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Distribution of aboveground biomass in corn stover

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Abstract

Corn stover can be a principal feedstock for bioenergy and industrial applications because of its abundance and its current underutilization. Development of strategies/systems for the postharvest handling of corn stover involves quantifying what corn stover biomass is available over time after grain physiological maturity has been reached. It also involves understanding how the biomass is distributed in the different aboveground components of the corn plant. The objectives of this preliminary investigation were to measure the allocation of biomass to aboveground components of the corn plant over time and to develop relationships for estimating total aboveground corn plant biomass through simple corn plant dimensional measurements. Aboveground biomass distribution for two corn cultivars (Pioneer 32K61 and 32K64 Bt) was studied in standing plants from roughly 1 week before grain physiological maturity until 4 weeks after grain harvest from other plots in the field. Over the monitoring period, the amount of dry matter in stover averaged 50% of the total aboveground dry plant mass with stalks comprising 50% of the stover dry matter at the time grain was harvested. This study indicated that the more conservative 0.8:1 stover:grain fresh weight ratio, rather than the 1:1 widely used, may be more realistic at the grain harvest moisture range of 18–31% w.b. Such precondition has not been clearly emphasized in the literature. Regression equations involving stalk diameter and plant height for DeKalb 626 derived to estimate fresh green weight and dry matter of the corn plant above the ground had a maximum R^2 of 0.75.

Keywords: Corn stover; Residue; Field drying; Stover:grain ratio; Residue multipliers

1. Introduction

It has been put forward that corn stover can be the strategic feedstock for both bioenergy and bio-based industrial products because of its abundance and proximity to existing grain-to-ethanol conversion facilities [1–3]. Key issues that need addressing are how to harvest and process corn stover to maximize its quality as a fuel or industrial feedstock, minimize material losses, and improve handling efficiencies. Development of strategies/systems for the postharvest handling of corn stover involves quantifying what corn stover biomass is available over time after physiological maturity of the grain has been reached. It also involves understanding how the biomass is distributed in the different aboveground components of the corn plant. Similar studies have been previously conducted,

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e.g., Cummins [4], Johnson et al. [5], Leask and Daynard [6], and Russell [7], from the standpoint of utilizing corn stover as forage and were thus terminated at grain physiological maturity. Understanding the total quantity of corn stover biomass and its moisture content from the time of corn kernel physiological maturity serves as a basis for the timing of harvest for grain and stover. Understanding how the biomass is distributed in the different aboveground components of the corn plant provides the basis for considering possible segregated processing. Objectives of this preliminary investigation were to measure the allocation of biomass to aboveground components of the corn plant over time and to develop relationships for estimating total aboveground corn plant biomass using simple corn plant dimensional measurements.

2. Materials and methods

2.1. Test material

Available corn in a 0.4 ha field at The University of Tennessee, Knoxville Experiment Station, Plant Sciences Unit, was taken as the test material for understanding dry matter distribution in corn stover fractions. While the field represented such a small sampling of corn to provide definitive numerical results, it represented material from which relative variations in plant fractions as the plants matured and were exposed to weathering could be monitored. The field had Sequatchie loam soil, which is a deep, well-drained alluvial soil on the first terrace of the Tennessee River. The field, which had not been in continuous corn, was divided into 32 plots, measuring 9.2×6.1 m, laid out on a 4×8 grid. A column consisted of four plots, each separated by a 2.1 m alley. A Bt cultivar, Pioneer [1] 32K64, and its parent cultivar, Pioneer 32K61, served as the treatments and each was randomly allocated to two plots within a column. Both hybrids had a comparative time to maturity of 114 days [8]. Each plot was planted to eight 0.76 m rows of corn on April 27, 2001. Fertilization, herbicide, and pesticide treatments followed recommended practices for Tennessee. Fertilization consisted of 168 kg N, and 90 kg each of P_2O_5 and K_2O equivalents. Just prior to planting, the plots received 561 kg ha^{-1} of 10–10–10 fertilizer through broadcast application. On May 27, 2001, the plots were side-dressed with 360 kg ha^{-1} of 34–0–0 (ammonium nitrate). After seed emergence, plant populations were thinned back to approximately 64,200 plants ha^{-1}. Irrigation was provided when precipitation was inadequate.

