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Vertical Distribution of Corn Stover Dry Mass Grown at Several US Locations

Wally W. Wilhelm · Jane M. F. Johnson · Dave T. Lightle · Douglas L. Karlen · Jeff M. Novak · Nancy W. Barbour · David A. Laird · John Baker · Tyson E. Ochsner · Ardell D. Halvorson · David W. Archer · Francisco Arriaga

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Abstract Corn (*Zea mays* L.) stover was identified as a renewable non-food agricultural feedstock for production of liquid fuels, biopower, and other bioproducts, but it is also needed for erosion control, carbon sequestration, and nutrient cycling. To help balance these multiple demands, our objectives were to (1) determine height distribution of corn stover biomass, (2) quantify the percentage of stover that is corn cob, and (3) develop a general relationship

The author Wally W. Wilhelm is deceased.

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W. W. Wilhelm
Agroecosystems Management Research Unit,
USDA-Agricultural Research Service,
117 Keim Hall,
Lincoln, NE 68583, USA

J. M. F. Johnson (✉) · N. W. Barbour
North Central Soil Conservation Research Laboratory,
USDA-Agricultural Research Service,
803 Iowa Ave,
Morris, MN 56267, USA
e-mail: Jane.johnson@ars.usda.gov

N. W. Barbour
e-mail: Nancy.barbour@ars.usda.gov

D. T. Lightle
USDA-NRCS National Soil Survey Center,
100 Centennial Mall N. Rm 152,
Lincoln, NE 68508-3866, USA
e-mail: dave.lightle@lin.usda.gov

D. L. Karlen · D. A. Laird
National Laboratory for Agriculture and the Environment,
USDA-Agricultural Research Service,
2110 University Boulevard,
Ames, IA 50011, USA

D. L. Karlen
e-mail: Doug.karlen@ars.usda.gov

D. A. Laird
e-mail: David.laird@ars.usda.gov

J. M. Novak
Coastal Plains Research Center,
USDA-Agricultural Research Service,
2611 W. Lucas St,
Florence, SC 29501, USA
e-mail: Jeff.novak@ars.usda.gov

J. Baker · T. E. Ochsner
Soil and Water Management Research Unit,
USDA-Agricultural Research Service,
439 Borlaug Hall 1991 Upper Buford Circle,
St. Paul, MN 55108, USA

J. Baker
e-mail: John.baker@ars.usda.gov

T. E. Ochsner
e-mail: Tyson.ochsner@okstate.edu

between plant harvest height and stover remaining in the field for a broad range of growing conditions, soil types, and hybrids in different regions. Plant height, dry grain, stover, and cob yield data were collected at eight US locations. Overall, stover yield increased about 0.85 Mg ha^{-1} and cob yield increased about 0.10 Mg ha^{-1} for each 1.0 Mg ha^{-1} increase in dry grain yield. At grain harvest, the stover-to-grain ratio ranged from 0.64 to 0.96 and cob-to-grain ratio ranged from 0.11 to 0.19. A strong nearly 1:1 linear (r^2=0.93) relationship between the relative cutting height and relative biomass remaining in the field was observed across all sites. These data were requested by the US Department of Agriculture-Natural Resource Conservation Service to help improve version 2 of the Revised Universal Soil Loss Equation (RUSLE2) and Wind Erosion Prediction System and better estimate corn stover harvest rates based on cutting height or selective organ harvest (e.g., grain and cob only). This information will improve the capacity of RUSLE2 and similar models to predict the erosion risk associated with harvesting corn residues.

Keywords Cobs · Crop residues · Corn stover · Harvest index RUSLE2 · Soil erosion · Soil organic matter

Abbreviations

(GLM)	General linear model
(HI)	Harvest index
(RUSLE2)	Revised Universal Soil Loss Equation version 2
(SOM)	Soil organic matter
(USDA-ARS)	US Department of Agriculture-Agriculture Research Service
(USDA-NRCS)	US Department of Agriculture-Natural Resource Conservation Service
(WEPS)	Wind Erosion Prediction System

A. D. Halvorson
USDA-Agricultural Research Service,
2150 Centre Ave. Bldg. D. Suite 100,
Fort Collins, CO 80526, USA
e-mail: Ardell.halvorson@ars.usda.gov

D. W. Archer
Northern Great Plains Research Laboratory, USDA-Agricultural Research Service,
PO Box 459, Mandan, ND 58554, USA
e-mail: David.archer@ars.usda.gov

F. Arriaga
National Soil Dynamics Research Laboratory, USDA-Agricultural Research Service,
411 S. Donahue Dr,
Auburn, AL 36832, USA
e-mail: Francisco.arriaga@ars.usda.gov

Present Address:
T. E. Ochsner
Department of Plant and Soil Sciences, Oklahoma State University,
Stillwater, OK 74078, USA

Introduction

Corn stover is anticipated to be a second-generation (non-food) agricultural feedstock for bioenergy, which will help reduce reliance on imported fossil fuel, increase revenue for farmers and rural communities, and reduce greenhouse gas emissions. Non-grain biomass (e.g., straw and stover) commonly called residue is viewed by some as an inexpensive, “unused” feedstock for enzymatic ethanol and other biofuel production or biopower through thermo-chemical processes (e.g., gasification or pyrolysis). Current projections to meet the 2022 target of ~76 billion liters per year of second-generation ethanol and other renewable fuels will require upwards of 218 million Mg of dry feedstock, which is equivalent to about 50% of the agricultural residue produced from the eight states leading in US crop production [4]. Furthermore, the amount of agricultural residue that can be harvested in a sustainable manner is still being determined since a portion of the residue needs to remain in the field to control erosion, maintain soil organic matter (SOM), and cycle nutrients [10, 32].

