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Predicting Corn Grain Yield Using Silage Starch Content and Crop Adjuster Methods

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ABSTRACT

Multi-peril crop insurance (MPCI) requires that if corn (*Zea mays* L.) is insured for grain and the producer wants to use it for another purpose, that is, silage, the producer must have the corn grain yield appraised before corn silage harvest. This appraisal requires an adjuster to determine the weight of grain corn, and based on stage of maturity, apply a factor to convert the determined weight to the weight of mature corn at 155 g kg^{-1} moisture. This study was designed to test the hypothesis that corn grain yield can be estimated accurately before grain is combine harvested using the USDA–Risk Management Agency (RMA) methods and routine silage quality measurements for starch. Corn was established at two locations from 2006 to 2008. Management factors involving planting date, hybrid, and harvest timing were applied to create a range in yield and forage quality. Both RMA methods and the starch-based method underestimated combine grain yield by 4 to 36% at silage harvest stages between 75 and 25% kernel milk (KM). At silage harvest, the starch method estimated final combine grain yield more accurately than the RMA maturity line weight (MLW) method, but when applied after silage harvest or just before grain harvest, the RMA Weight method was the better predictor of final combine grain yield. With careful assessment, starch-analysis of silage theoretically could produce an equitable estimate of grain yield for insurance adjustments.

Multi-peril crop insurance is a type of crop insurance that covers many different naturally occurring stresses including hail, drought, and excess moisture. Current policy requires that if corn is insured for grain and the producer wants to use it for another purpose, that is, silage, the producer must have the corn appraised before silage harvest occurs (Anonymous, 2013). Appraisals usually happen before harvest, however, when adjusters cannot appraise the crop before harvest, then check strips must be left for later appraisal. Check strips often lead to inaccurate grain yield estimates due to losses of the exposed corn to other perils that occur after silage harvest, such as lodging associated with high winds and wildlife damage. Alternative methods of predicting the grain yield potential of a stressed corn crop would be useful for producers who insure a crop for grain but subsequently harvest it for silage.

One alternative to assessing a check strip for grain yield following silage harvest would be to estimate potential grain yield based on silage yield and quality. Starch content is a proxy for estimating grain content of silage, and might be useful to estimate final grain yield. In addition, many dairies contract with grain producers for silage. These contracts currently use grain equivalents (grain yield per unit of forage harvested) to estimate the amount of grain that could have been combine harvested. Development of a method for predicting grain yield from a routine silage quality measurement would be useful in contract negotiations between dairy producers and grain producers.

Corn kernel development is a complex and multifaceted process (Saini and Westgate, 2000). The accumulation of starch in the corn kernel follows a sigmoid or s-shaped pattern of growth. There is an initial lag phase during which endosperm cells undergo division with little starch accumulation. The second phase of growth is linear with continuous accumulation of dry matter, mostly starch, within the endosperm. In the final phase, starch accumulation slows until the kernel attains physiological maturity. Depending on how kernel growth rates are calculated, the rate of kernel dry matter accumulation during grain filling is a linear function with grain yields accumulating at a rate of 26 to 45 mg × 10^{-2} °C d^{-1} (Borrás and Otegui, 2001), 4.75 g plant^{-1} (Hanway, 1962), or 5.9 to 10.6 mg kernel^{-1} d^{-1}(Jones et al., 1996).

Silage harvest often begins at the end of the linear phase of kernel dry matter accumulation when whole plant dry matter yield is close to maximum and moisture is ideal for ensiling (Allen et al., 2003; Cummins, 1970; Fairey, 1980, 1983; Irlbeck et al., 1993; McAllan and Phipps, 1977; Phipps and Weller, 1979; Vattikonda and Hunter, 1983; Wiersma et al., 1993; Wilkinson and Phipps, 1979). Significant increases in grain fill can occur during the final stages of kernel development between

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Abbreviations: ivNDFD, in vitro neutral detergent fiber digestibility; KM, kernel milk; MLW, maturity line weight method; MPCI, multi-peril crop insurance; NDF, neutral detergent fiber; RMA, Risk Management Agency.

the time of silage harvest and grain harvest. Afuakwa and Crookston (1984) and Thornton et al. (1969) found that grain yield increased 34 to 43% following the fully dented stage and 10 to 12% after the 50% KM stage. Silage starch content can increase by 35% as dry matter increases from 295 to 350 g kg^{-1} (Cox and Cherney, 2005).

