoder (Fig. 4). However, forest floors within cottonwood plots were found to have double the amount of mull-like (vermimull and mullmoder, P = 0.05) humus forms and a lesser (but not significantly different) proportion (38% vs. 55%) of mor-like (mormoder and humimor) humus forms compared to conifer plots.

Forest floors of cottonwood plots had a higher pH and lower concentrations of exchangeable K and Fe (Table 7) when compared to conifer plots. Mineral soil within cottonwood plots had a higher total N concentration and base saturation and lower concentrations of exchangeable Fe and Al than mineral soil of conifer plots (Table 8).

F . 4. Frequency of humus forms within (A) cottonwood and (B) conifer plots (n = 6).

Tab e 7
Properties of the forest floor in cottonwood and conifer plots (n = 6).

Property	Cottonwood plots		Conifer plots		P	Power
Weight (kg ha^{-1})	144,922	(37,113)	133,190	(114,625)	0.77	0.08
Bulk density (g cm^{-3})	0.23	(0.04)	0.20	(0.05)	0.21	0.28
pH (1:1 $CaCl_2$)	4.4	(0.45)	3.9	(0.52)	0.04	0.51
Total C (g kg^{-1})	308	(94)	372	(89)	0.09	0.30
Total C (kg ha^{-1})	43,891	(13,678)	46,193	(36,339)	0.86	0.10
Total N (g kg^{-1})	10.2	(1.5)	12.1	(2.9)	0.12	0.38
Total N (kg ha^{-1})	1477	(428)	1827	(2042)	0.64	
C:N ratio	30.2	(7.6)	30.8	(2.9)	0.77	
Mineralizable N (mg kg^{-1})	242	(51)	254	(44)	0.76	
Mineralizable N (kg ha^{-1})	34.4	(8.6)	38.0	(42.6)	0.85	0.07
NO_3-N (mg kg^{-1})	0.83	(0.92)	0.91	(1.16)	0.90	0.06
NO_3-N (kg ha^{-1})	0.11	(0.12)	0.07	(0.08)	0.49	0.16
NH_4-N (mg g^{-1})	27.4	(9.3)	32.8	(15.9)	0.51	0.16
NH_4-N (kg ha^{-1})	3.96	(1.52)	5.76	(8.32)	0.60	0.12
N mineralization ($^{-1}$) (mg kg^{-1} day^{-1})	0.86	(0.85)	3.95	(2.81)	0.04	
Available P (mg kg^{-1})	59.7	(22.0)	54.4	(11.6)	0.39	
Available P (kg ha^{-1})	8.09	(2.24)	6.54	(4.09)	0.55	0.19
Total S (g kg^{-1})	1.25	(0.19)	1.44	(0.32)	0.16	0.32
Total S (kg ha^{-1})	180	(49)	214	(233)	0.70	0.09
Exch K (cmol kg^{-1})	0.81	(0.21)	1.02	(0.14)	0.07	
Exch Ca (cmol kg^{-1})	25.3	(6.9)	23.0	(7.1)	0.64	0.13
Exch Mg (cmol kg^{-1})	2.56	(0.80)	2.74	(0.34)	0.55	0.12
Exch Mn (cmol kg^{-1})	0.50	(0.19)	0.48	0.18)	0.89	0.07
Exch Fe (cmol kg^{-1})	0.06	(0.04)	0.21	(0.15)	0.03	
Exch Al (cmol kg^{-1})	1.71	(0.84)	3.07	(1.81)	0.15	0.47
Exch Na (cmol kg^{-1})	0.34	(0.02)	0.33	(0.03)	0.29	0.16
CEC (cmol kg^{-1})	31.3	(7.0)	30.7	(5.5)	0.93	0.06
Total exchangeable bases (cmol kg^{-1})	29.0	(7.7)	27.1	(7.4)	0.71	0.11
Base saturation (%)	91.7	(5.7)	86.6	(8.9)	0.32	0.30

Values in parentheses represent standard deviations. Single and double underlined values indicate significant differences at P < 0.1 and P < 0.05, respectively.

Tab e 8
Properties of mineral soil in cottonwood and conifer plots (n = 6).

Property	Cottonwood plots		Conifer plots		P	Power
Bulk density ($g\,cm^{-3}$)	0.74	(0.15)	0.72	(0.26)	0.95	0.07
Coarse fragments (%)	42.0	(9.9)	31.8	(13.8)	0.05	
W_G ($g\ H_2O\,g^{-1}$ soil)	0.58	(0.24)	0.54	(0.25)	0.79	0.08
W_V ($g\ H_2O\,cm^{-3}$)	0.35	(0.10)	0.32	(0.06)	0.53	0.15
pH ($CaCl_2$)	4.50	(0.20)	4.15	(0.33)	0.12	0.67
Total C ($g\,kg^{-1}$)	73.9	(16.2)	71.8	(15.2)	0.62	0.08
Total C ($kg\,ha^{-1}$)	34,980	(12,098)	35,604	(22,820)	0.92	0.01
Total N ($g\,kg^{-1}$)	3.33	(0.78)	2.98	(0.53)	0.07	
Total N ($kg\,ha^{-1}$)	1557	(477)	1432	(733)	0.54	0.09
C:N ratio	22.5	(3.4)	24.2	(3.0)	0.18	0.20
Mineralizable N ($mg\,kg^{-1}$)	79.2	(24.1)	71.0	(12.4)	0.30	0.17
Mineralizable N (kg ha						

4.2. Nitrogen availability

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