Typically in the USA, unless corn stover is harvested for animal feed or bedding it remains in the field. Crop residue retained in the field replenishes SOM, recycles nutrients (e.g., N, P, K, etc.) and when kept on the soil surface can reduce runoff and minimize soil erosion [15, 16, 19, 31]. While the amount of biomass needed to sustain SOM can exceed the amount needed to control water and soil erosion [32], it is still critical to understand the relationship between residue harvest and soil erosion.

Mechanical harvesting-systems are being developed and tested that collect corn grain and stover, or grain and cobs in one-pass [12, 26]. The amount of stover that remains in the field will vary depending upon the cutting height [12] and/or if the cobs are collected during harvest [11]. Shinner and Binversie [24] reported that 56% of the stover dry mass was in stalk, 15% in cob, 8% in husk, and 21% in leaves. This is similar to data presented by Pordesimo et al. [22]. Both studies segregated biomass by organ, however, during a one-pass harvest operation, the harvested stover would be comprised of multiple organs, and the relative proportions of stalk, cobs, husks, and leaves will vary with cutting height. As the cutting height is lowered, the amount of stover remaining on the soil surface to prevent erosion and to maintain SOM decreases. In addition to the mass of stover, diameter of the remaining stalks likely will change depending on the cutting height. Stalk diameter in conjunction with orientation (i.e., flat or standing) will determine soil coverage and the amount of protection. After a low-cut, one-pass harvest, fields with vertical corn stubble (~10 cm) without tillage can still be vulnerable to water erosion [12].

It is likely that one-pass harvest operations would occur at grain harvest. However, harvest index (HI) was defined as the ratio of grain yield to total aboveground biomass at physiological maturity [8]. Sampling at both physiological maturity and grain harvest allows comparison of HI. If apparent HI decreases between the physiological maturity and grain harvest, it indicates a decrease in the harvestable stover. Loss of harvestable stover could be caused by leaf drop or loss of tassels and stalk above the ear. Ensiling corn stover is also being considered as a strategy to improve harvest timeliness and reduce harvest losses [25], but does not necessarily provide an economic advantage compared with dry storage methods (e.g., bales) [2] and can limit market flexibility because the grain and stover remain combined when harvested for silage. However, ensiling could accommodate earlier harvest of stover at higher water content. Currently, the RUSLE2 and Wind Erosion Prediction System (WEPS) models are being modified by US Department of Agriculture-Natural Resource Conservation Service (USDA-NRCS) to accommodate fractional harvest of stover at the time of grain harvest. However, modification of these models is limited by the lack of data describing the distribution of corn stover mass or stem diameter with plant height [13]. To expand the RUSLE2 domain and improve its handling of stover removal practices, data are needed from a broad range of locations with different hybrids, soil fertility, soil types, and climate to describe dry stover mass distribution with plant height. The objectives of the study were to (1) determine the height distribution of corn stover mass; (2) determine the percentage of stover mass that is corn cob; and (3) develop a general relationship between plant harvest height and the mass of stover remaining in the field.

Materials and Methods

Experimental Sites

In 2007, a multi-location experiment was conducted with collaboration among eight ARS laboratories located at Ames, IA; Auburn, AL; Fort Collins, CO; Florence, SC; Lincoln, NE; Mandan, ND; Morris, MN; and St. Paul, MN (Fig. 1). All laboratories are participating in a USDA-ARS multi-location Renewable Energy Assessment Project (REAP) to ensure that soil resources continue to meet production demands for food, feed, and fiber, as well as feedstock for fuel production (http://www.ars.usda.gov/research/programs/programs.htm?np_code=202&docid=15193). Each location had at least one site and sampling date, although some had multiple sites, management practices, and/or sampling dates (Table 1). Collectively, these locations represent a wide range of climates, soil types, hybrids, planting dates, population densities, and cultural practices associated with corn production throughout the USA. The Mandan site represents the most northern location (Fig. 1) and collected plants for two hybrids with different maturity dates, which were the shortest of among the locations (Table 1). Ames is located solidly in the US Corn Belt. Morris, St. Paul, and Lincoln locations are either within the Corn Belt or on the periphery, depending on how narrowly the region is defined. Auburn and Florence sites represent the south-