The objective of this study was to test the hypothesis that corn grain yield can be estimated accurately before the grain is combine harvested. This hypothesis was tested using forage starch content and two methods developed by the USDA–Risk management agency (RMA). The first method is the maturity line weight method, which is used before the corn kernels are physiologically mature, and the second is the weight method, which is used when the grain is physiologically mature, but below approximately 400 g kg^{-1} moisture (Anonymous, 2013). These three test methods were compared to a reference method where final grain yield was measured using a combine.

MATERIALS AND METHODS

Experiments were conducted during 2006, 2007, and 2008 at the University of Wisconsin Agricultural Research Stations near Arlington, WI, and the Russell Larson Agricultural Research Farm near State College, PA. The experimental design was a randomized complete block in a split-split-plot arrangement with four replications (Gomez and Gomez, 1984). Main plots were planting date, split plots were hybrid, and split-split plots were harvest date. The soil at Arlington is a Plano silt loam (fine-silty, mixed, superactive, mesic Typic Argiudoll) and at State College is a Hagerstown silt loam (fine, mixed, superactive, mesic Typic Hapludalf). Management practices were typical of those used commercially. Pre-plant soil samples from 0- to 15-cm depth were analyzed for residual nutrient levels (Table 1). Two hybrids, Pioneer 37R71 (97 d relative maturity) and Syngenta NK Brand 58-D1 (108 d relative maturity) were planted each year at each location. Individual plots were four rows wide, 0.76 m apart, and measured 7.6 m long.

In all years at Arlington, urea (46–0–0) was broadcast pre-plant (Table 1). Additionally, a starter fertilizer was applied each year. In each year, the soil in the study area was prepared for seeding by fall plowing followed by spring field cultivating. On each planting date, a Kinze (Kinze Manufacturing, Williamsburg, IA) planter was used to seed the hybrids at a rate of 8.15 seeds m^{-2} in furrows 5-cm deep in rows 76 cm apart to achieve a target plant density at harvest of 7.41 plants m^{-2}. Plots were thinned and later checked for doubles and late emerging plants. Weeds were controlled by applying pre-emergence a tank mixture of 1.05 kg a.i. ha^{-1} dimethenamid (Outlook), [(*RS*) 2-chloro-*N*-(2,4-dimethyl-3-thienyl)-*N*-(2-methoxy-1-methylethyl)acetamide] and 0.175 + 0.0648 kg a.i. ha^{-1} clopyralid + flumetsulam, (Hornet), [3,6-dichloro-2-pyridinecarboxylic acid] + [*N*-(2,6-difluorophenyl)-5-methyl[1,2,4] triazolo[1,5-*a*] pyrimidine-2-sulfonamide]. No insecticide was applied in 2006 and 2007. In 2008, the Western corn rootworm variant (*Diabrotica virgifera* LeConte and Diabrotica barberi Smith and Lawrence) was controlled using 0.148 kg a.i. ha^{-1} tefluthrin (Force 3G), [(2,3,5,6-tetrafluoro-4-methylphenyl) methyl-(1α,3α)-(Z)-(±)-3-(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2-dimethylcyclopropanecarboxylate].