Collection of Pioneer plants for dimensional measurements at the late dent stage was inadvertently missed, hence dimensional measurements were made instead on DeKalb 626 plants cut from another field in the Knoxville Experiment Station. That field of corn received the same cultural management as the field of Pioneer corn. The field was planted on May 21 and the test material was harvested on September 25.

[1] Trade names are provided for the sake of factual reporting. The University of Tennessee neither guarantees nor warrants the standard of the product and the use of the trade name implies no approval of the product to the exclusion of others.

2.2. Biomass monitoring

Four interior plots of the Pioneer corn, two each on adjacent plot columns—one planted to Pioneer 32K64 and the other to Pioneer 32K61—were selected for sampling. By this selection, border effects such as smaller plants and preferential drying because of greater wind and sun exposure would be eliminated. Sampling started at the late dent stage and continued until four weeks after the time the grain was deemed suitable for harvest. The grain was judged ready for harvest in mid-September, and thus some plots not immediately bordering the sampling plots were harvested on September 28, 2001, using a two-row field plot combine.

Sampling was undertaken between August 9 and November 26, 2001, roughly a week before grain physiological maturity until several weeks after grain harvest time. Two randomly selected corn plants were manually harvested from each corn plot serving as the observation unit for the experiment. The plants were cut by hand 15.2 cm from the ground, a reasonable and realistic distance to minimize soil contamination in a mechanized operation, and taken to the laboratory for processing. According to Johnson and Lamp [9], cutting the corn plants at the soil surface would add another 10% to stover yields over normal harvesting practices. The cut plants were meticulously separated into leaves (leaf blades only), stalks (including tassel and leaf sheaths), husks (including the shank), and ears. The sheath resembled the hardier stalk material so it was included as part of the stalk fraction. In their studies on corn stover digestibility, Sewalt et al. [10] and Rebolé et al. [11] partitioned leaves and stalks in the same way. Each fraction was weighed separately. Since there was great variation in the drying of leaves and stalk sections vertically along the plant, these stover fractions were shredded separately in a chipper/shredder to obtain a homogenous sample for moisture-content determination and later chemical analysis. The chopped leaf and stalk material was immediately collected, sealed in separate plastic sample bags, and stored at $-20°C$. With the rupture and breakage of the plant material, it is likely that moisture could have been lost in the chopping process, but this was assumed to be a negligible amount that was a consistent error across all samples.

Moisture content of the different plant components was determined according to ASAE standards [12]. All plant fractions except the grain were treated as forage and were dried for 24 h at 103°C [13]. To improve sample uniformity and enhance drying, the cob and husk were cut into 2.54 cm pieces before being placed into the convection oven. Stalks and leaves were already shredded. The grain was dried for 72 h at 103°C [14]. Moisture content, mass of the fresh sample, and plant population were used to calculate dry matter yields ($t\ ha^{-1}$) of each corn plant component.

2.3. Plant dimensional measurements

Forty Dekalb 626 plants were obtained from a single interior row by manually cutting the stems 15.2 cm from the ground. The plants were brought to a laboratory where each was separated into its component parts following the same procedure described previously. Total height (cm) of the stalk, including the tassel, was measured, as well as the height up to the third leaf from the tassel end. Using a Vernier caliper, diameters of the stalk with the leaf sheath were measured in at 55.9, 106.7 and 152.4 cm from the base of stalk. Since corn stalks are not circular in cross section, two diameter measurements were taken, one orthogonal to the other, at each height. The first diameter measurement was always taken in the direction parallel to the leaf midrib. The average of these two readings was taken as the diameter at each height. For each plant, the weight of each component fraction was measured and its moisture content measured according to ASAE standard procedures. Leaves and stalk of each plant were cut into 2.54 cm sections, rather than shredded, for moisture-content determination. The relationship between corn plant dimensions and the fresh weight and dry weight of the corn stover was investigated through multiple linear regression [15].

