Dynamics of Crop Residue Composition-Decomposition: Temporal Modeling of Multivariate Carbon Sources and Processes

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Objective:
- To examine multivariate relationships in structural carbohydrates (STC) plus lignin and non-structural carbohydrates (NSC) and their impact on:
  - C:N ratio, and
  - The dynamics of kinetic coefficients [overall (k_o), active (k_a) and passive (k_p)] of residue decomposition of stems, leaves and roots of alfalfa, corn, soybean, cuphea and switchgrass.

Composition-Decomposition:
- Structural Carbohydrates:
  - Cellulose, Hemicellulose,
  - Acid soluble & non-soluble lignin
- Non-structural Carbohydrates:
  - Sugars, Starch
- CO_2 released during 500 days of decomposition
- Ratios among major components
- k_o, k_a, and k_p

Calculations:
- First order kinetics model:
  $C_{to}=C(1-\exp(-kt))\ldots\ldots k_o$
- Double exponential model
  $C_t=C_a\exp(-k_a t)+(100-C_a)\exp(-k_p t)\ldots$. k_a & k_p
- C:N (and other) Ratios

Results:
- Different patterns of investment,
- Inconsistencies in the relationship between STCs and NSCs in roots, stems, and leaves, and
- Differences in construction cost (g glucose per g dry matter) among crops and among organs within crops.

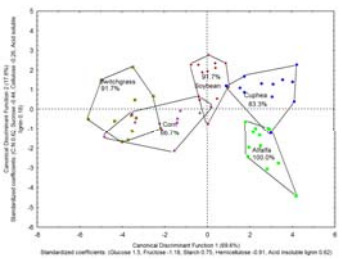

Fig. 1. Large levels of discrimination (i.e., percent correct classification) among crops based on their biochemical constituents

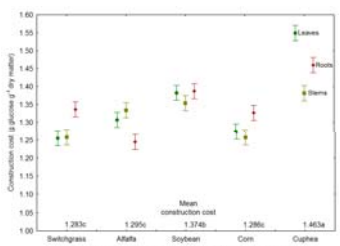

Fig. 2. Large and significant differences in construction cost (g glucose per g dry matter) among and within crops based on their biochemical constituents. Alfalfa roots are least, and Cuphea leaves are most "expensive."

C:N ratio

Table 1. Variance explained (adjusted R^2), and percent variance in N, C and C:N ratio accounted for by differences among crops (alfalfa, corn, cuphea, soybean and switchgrass), among organs (leaves, stems and roots) and among organs within crops.

Source of variation	Adjusted R^2	Percent variance due to		
		Crops	Organs	Organs(crops)
Carbon	91.0**†	19.7	1.0	70.9**
Nitrogen	97.0**	53.3**	33.7**	10.3**
C:N ratio	87.0**	35.0**	35.0**	14.4**

† **, significant at p<0.001

Table 2. Coefficients and test statistics of Partial Least Square (PLS) regression models to predict C:N in five crops (alfalfa, corn, cuphea, soybean and switchgrass) and their organs (stems, leaves and roots) using eight biochemical constituents (glucose, fructose, sucrose, starch, cellulose, hemicellulose, acid soluble lignin and acid insoluble lignin).

Crop/Organ	Calibration model				Validation model			
	Intercept	Slope	R^2-value	RMSE	Intercept	Slope	R^2-value	RMSE
All crops	20.4	0.55	55.0	19.0	22.3	0.47	52.0	20.9
Alfalfa	1.93	0.88	89.0	1.66	2.64	0.84	85.0	1.87
Corn	12.3	0.75	75.0	23.2	15.6	0.68	61.0	29.3
Cuphea	1.06	0.87	88.0	1.61	1.94	0.82	82.0	2.10
Soybean	25.7	0.66	62.0	20.2	32.3	0.57	52.0	23.0
Switchgrass	28.9	0.62	59.0	23.9	35.0	0.49	46.0	29.0
Leaves	9.96	0.59	59.0	7.7	11.1	0.55	49.0	8.0
Stems	30.8	0.54	54.0	20.3	31.8	0.53	54.0	21.0
Roots	14.1	0.68	68.0	12.6	18.4	0.59	54.0	16.4
Roots (1)†	13.3	0.70	71.0	16.6	14.9	0.66	61.0	19.1
Roots (2)	13.2	0.71	71.0	17.4	15.0	0.66	61.0	19.6
Roots (3)	14.2	0.69	78.0	16.7	16.0	0.63	58.0	19.2
Roots (4)	30.1	0.33	33.0	18.4	33.7	0.25	20.0	20.5
Roots (5)	23.6	0.48	57.0	16.3	26.3	0.43	34.0	18.8
Roots (6)	24.4	0.46	46.0	16.6	27.1	0.42	28.0	19.2

† Independent variables are biochemical constituents: (1) in leaves, stems, and roots; (2) in stems and leaves; (3) in stems; (4) in leaves; (5) only C:N ratio in stems and leaves; and (6) only C:N ratio in stems.

Table 3. Percent variance in kinetic coefficients due to several sources in a decomposition study.