In all years at State College, urea (46–0–0) was broadcast pre-plant and a liquid starter fertilizer 7–21–7 was applied each year (Table 1). Each trial at this location was no-till planted. On each planting date, a Monesem (Monosem, Inc, Kansas City, KS) planter was used to seed the hybrids at a rate of 8.4 seeds m^{-2} in furrows 5-cm deep to achieve a target plant density at harvest of 7.41 plants m^{-2}. Weeds were controlled each year by applying pre-emergence a tank mixture 0.84 kg ha^{-1} acid equivalent glyphosate (Roundup Weathermax), [isopropylamine salt of N-(phosphonomethyl)glycine) of glyphosate], 2.24 kg a.i. ha^{-1} acetochlor (Degree Extra) [(2-clhoro-N-ethoxymethyl-N-(2-ethyl-6-methylphenyl)acetemamide] and 1.12 kg a.i. ha^{-1} atrazine [2-chloro-4-(ethylamine)-6-(isopropylamino)-s-triazine]. A post emergent application of 0.269 kg a.i. ha^{-1} nicosulfuron (Steadfast ATZ), {2-[[(4,6-dimethoxypyrimidin-2-yl)aminocarbonyl]aminosulfonyl]-N,N-dimethyl-3-pyridinecarboxamide}, 0.012 kg a.i. ha^{-1} rimsulfuron (N((4,6-dimethoxypyrimidin-2-yl) aminocarbonyl)-3-(ethylsulfonyl)-2-pyridinesulfonamide),

Table 1. General plot management characteristics and environment descriptors for the experiments conducted during 2006 to 2008.

	Arlington, WI			State College, PA		
Descriptor	2006	2007	2008	2006	2007	2008
Previous crop†	soybean	soybean	soybean	corn	corn	soybean
Soil fertility						
pH	6.2	6.7	6.4	6.6	6.0	6.6
Organic matter, g kg^{-1}	31	25	33	23	19	21
P, mg kg^{-1}	46	19	38	50	23	50
K, mg kg^{-1}	116	105	102	87	88	87
Fertilizer						
Starter (N–P–K), kg ha^{-1}	15–39–50	15–39–50	4–13–0	9–11–7	9–11–7	9–11–7
N, kg ha^{-1}	168	168	168	232	258	161
Planting date						
Early	28 Apr	30 Apr	1 May	28 Apr	4 May	3 May
Late	1 June	1 June	2 June	31 May	30 May	2 June
RMA‡ sampling date and silage harvest date	31 Aug., 13 and 25 Sept.	28 Aug., 6 and 14 Sept.	9 and 19 Sept., 1 Oct.	8, 15, and 21 Sept.	6, 14, and 21 Sept.	5, 15, and 22 Sept.
Grain harvest date	24 Oct.	18 Oct.	31 Oct.	15 Nov.	5 Nov.	27 Oct.
Fall frost date§	12 Oct.	24 Oct.	3 Oct.	13 Oct.	29 Oct.	19 Oct.

† Corn, *Zea mays* L.; soybean, *Glycine max* L.

‡ RMA, Risk Management Agency.

§ Fall frost date: < 0°C.

0.84kgha^{-1}atrazine[2-chloro-4-(ethylamine)-6-(isopropylamino)-s-triazine] and 0.28 kg ha^{-1} acid equivalent of Diglycoamine salt of 3, 6 dichloro-o-anisic acid (Clarity). In each year at this location, 0.148 kg a.i. ha^{-1} tefluthrin (Force 3G) was applied to control the Western corn rootworm.

Methods for Estimating Grain Yield

In the fall, whole-plant (silage) plots were harvested using a tractor driven, three-point mounted one-row chopper (New Holland 707, New Holland, PA) and automated weighing system at Arlington and State College. One row was analyzed for whole plant yield and quality. Plot weight and moisture content were measured, and yields were adjusted to Mg dry matter ha^{-1}. For each forage harvest, plot subsamples of approximately 1 Kg were dried, ground, and analyzed for neutral detergent fiber (NDF), in vitro cell wall digestibility (NDFD), and starch content. All plot subsamples were analyzed at the University of Wisconsin Soil and Plant Analysis Laboratory in Marshfield, WI. All forage quality components were determined using NIR techniques using the same global equation derived for the hybrid evaluation program (Lauer et al., 2013). Forage harvests were targeted for the KM growth stages of 75, 50, and 25% KM on the early planted full-season hybrid, Syngenta NK Brand N58-D1. Twice weekly KM growth stages were determined by selecting five random ears from plants growing in adjacent rows of the plot. At the 75, 50, and 25% KM stages, experienced yield adjusters estimated grain yield using the RMA MLW method (Anonymous, 2013). For the combine harvest, yield adjusters estimated grain yield using the RMA weight method (Anonymous, 2013).