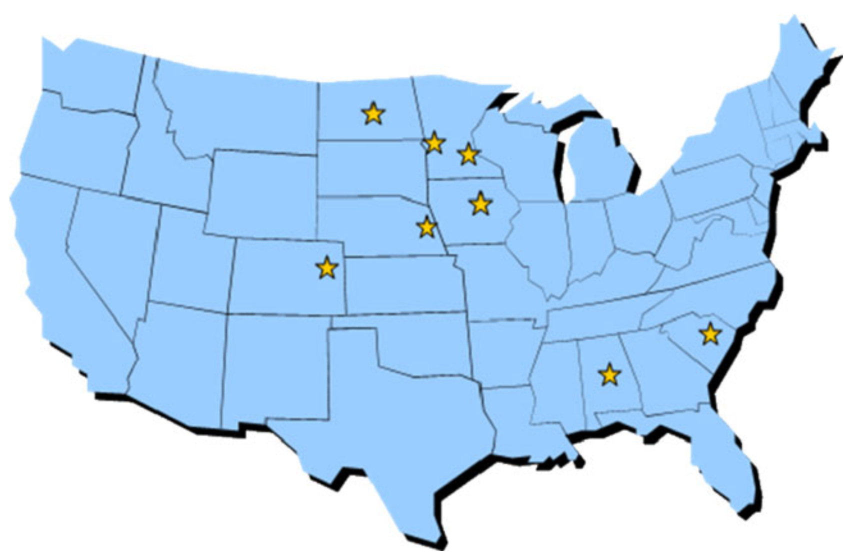

Fig. 1 USDA-Agricultural Research Service locations contributing to this experiment: Ames, IA; Auburn, AL; Fort Collins, CO; Florence, SC; Lincoln, NE; Mandan, ND; Morris, MN; and St. Paul, MN. All locations are part of an USDA-Agricultural Research Service cross-location project–REAP to ensure the soil resource indefinitely meets the needs of food, feed, fiber, and fuel

Table 1 Ancillary and descriptive data for the eight locations across the USA included in the study

Location	Field or treatment	Soil and series	Rotation	Tillage	Hybrid, relative maturity	Plant density	Sampling date, 2007	
						Plant ha^{-1}	Physiological maturity	Grain harvest
Ames, IA	Boyd farm	Clarion loam	M[a]–Sy since 2002	Chisel/disk	Pioneer 34A20, 109 day	74,000	6 Sep.	NS
	Bruner	Cannisteo silty clay loam	cM since 2004	Chisel/disk	Agrigold 6395, 109 day	74,000	13 Sep.	NS
	Biochar applied no biochar	Coland clay loam	M–Sy	Chisel-plow	Pioneer 34A20, 109 day	74,000	NS	5 Oct.
Auburn, AL	Old Cotton Rotation site	Pacolet fine sandy loam	M–C, winter legumes, irrigated	Spring paraplow	Dekalb 69-72 RR, 119 day	93,860	NS	19 Sep.
	Tennessee Valley Research Station	Decatur silt loam	M–C, winter cereal rye cover	Disk	Pioneer 31D61 YGCB, 120 day	92,860	NS	20 Sep.
Florence, SC	Conventional Conservation	Norfolk sandy loam	M–Sy	Paraplow/ disk Paraplow	DK 69-72 (RR2) AF2, 119 day	54,320	NS	10 Sep.
Fort Collins, CO	Conventional No tillage	Fort Collins clay loam	Irrigated, cM	Plow No tillage	Pioneer 39B77BtLL, 88 day	92,220	11 Sep.	23 Oct.
Lincoln, NE	Disk No tillage	Aksarben silty clay loam	Irrigated, cM	Disk No tillage	DeKalb 61-69, 110 day	79,000	12 Sep.	11 Oct.
Mandan, ND	85 day	Temvik-Wilton silt loam	Sf	No tillage	Legend LR9385RR, 85 day	62,700	26 Sep	29 Oct.
	79 day				Legend LR9779RR, 77 day		24 Sep.	29 Oct.
Morris, MN	Swan Lake Research Farm	Barnes clay loam	M–Sy	Chisel-plow	Cropland 296TS MF-B7, 92 day	77,780	11 Sep.	28 Sep.
St. Paul, MN	Rosemount	Waukegan silt loam	M–Sy	Chisel-plow	Dekalb DKC 50-20, 100 day	74,000	9 Sep.	1 Oct.

The field or treatment refers to parent experiment from which plants were collected

[a] Abbreviations: *C* cotton, *cM* continuous maize, *M* maize, *NS* not sampled, *Sf* sunflower, *Sy* soybean

ernmost locations, using the longest maturity hybrids. Fort Collins site was the western-most location of the study. Florence, Fort Collins, and Lincoln sites collected plants from contrasting tillage management systems. At grain harvest, the Ames site collected plants from a study evaluating effects of amending soil with a by-product from thermochemical energy production. The Lincoln site, Fort Collins site, and one field at the Auburn site were irrigated, while all other sites were rainfed.

Sample Method

Plants were sampled destructively from a 1.0 m^2 area at physiological maturity and/or at grain harvest. The number of plants included in the 1.0 m2 ranged from five to ten depending on planting population (Table 1). The corn plants were cut as close to the soil surface as possible. Ears were removed from the husk and dried separately. The height to the base of the grain-containing ear (ear height), height to the node at which the ear shank was attached to the stalk (shank height), and plant height were recorded to the nearest centimeter for each plant. Corn stalks were marked at 10-cm intervals starting at ground-level and continuing upward with the top segment being one 10-cm interval above the base of the primary grain-containing ear. All plant material above the top interval was pooled into a single above-ear sample. All plant parts (cob, above-ear, and 10-cm increment samples) were oven-dried at 60°C to a constant weight. Grain was removed from cob prior to determining dry cob weight.