3. Results and discussion

3.1. Corn stover mass distribution

Fig. 1 shows dry matter yields for each stover fraction over the entire 109 day study period that started at the late dent stage and continued up to several weeks after grain had reached harvest moisture. Considering that plotted variations in dry matter distribution of Pioneer 32K64 and 32K61 over time were closely overlapping, their results were combined and the average is presented. The dry matter yields peaked when the stover fractions were harvested at the time of grain physiological maturity, in this study, roughly 118 days after planting. At that time, the grain had a moisture content of 30.6% (In this paper moistures presented are wet basis unless stated otherwise.), and the grain, stalk, leaf, cob, and husk accounted for 13.0, 7.9, 3.3, 2.4 and 2.0 $t\ ha^{-1}$, respectively. Distribution of aboveground dry matter was therefore 45.9% grain, 27.5% stalk, 11.4% leaf, 8.2% cob, and 7.0% husk. The grain percentage matched the 45% that

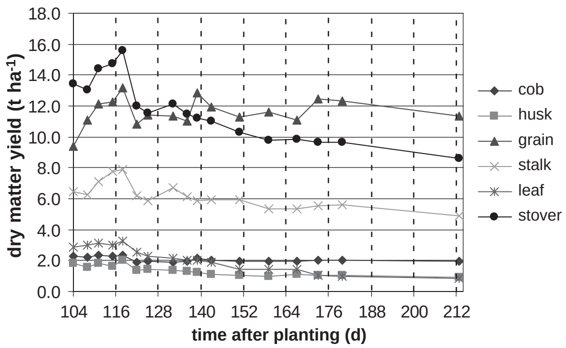

Fig. 1. Dry matter content in corn plant fractions.

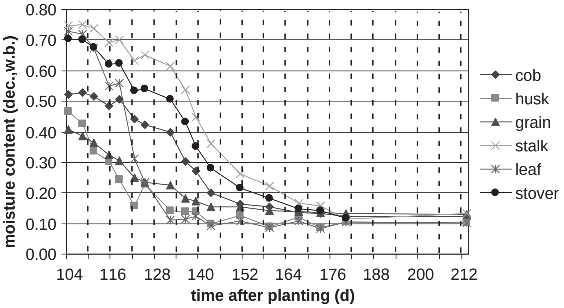

Fig. 2. Field drying of aboveground components of standing corn plants.

Nielsen [16] in Indiana had stated as the grain percentage of the total dry matter yield of a cornfield. Leask and Daynard [6] in Ontario, Canada, found that approximately 50% of the mature plant dry weight was grain. Preston and Schwinn [17] and Johnson et al. [5] found similar results in their studies in Ohio. Linden et al. [18] in Minnesota found the ratio of grain dry matter to total plant dry matter averaged 56% over a 13 year period, with yearly values not varying significantly. Data collection by Lipinsky et al. [19] over a 4 year period in Iowa showed that at 23% grain moisture (typical at harvest time in the US Midwest) the grain made up 53.1% of the total plant dry weight. Interestingly, all these results for different cultivars planted south to north in North America over different years clustered around 50% at grain physiological maturity. Excluding the grain, distribution of mass in stover at grain physiological maturity in this study was 50.9% stalk, 21.0% leaf, 15.2% cob and 12.9% husk. This biomass distribution in stover compared well to that reported in the literature [7,9,20].

As drying of the plant components progressed after grain physiological maturity (Fig. 2). (A discussion about the field drying of corn stover fractions is presented elsewhere [12].), and the components became brittle, physical loss of material from the plants due to weathering (wind and rainfall) increased to the point that they were more visually evident. Leaf blades, tassels, tops of the stalks, and husk leaves started breaking off. Dry matter yields of stalk, leaf, and husk fractions declined after 118 days, with the leaf fraction sustaining the most rapid and greatest losses. By the end of the study period, 213 days after planting, the leaves had lost 74% of the maximum-recorded dry matter. Dry matter losses for husk and stalk fractions were lower than for the leaf, but were still substantial at 54% and 38%, respectively. Dry matter losses in the cob and grain fractions, at 18% and 13%, respectively, were minimal, more likely representing deterioration of the dry matter by respiration and/or microbial action. The amount of dry matter in stover ranged from 8.6 to 15.6 t ha^{-1} (3.8–7.0 t ac^{-1}) over the monitoring period, with an average of 11.7 t ha^{-1} (5.2 t ac^{-1}). Dry matter in the grain also averaged 11.7 t ha^{-1}. Prior to grain physiological maturity, much of the dry matter was in the stover fractions. This relationship was reversed after grain maturity (Fig. 1).