Factors	k_o	k_a	k_a
Decomposition days (DCD)	18.5**	16.0**	44.6**
Crops	29.3**	31.1**	12.1*
Organs	23.7**	28.9**	8.5*
Crops*DCD	4.2*	4.5*	12.5
Organs*DCD	3.4*	2.6*	6.9
Organs(Crops)	15.1**	12.3**	5.7
Adjusted R^2	0.93*	0.93*	0.89*

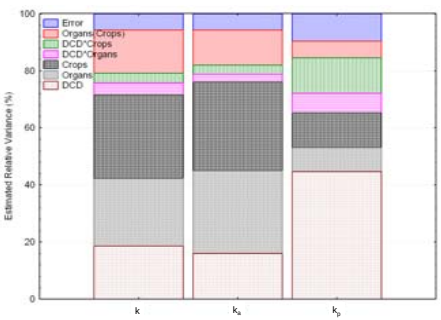

Fig. 3. Percent variance in kinetic coefficients due to several sources in a decomposition study.

Discrimination among plant organs & Prediction of C:N ratios

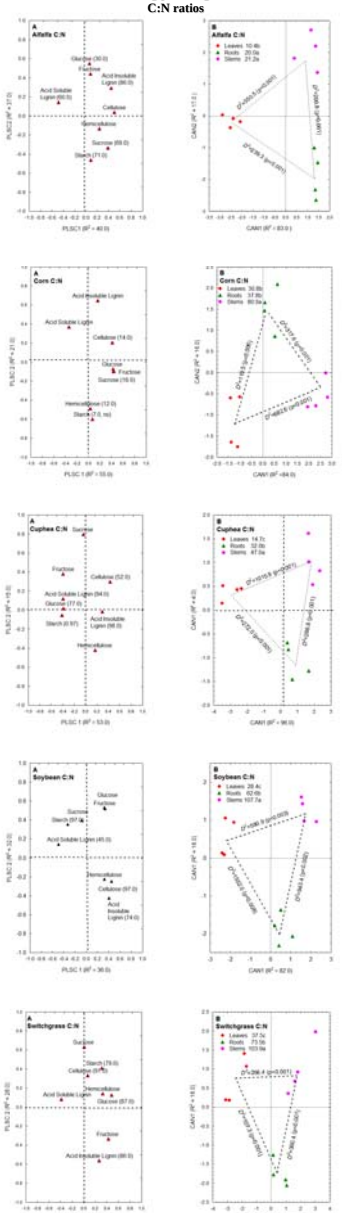

Fig. 4. [A] Loadings, significant R^2 values of biochemical constituents, and amount of variation in C:N ratio accounted for by the first partial least squares components;

[B] Discrimination, squared Mahalanobis distances (D^2) and mean separation among C:N ratio estimates in leaves, stems and roots of five crops based on their biochemical composition.

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Table 4. Model coefficients and test statistics using biochemical constituents and their ratios in predicting overall [(k_o), active (k_a) and passive (k_p)] kinetic coefficients for five crops.