Barren plants were excluded from the stover-to-grain ratios or HI due to the small sample size. Including barren plants skewed the stover-to-grain ratio to extremely high (>4) values. The Mandan and Lincoln locations were the only sites that reported barren plants within the sampled area.

Statistical Analysis

The study used a multi-location approach to ascertain general relationships among plant yield parameters. This was not designed nor intended to be used for examining differences associated with location, soil resource, management practices, and/or hybrid selection. Descriptive statistics (mean and standard error) were calculated using Proc mean within SAS 9.1 software (SAS Institute Inc., Cary, NC) to provide information on the range and variation of the data used in the regression analyses. Linear regression functions within the SigmaPlot software for Windows version 10.0 (Systat Software, Inc., Chicago, IL) were used to assess linearity. Using data only from locations (Table 1) that sampled the same fields at both physiological maturity and grain harvest, a general linear model using SAS software, version 9.1, [23] was used to determine if there were statistically significant differences due to sample date. Variability due to location and location-specific factors (e.g., management practice, hybrid, etc.) was included in the error term.

Results

Height

Plant height varied among locations (Fig. 2) reflecting the impact of hybrids, relative maturity ratings, and management and climatic conditions. At physiological maturity, plant height ranged from 185 cm at the Mandan site to a maximum of 276 cm at the Ames site. In general, there was a loss in total plant height between physiological maturity and grain harvest due to breakage and loss of tassel. Breakage at the top of plants increased the observed variability at most location by grain harvest. Because of breakage, the average maximum plant height at grain harvest was about 240 cm.

Ear and shank height varied among locations (Fig. 2). At grain harvest, minimum ear height was 75 cm at the Mandan site and the maximum ear height was 110 cm at the Fort Collins site. Average shank height was at or below the ear except at the Auburn site, where the ear dropped at maturity so that it hung below the ear shank. This is a typical characteristic of hybrids grown in southern US where rainfall and humidity can be high following physiological maturity. In general, the primary ear and shank were located in the lower half of the corn stalk. Ear and shank heights provide valuable information for estimating stover that may be harvested with one-pass combine systems as cutting height would be set below the ear for harvesting grain.

The above-ear stover fraction including cobs represents about 50% of the total dry stover biomass corresponding to 3 (Mandan) to 6 dry Mg ha^{-1} (Ames; Fig. 3). On average, cobs represented about 18% of the total stover biomass at grain harvest (Fig. 3; Table 2).

The mass of 10-cm segments was relatively constant below 60 cm when averaged across all locations (Fig. 4). The mass increased for the segments above 65 cm as ear shank and husk were included in these upper segments (Figs. 2 and 4).

Stalk diameter decreased linearly as a function of the plant height at least to 100 cm (Fig. 4). The number of observations above 65 cm decreased because the ear height varied among locations (Fig. 2), and diameter measurements were only taken to one increment above the ear. The reduction in observations is reflected in the increased standard error.

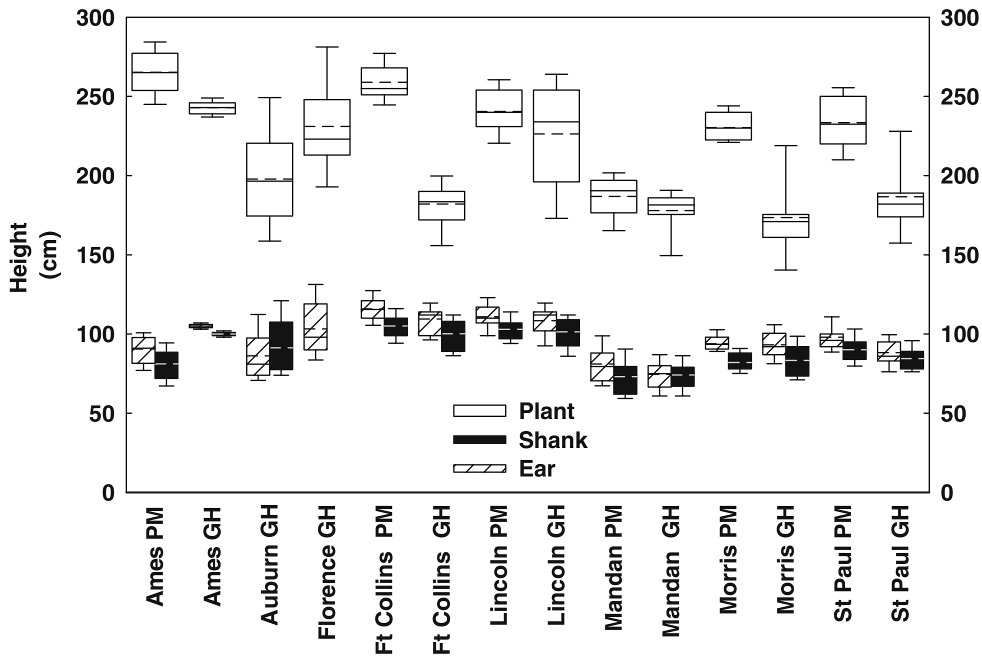

Fig. 2 Plant (*open boxes*), ear (*hatched boxes*), and shank (*solid boxes*) height measured at physiological maturity (*PM*) and grain harvest (*H*) from multiple sites across the USA. The *solid line* in each *box* is the median and the *dashed line* is the mean. The *bottom* and *top* of the *box* is the 25th and 75th percentile, respectively, while the *whiskers* are errors bars indicative of the 90th and tenth percentiles. Different fields were sampled in Ames at PM than at GH