When the grain moisture was 18.3%, the stalk, cob, husk, and leaf moisture contents were 53.8%, 30.4%, 13.9%, 11.5%, respectively. Over the years, dry matter in aboveground corn plant fractions has been expressed using three different ratios: (1) grain:total plant dry matter, (2) stover:total plant dry matter, and (3) stover:grain fresh weight (residue multiplier).

Biomass allocation in aboveground corn fractions has also been alternatively expressed as the proportion of stover dry matter to the total aboveground plant dry matter or the proportion of stover dry matter to grain fresh weight. These ratios are widely used without recognizing their variation with grain moisture because, judging from the literature, their variation after grain maturity has not been adequately researched. In regard to the former ratio, Ayres and Buchele [21] reported that the non-grain portion of the corn plant contains approximately one half of the total plant dry matter when grain moisture content is at the nebulous “suitable for harvest” range. Results of this study are more definitive in showing that between 18% and 31% grain moisture, the average ratio between stover dry matter and total plant dry matter was 0.52 (Table 1).

Variation in the stover to grain ratio as the corn plant matures and then as it deteriorates during senescence is presented in Table 1 as well. Also known as residue multipliers, the stover:grain ratio is commonly used for preparing quick order-of-magnitude estimates of a particular residue production; and their limitations must be understood to avoid unnecessary interpretive mistakes or inappropriate applications [22]. The ratios express dry matter residue yield in relation to field weight of harvested grain. As Table 2 shows, these are affected by the maturity stage of the plants and

Table 1
Ratio of stover to total aboveground dry matter and grain fresh weight from the late dent stage up to several weeks after grain has reached harvest moisture[a,b]

Time after planting (day)	Grain MC (% w.b.)	Stover dry matter (t ha^{-1})	Total dry matter (t ha^{-1})	Grain fresh weight (t ha^{-1})	Stover:total dry matter	Stover:grain
104	40.8	13.43	22.84	15.69	0.59	0.86
108	38.5	13.02	24.11	18.03	0.54	0.72
111	36.3	14.40	26.53	19.07	0.54	0.75
115	32.4	14.71	26.97	18.14	0.55	0.81
118	30.6	15.57	28.76	19.05	0.54	0.82
122	25.1	12.02	22.82	14.43	0.53	0.83
125	23.4	11.52	22.95	14.97	0.50	0.77
132	22.5	12.11	23.44	14.64	0.52	0.83
136	18.3	11.48	22.53	13.54	0.51	0.85
139	17.4	11.23	24.05	15.54	0.47	0.72
143	15.4	11.02	22.95	14.10	0.48	0.78
151	15.6	10.33	21.64	13.40	0.48	0.77
159	14.1	9.76	21.38	13.54	0.46	0.72
167	13.9	9.82	20.88	12.84	0.47	0.77
174	13.6	9.67	22.12	14.41	0.44	0.67
181	13.1	9.64	21.97	14.19	0.44	0.68
213	13.0	8.61	19.93	13.00	0.43	0.66

[a]Pooled data for Pioneer 32K64 and 32K61.
[b]Grain in some plots harvested 154 days after planting.