Phase	Factors	k_o			k_a			k_p		
		Model I	Model II	Model III	Model I	Model II	Model III	Model I	Model II	Model III
Early <30 DCD	C:N	*(-)¶		*(-)	*(-)		*(-)	*(-)		*(-)
	NSC:STC	*(+)		ns	*(+)		ns	*(+)		ns
	Lig:N	*(-)		*(-)	ns		*(-)	ns		*(-)
	L:HCel	*(+)		*(-)	*(+)		ns	*(+)		ns
	Sugars		* (+)	*(-)		*(+)	*(-)		* (+)	*(-)
	Starch		*(+)	*(+)		*(+)	*(+)		*(+)	*(+)
	HC		*(-)	*(-)		*(-)	*(-)		*(-)	*(-)
	Cel		*(-)	*(-)		*(-)	*(-)		*(-)	*(-)
	AIL		*(-)	*(-)		*(-)	*(-)		*(-)	*(-)
	ASL		*(+)	* (+)		*(+)	*(+)		*(+)	*(+)
	Mean	**0.136**	**0.136**	**0.136**	**0.129**	**0.129**	**0.129**	**0.0007**	**0.0007**	**0.0007**
	Predicted mean	***0.146*a§***	***0.147*a***	***0.130b***	***0.132a***	***0.134a***	***0.123b***	***0.0007a***	***0.0007a***	***0.0008a***
	β	*0.210Ba†*	*0.307Aa*	*0.297Aa*	*0.202Ba*	*0.291Aa*	*0.282Aa*	*0.0009Bb*	*0.0015Ab*	*0.0012Ab*
	RMSE	*0.051*	*0.042*	*0.039*	*0.045*	*0.036*	*0.033*	*0.0003*	*0.0003*	*0.0003*
	R^2	*0.53*	*0.68*	*0.72*	*0.56*	*0.71*	*0.76*	*0.23*	*0.32*	*0.32*
Med >30 <90 DCD	C:N	*(-)		*(-)	*(-)		* (-)	*(-)		* (-)
	NSC:STC	ns‡		* (-)	ns		ns	ns		ns
	Lig:N	*(-)		*(-)	*(-)		*(-)	ns		*(-)
	L:HCel	ns		ns	ns		ns	ns		ns
	Sugars		ns	*(+)		* (-)	*(+)		*(-)	*(+)
	Starch		ns	*(+)		*(+)	*(+)		*(+)	*(+)
	HC		*(-)	*(-)		* (-)	*(-)		*(-)	*(-)
	Cel		*(-)	*(-)		*(-)	*(-)		*(-)	*(-)
	AIL		ns	*(-)		*(-)	*(-)		*(-)	*(-)
	ASL		*(+)	* (+)		*(+)	ns		*(+)	ns
	Mean	***0.094***	***0.094***	***0.094***	***0.091***	***0.091***	***0.091***	***0.0015***	***0.0015***	***0.0015***
	Predicted mean	***0.094***	***0.089***	***0.093***	***0.092***	***0.088***	***0.087***	***0.0015***	***0.0015***	***0.0013***
	β	*0.138Bb*	*0.201Ab*	*0.180Ab*	*0.139Bb*	*0.206Ab*	*0.191Ab*	*0.0020Aa*	*0.0025Aa*	*0.0023Aa*
	RMSE	*0.031*	*0.023*	*0.023*	*0.029*	*0.024*	*0.021*	*0.0005*	*0.0006*	*0.0005*
	R^2	*0.56*	*0.74*	*0.76*	*0.63*	*0.74*	*0.81*	*0.45*	*0.30*	*0.45*
Late >90 DCD	C:N	*(-)		*(-)	*(-)		*(-)	*(-)		*(-)
	NSC:STC	ns		ns	ns		ns	ns		ns
	Lig:N	*(-)		*(-)	*(-)		*(-)	*(-)		*(-)
	L:HCel	ns		ns	ns		ns	ns		ns
	Sugars		ns	ns		ns	ns		ns	ns
	Starch		ns	*(-)		ns	*(-)		ns	ns
	HC		*(-)	*(-)		*(-)	*(-)		*(-)	*(-)
	Cel		*(-)	*(-)		*(-)	*(-)		*(-)	*(-)
	AIL		*(-)	ns		*(+)	ns		*(-)	*(+)
	ASL		ns	ns		ns	ns		ns	ns
	Mean	***0.075***	***0.075***	***0.075***	***0.081***	***0.081***	***0.081***	***0.0008***	***0.0008***	***0.0008***
	Predicted mean	***0.074***	***0.079***	***0.072***	***0.071*c***	***0.091*a***	***0.079b***	***0.0008***	***0.0008***	***0.0008***
	β	*0.102Bc*	*0.153Ac*	*0.134Ac*	*0.123Bb*	*0.178Ac*	*0.161Ac*	*0.0009Ab*	*0.0009Ac*	*0.0009Ac*
	RMSE	*0.024*	*0.0167*Ac*	*0.019*	*0.024*	*0.021*	*0.018*	*0.00013*	*0.0015*	*0.00013*
	R^2	*0.54*	*0.78*	*0.72*	*0.65*	*0.73*	*0.81*	*0.38*	*0.19*	*0.36*

¶, *() *significant negative (-) or positive (+) regression coefficient of factor on k_o,ka or kp within each model*
*§, * the simulated k mean is significantly different from the measured k mean within each Model, a Simulated means followed by the same letter for each k are not significantly different.*
†: β followed by the upper case letter within each k do not differ significantly, those followed by same small case letter do not differ significantly among phases.

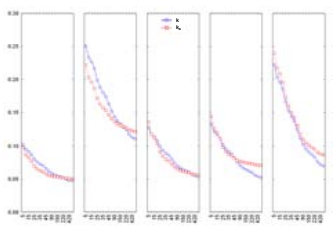

Fig. 5. Alfalfa and cuphea have faster rates of decomposition, followed by corn and soybean, then by switchgrass based on overall (k_o), or active (k_a) kinetic coefficients.

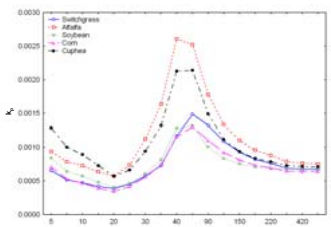

Fig. 6. Differences in passive decomposition rate (k_p) between crops were largest between ~ 40-100 days, after which a gradual decline in k_p and smaller differences between crops were observed.

Conclusions:
- Biochemical composition classified crops & organs with large accuracy.
- Crops and organs differed in their construction costs. Cuphea leaves and alfalfa roots were most and least expensive, respectively.
- C:N is largely determined by N; most of its variation is accounted for by differences among crops and among organs.
- C:N in roots can be estimated by biochemical composition of leaves and stems (R^2=0.61).
- Biochemical composition singly or in combination with Ratios explained large (R^2 0.68-0.81) variation in k_o and k_a. Ratios became more important in explaining variation in k_p >90 DCD.
- A 90-100 DCD period is enough to delineate significant differences among crops, among organs and among organs within crops.
- Residues with large C:N (>40)may be better used as biomass for bioenergy; residues with small C:N (<20) may be better used for nutrient re-cycling.