Grain, Stover, and Cob Yield

Dry grain yield and stover yields were estimated from plants harvested in the small (1.0 m^2) plots (Table 2). At physiological maturity, stover yield ranged from 8 Mg ha^{-1} at the Mandan, Morris, and St. Paul sites to 11 Mg ha^{-1} at the Ames site (Table 2). When comparing stover yields using data-collected sites, yields decreased as much as 39% (Fort Collins) between physiological maturity and grain harvest. This is consistent with reduced plant height due to breakage (Fig. 2) and possibly loss of leaf material. The stover yield at physiological maturity more closely reflects total stover produced, while stover yield at grain harvest represents the pool that may be harvested in a one-pass harvest operation.

At grain harvest, the Mandan site had the lowest dry grain yield (6.5 Mg ha^{-1}) (Table 2), which is typical for short-season hybrids in central North Dakota. The North Dakota state corn grain yield in 2007 was 6.2 dry Mg ha^{-1} [30]. At both Morris and St. Paul sites, the dry grain yields (~8 Mg ha^{-1}) were lower than typical due to inadequate rainfall during the 2007 growing season. The Minnesota

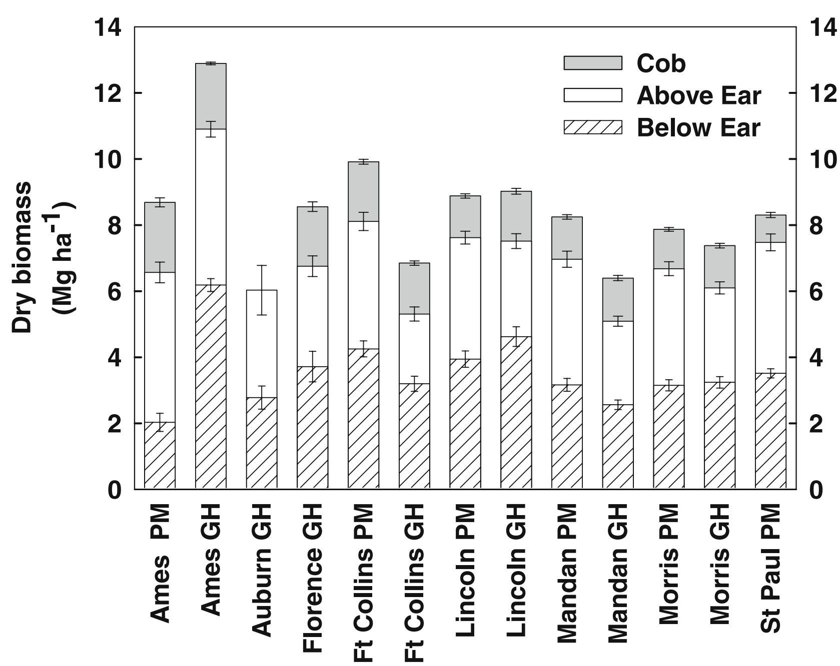

Fig. 3 Dry biomass of cob, above-ear, and below-ear stover fractions collected at two sampling dates, physiological maturity (*PM*) and grain harvest (*GH*) from locations across the USA. *Error bars* are standard errors for each stover fraction, *bar* represent total stover (sum of fractions). Different fields were sampled in Ames at *PM* and *GH*. Cob biomass was not available from the Auburn site

Table 2 Dry mass of cob, stover (including cob) and dry grain from corn sampled at physiological maturity and at grain harvest from locations, across the U.S. Values are location means and standard error (SE)

Location	Cob	Stover	Grain	Cob	Stover	Grain
	Physiological maturity, Mg ha^{-1} (SE)			Grain harvest, Mg ha^{-1} (SE)		
Ames, IA	2.78 (0.60)	11.47 (0.18)	11.54 (0.68)	2.00 (0.04)	12.90 (0.36)	13.81 (0.31)
Auburn, AL	NA	NA	NA	NA	NA	9.06 (0.83)
Florence, SC	NA	NA	NA	1.80 (0.79)	9.38 (0.92)	8.48 (0.76)
Fort Collins, CO	1.81 (0.07)	9.92 (0.55)	11.27 (0.77)	1.54 (0.07)	6.85 (0.47)	10.62 (0.54)
Lincoln, NE	1.26 (0.07)	8.67 (0.42)	11.04 (0.48)	1.41 (0.09)	7.65 (0.55)	11.74 (0.78)
Mandan, ND	1.28 (0.07)	8.06 (0.40)	6.41 (0.45)	1.05 (0.08)	5.55 (0.38)	6.55 (0.50)
Morris, MN	1.19 (0.06)	7.51 (0.33)	7.97 (0.40)	1.28 (0.07)	6.94 (0.34)	8.70 (0.53)
St. Paul, MN	0.83 (0.08)	8.20 (0.49)	8.19 (0.97)	0.92 (0.04)	6.79 (0.40)	8.75 (0.37)
Mean of all observations	1.38 (0.05)	8.64 (0.27)	9.16 (0.66)	1.33 (0.04)	7.30 (0.25)	9.60 (0.31)
n	111	111	111	121	121	125

Note: At Ames locations, different fields were sampled at physiological maturity than at grain harvest

NA not available

state average corn grain yield was 0.80 and 1.6 dry Mg ha^{-1} lower in 2007 compared with that in 2006 and 2005 yields, respectively [30]. Yields at other locations were at or above their respective state averages.