Table 2
Regression equations between corn plant dimensions and stover fresh weight and dry weight

Above ground corn stover	Regression equation	Coefficient of determination, R^2
Fresh weight	$y = -474.12 + 155.75 * d1 + 65.63 * d2 + 53.59 * d3 + 169.14 * h3 + 2.85 * h_t$	0.7567
	$y = -472.22 + 155.93 * d1 + 65.83 * d2 + 53.46 * d3 + 171.9 * h3$	0.7567
	$y = 1.89 + 0.71 * d1^2 h3$	0.7185
Dry weight	$y = -235.64 + 77.41 * d1 + 32.62 * d2 + 26.64 * d3 + 84.05 * h3 + 1.42 * h_t$	0.7567
	$y = -234.69 + 77.50 * d1 + 32.72 * d2 + 26.57 * d3 + 85.42 * h3$	0.7567
	$y = -75.65 + 2.78.14 * d1^2 h3$	0.7148

$d1$, $d2$, and $d3$ are the mean diameter measurements at 55.9, 106.7 and 152.4 cm from the base of the stalk, respectively. h_t is the total height of the stalk with the tassel. $h3$ is the height up to the third leaf from the tassel end.

corresponding grain moistures at the time of harvest. The latter point has not been generally presented and emphasized enough in the literature. Oursbourn et al. [23] cited literature that has reported ratios ranging from 0.68:1 to 1:1, but they used a ratio of 1.07:1 in estimating corn residue yields in Texas. Ratios from the US and elsewhere tabulated by Smil [22] ranged from 0.58 to 4.00. How the figures were derived by the respective authors, much less the stage of maturity of the corn nor moisture content of the grain to which these ratios corresponded to, was not indicated. Presumably, the ratios referred to corn plant material at the time of grain harvest. In his study in Iowa, Russell [7] found the stover to grain ratio at grain physiological maturity to be 1.0, when adequate precipitation was received. Smil [22] stated that for American corn, stover:grain ratios cluster closely around 1:1. Table 1 shows that a 1:1 ratio is high. The data obtained indicates that a 0.8:1 ratio is more appropriate when the grain is harvested at about grain physiological maturity. Based on data accumulated over the years, using a 1:1 ratio for estimating the mass of residue yield (dry weight) from the mass of grain yield (fresh weight) is certainly a convenient practice but needs caution. The availability factor concept that Klass [24] reemphasized, which for corn was 0.6, definitely needs to be considered in making material estimates.

3.2. Regression equations

Initial regression analyses of corn plant measurements are presented in Table 2. The measurements were taken when stover moisture was 50.3%. Other studies have shown that the square of the basal diameter times the height could be correlated with the total biomass in both eucalyptus and pine trees [25–27]; hence, this was one relationship tested. The table shows that stalk diameter and height measurements of corn plants could be used in estimating both fresh weight and dry weight of corn stover. However, since the highest R^2 obtained was only 0.76, these regression equations may be used in estimations but with a degree of caution.

4. Conclusions

For this particular study, at grain physiological maturity when grain moisture was 30.6%, grain, stalk, leaf, cob, and husk accounted for 13.0, 7.9, 3.3, 2.4 and 2.0 t ha^{-1}, respectively. Distribution of aboveground dry matter was therefore 45.9% grain, 27.5% stalk, 11.4% leaf, 8.2% cob and 7.0% husk. Prior to grain physiological maturity, much of the dry matter was in the stover fractions while the opposite became true after grain maturity. Over the monitoring period, the amount of dry matter in stover averaged 50% of the total dry plant material, with stalks comprising 50% of the stover dry matter at the time grain was harvested.

Over the years, dry matter in aboveground corn plant fractions has been expressed using three different ratios: (1) grain:total plant dry matter, (2) stover:total plant dry matter and (3) stover:grain fresh weight (residue multiplier). These ratios have been used in estimating corn stover biomass. Nielsen [16] stated that grain percentage was 45% of the total dry matter yield of a cornfield. Ayres and Buchele [21] reported that the non-grain portion of the corn plant contained approximately half of the total plant dry matter when the moisture content of the grain is suitable for harvest. Smil [22] stated that for American corn, stover:grain ratios cluster closely around 1:1. This study supports the two former results but with the qualification: grain moisture is between 18% and 31%. The moisture range at which these first two ratios are applicable has not been emphasized enough in the literature. This study indicates that the more conservative 0.8:1 stover:grain fresh weight ratio may be more realistic.

Regression analysis results showed that stalk diameter and height measurements of corn plants could also be used in estimating both fresh weight and dry weight of corn stover. However, since the highest R^2 obtained was only 0.76, these regression equations may be used with caution in estimations.

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