The reduction in harvested stover material between physiological maturity and grain harvest resulted in a significant increase in HI from 0.50 to 0.57 calculated from stover and grain yields at Fort Collins, Lincoln, Mandan, Morris, and St. Paul sites (Table 2). The HI at physiological maturity ranged from 0.44 at the Mandan site to 0.56 at the Lincoln site, but, at grain harvest, the observed HI were 0.55 and 0.61 for Mandan and Lincoln sites, respectively. Similar changes in HI were observed at Morris, St. Paul, and Fort Collins sites between physiological maturity and grain harvest.

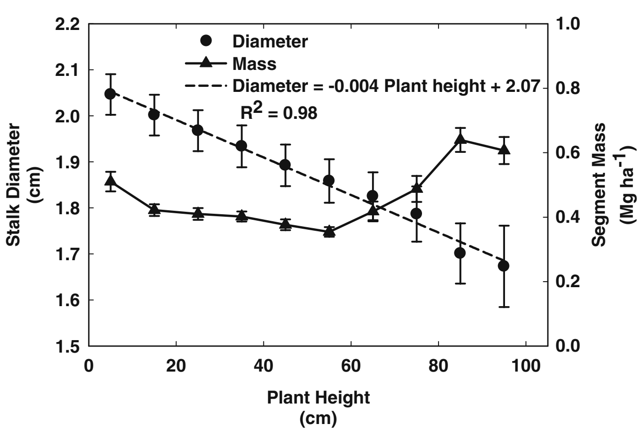

Fig. 4 Average stalk diameter and mean segment mass of 10-cm increments from below the ear; *error bars* are standard error

Harvest Weight and Cutting Height

The amount of corn stover harvested or returned to the field varies proportionally with the cutting height (Fig. 5). For example, a cutting height of 25 cm would leave 3.4 Mg ha^{-1} in the field at the Ames site but only about 1 Mg ha^{-1} at the Auburn site. Plant heights (Table 2) and plant biomass (Fig. 3) varied substantially among the various sites. Therefore, relative plant height (Eq. 1) and relative biomass (Eq. 2) were calculated to normalize the data for direct comparison.

$$(\text{Cutting height}/\text{total plant height})*100 = \text{Relative cutting height } (\%) \quad (1)$$

$$(\text{Stover remaining in field}/\text{total stover mass})*100 = \text{Relative biomass}(\%) \quad (2)$$

The relationship between relative height and biomass was consistent among sites (Fig. 6). Relative stover biomass returned to the field as a function of relative cutting height showed a strong (r^2=0.93) nearly (1:1) linear relationship (Fig. 6). Using this relationship, a relative cutting height of 40% would return about 43% of the biomass, which would harvest the material above the ear including the cob (Table 2).

Discussion

Grain yield data are readily available for corn and can be estimated in-field with yield monitors. The amount of stover and cob are proportional to grain yield [11, 20, 22]

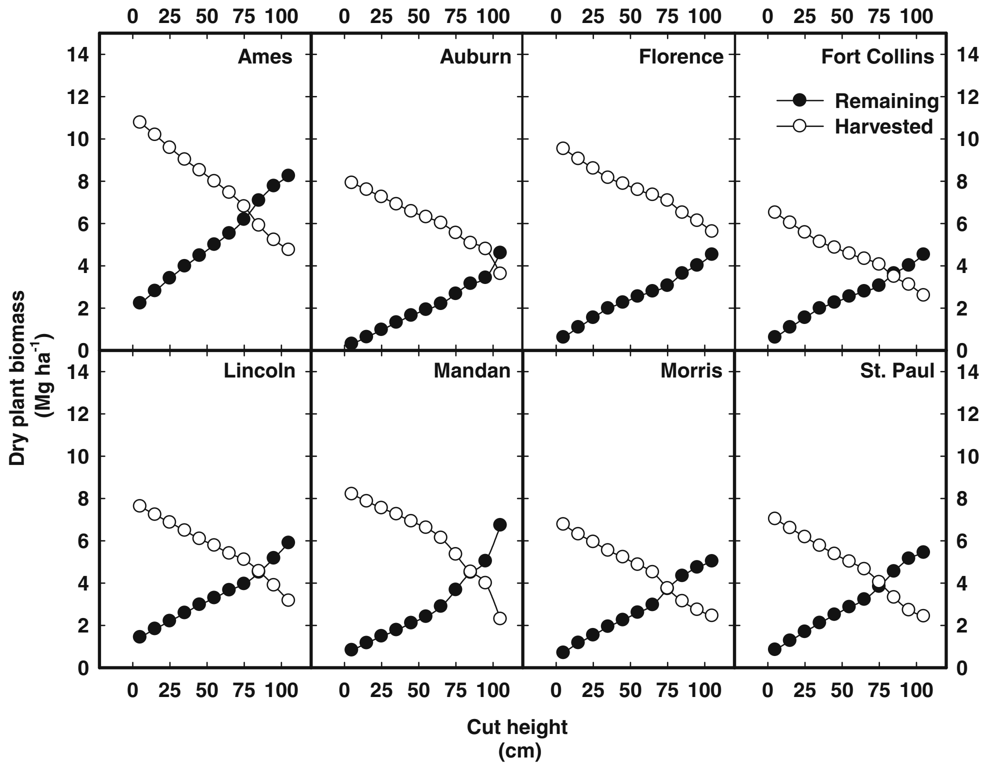

Fig. 5 Stover biomass that would be harvested (H) or retained in the field (R) calculated at mid-point of 10-cm incremental cutting heights at eight locations across the USA using data at grain harvest. Cob mass not included at Auburn site. Stover on the ground was assumed to remain in the field

(Fig. 6). Thus, estimates of cob and or stover can be made based on cob-to-grain and stover-to-grain ratios or harvest index values [14, 22]. Stover-to-grain ratio is related inversely to harvest index. Harvest index is the ratio of dry grain to total dry aboveground biomass. For example, a stover-to-grain ratio of 1.0 is the same as a harvest index of 0.5. At physiological maturity, overall average HI was 0.50. A stover-to-grain ratio of 1.0 or a harvest index of 0.5 has been used to estimate feedstock availability [4]. However, results at grain harvest are consistent with the suggestion that a higher HI at grain harvest maybe more appropriate for estimating harvestable stover [14, 22]. At these locations, stover yield increased 0.85 Mg ha^{-1} for every 1 Mg ha^{-1} increase in dry grain yield (Fig. 7, Table 2). Cob dry biomass increased 0.1 Mg ha^{-1} for every Mg ha^{-1} increase in dry grain yield; similar data was reported by Halvorson and Johnson [11].

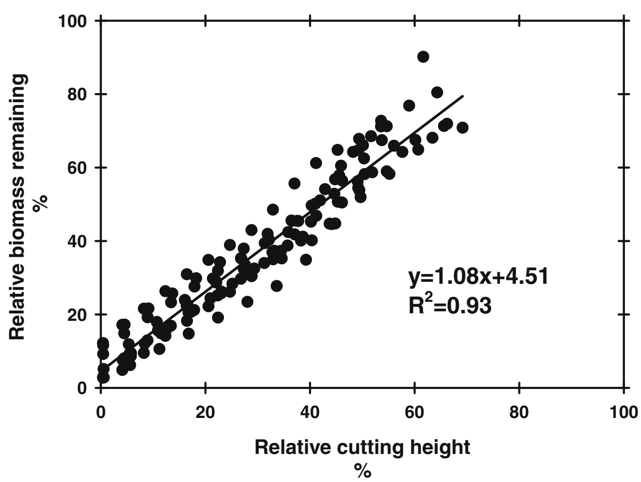

Fig. 6 Relative stover biomass remaining in the field (stover biomass remaining in the field divided by total stover biomass and multiplied by 100) as a function of relative cutting height (cutting height divided by plant height *100) using data from all locations at the grain harvest sampling date

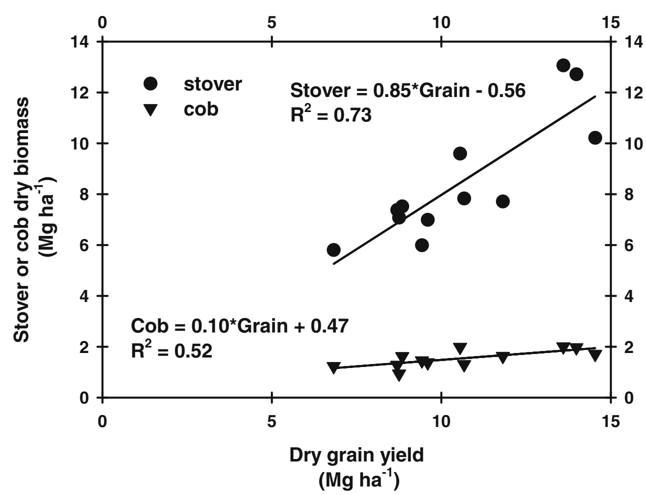

Fig. 7 Relationship between dry grain yield and dry stover (*circles*), or between dry grain and dry cob (*triangles*) yields (Table 2) collected at grain harvest from eight locations across the USA (Fig. 1) in 2007. For both regression equations, $P \leq 0.005$ that the slope was different from zero

For regions with a high yield potential (Table 2), a one-pass harvest operation just below the shank (Fig. 2) may return sufficient residue to control erosion and maintain SOM. For example, the dry stover yield in 2007 at the Ames location was about 13 Mg ha^{-1} (Table 2); assuming that 5.5 Mg ha^{-1} $year^{-1}$ stover [16, 32] needs to be returned to the field to control wind and water erosion and to sustain SOM for continuous corn, the cutting height would need to be about 85 cm (35% of plant height) (Fig. 6). At the Ames site, the average shank height was 100 cm, therefore cutting just below the shank should leave adequate residue in the field in this example. In contrast, the amount of residue returned to the field if stover were harvested may not be sufficient to maintain SOM or protect against erosion at some locations. For example, the dry stover yield in 2007 at the Morris location was about 7 Mg ha^{-1} (Table 2); still assuming that 5.5 Mg ha^{-1} yr^{-1} stover [16, 32] needs to be returned to the field, the cutting height would need to be about 150 cm (67% of plant height; Figs. 2 and 6). This cutting height would be above the ear as the average ear height was 93 cm (Fig. 2), suggesting that one-pass sustainable stover harvest at current yields may not be feasible in this example. Cob yield at the Morris site in 2007 was 1.3 Mg ha^{-1} (Table 2); thus, if only cobs were harvested, then about 5.7 Mg ha^{-1} stover could be retained. At the low-yielding sites, it may be economically and environmentally more viable to harvest grain and cobs, and return everything else to the field. One-pass systems for harvesting grain and cobs are being developed and tested in collaborations among machinery manufacturers and bioenergy industry. It is probable that the economically and environmentally feasible amount of stover that can be harvested will be regionally and even field-specific.

Corn stover or corn cobs are potential bioenergy feedstocks for both large-scale cellulosic ethanol syntheses and/or for local or regional thermochemical biopower substituting for natural gas or coal. The scale of utilization will in part depend on the amount of feedstock available locally. In regions with lower corn yields, it may be feasible to support local or regional thermochemical biopower but not large-scale ethanol production because most of the stover would need to be returned to the land for maintaining SOM making a large-scale plant economically and environmentally unfeasible [32]. However, it may be possible to increase stover harvest by applying manure, compost, biochar, or other amendments and by growing cover crops or living mulch [9, 15, 18]. Cover crops and living mulch can reduce the risk of erosion and can help maintain SOM [15]. Application of soil amendments can help maintain SOM and fertility. For example, applying biochar obtained from pyrolyzed pecan shells to a Norfolk sandy loam soil at rate equivalent to 20 Mg ha^{-1} substantially increased soil pH and the concentration of total C, Ca, Cu, K, and P [21]. The by-product of cellulosic ethanol production, which is high in lignin, increased the amount of humic acid proportional to the rate of by-production applied [17]. Therefore, it may be possible to maintain or replenish the soil carbon pool by applying other C-rich agricultural byproducts, while correspondingly removing stover for biofuel production.

USDA-NRCS is using the data from this study to parameterize the mass of stalk, leaf, and cob removed and remaining in these pools at different cutter bar heights and using different grain and residue harvesting methods within RUSLE2 and WEPS. In addition, these data are useful for verifying and/or updating vegetative databases such as the stover-to-grain ratio of corn. Embedded processes within the RUSLE2 and WEPS operations databases reflect conversion of live biomass to standing and flat residue pools during grain harvest [29]. Other processes can result in the removal of material from these pools either by grain harvest or subsequent operations. As new harvest machinery is designed and marketed to simultaneously harvest grain and residue, the amount of residue harvested will change with the cutting height (Figs. 2, 5, and 6).

Currently, RUSLE2 and WEPS models are being used in several national and regional studies to model the water and wind erosion rates on fields where crop residues may be harvested as cellulosic bioenergy feedstocks. In addition, local USDA-NRCS conservationists are being asked by producers to run the models and facilitate decisions regarding which fields could support residue harvesting and how much may be harvested without degrading the soil resource. Updating the database input parameters in these models is useful as yields and stover production will vary across the USA. Furthermore, these results will help producers to evaluate economic returns from harvesting corn stover and avoid degradation of their soil resource.

The mechanisms by which retaining plant biomass protects the soil from erosion are well-documented [1, 3, 5, 6, 27, 28]. Standing residue tends to be more effective at reducing wind erosion relative to flattened residue, as would residue that is perpendicular rather than parallel to the prevailing wind [28]. Relative soil losses from a residue-covered soil compared with an exposed soil decrease exponentially with increasing land cover [3, 7, 19]. This study also showed that stalk diameter decreases gradually with height (Fig. 4). Thus, if the stubble remained upright, protection against water erosion would be expected to be similar or decrease slightly for cutting heights between 10 and 50 cm. The ability to resist wind erosion would increase as the cutting height increased.

The erosion control benefits would differ if the remaining stubble were chopped or tilled. Following a 50-cm harvest height with a chopping operation reduces the standing stubble height to 10–20 cm; the chopped material would cover more soil than standing stubble. However, chopped material can be transported by wind and via overland flow if rainfall rates greatly exceed the soil's infiltration capacity.

Corn stover or corn cob yields are directly proportional to dry corn grain yield. The HI at physiological maturity can estimate total stover produced, but due to stover loss during dry down results in an increase in HI by grain harvest. Therefore, HI determined at grain harvest may provide a better estimate of what might be available during a one-pass harvest operation. The amount of stover remaining on the land to protect the soil and provide ecosystem services varies with cutting height and organ harvested. The amount of stover that can be sustainably harvested will vary by region, in some locales especially with lower grain yields harvesting only cobs may be the most feasible option. This information, though still limited, will improve the capacity of RUSLE2, WEPS, and other models to predict erosion risks associated with harvesting corn stover. It will also help ensure the sustainability and feasibility of the fledging biofuels industry in the USA and elsewhere.

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