Grain yield and moisture content were automatically measured using a GrainGage linked to a HarvestData system (Juniper Systems, Logan, UT) mounted on a two-row Kincaid plot combine (Kincade Equipment Manufacturing, Haven, KS) at Arlington and mounted on a two-row Almaco plot combine (Almaco, Nevada, IA) at State College. Grain yields were adjusted to 15.5 g kg^{-1} moisture.

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Grain yield at 155 g kg^{-1} moisture was estimated assuming that grain was 715 g kg^{-1} starch on a dry matter basis (Perry, 1988):

$$\text{Grain yield-Starch method} = \text{Forage dry matter yield} \times \frac{\text{Starch content}}{100} \times \frac{100}{100-15.5} \times \frac{1}{0.715} \quad [1]$$

Grain equivalents (Mg grain Mg^{-1} forage) were calculated for each date.

$$\text{Grain yield equivalent in silage at 650 g kg}^{-1}\text{ moisture} = \frac{\text{Combine grain yield at 155 g kg}^{-1}\text{ moisture}}{\text{Forage dry matter yield} \times \frac{100}{100-65}} \quad [2]$$

Data Analysis

Statistical analyses were performed using the PROC MIXED procedure within SAS software (version 9.4 SAS Institute Inc., Cary, NC). In the random statement Environment and Rep were random effects such that Environment Rep(Environment) Planting date×Rep(Environment), Planting date×Hybrid×Rep(Environment) were the error terms to which all main effects and interactions were tested. Treatment mean comparisons were made using least significant difference when F values were significant ($P \leq 0.05$).

RESULTS AND DISCUSSION

The weather during 2006 was fairly representative of weather during a normal year. At both sites in 2007, a late fall may have created a situation where the late hybrid had a chance to extend its grain-fill period much later in the fall. In 2008, abnormally cool, wet conditions experienced during the first half of May, contributed to corn silage yields being lower than anticipated for the early planting date. Pioneer 37R71 during 2006 had significant lodging issues and was dropped from the analysis. For Wisconsin, actual KM averaged 76, 43, and 23%, while for Pennsylvania, actual KM averaged 47, 47, and 24%, respectively.

There are substantial differences among environments as evidenced by the scatter of data points in Fig. 1a and 1b. Final combine yields across environments averaged 11.7 to 12.5 Mg ha^{-1} at Arlington and 9.4 to 11.4 Mg ha^{-1} at State College. During silage harvest, RMA methods estimated grain yield at 7.5 to 9.3 Mg ha^{-1} for Arlington and 6.1 to 8.1 Mg ha^{-1} for State College, thereby underestimating final combine yield by 36, 26, 35, and 29% , respectively. Starch method grain yield estimates were 8.4 to 9.0 Mg ha^{-1} at Arlington and 6.8 to 9.1 Mg ha^{-1} at State College, thereby underestimating final combine by 28, 28, 27, and 20% , respectively.

Yield and forage quality traits were impacted by planting date, hybrid, and harvest timing for most of the variables studied (Table 2), creating a range of yield and forage quality responses (Tables 3, 4, and 5). Combine grain yield ranged from 4.3 to 14.7 Mg ha^{-1} (Fig. 1). Forage dry matter yield ranged from 15.3 to 19.3 Mg ha^{-1} for main effects (Table 3) and from 11.7 to 24.3 Mg ha^{-1} for treatment means (data not shown). Both planting date × hybrid and planting date × harvest timing interactions were observed for most measurements (Table 2). Three-way interactions were observed for starch-based grain yield, grain equivalents using RMA methods and forage yield. Environment, planting and harvest dates likely impacted the performance of the hybrids. For example, late planting which reduced grain yield and starch content had greater impact on the longer season hybrid, Syngenta NK Brand N58-D1 (Table 4). Likewise, delaying silage harvest had greater impact on grain yield for later planted corn (Table 5). Early planted corn had higher silage yield, greater starch content and grain yield, however, less relative change occurred with delayed harvest, while later planted corn tended to increase both starch content and grain yield at a greater rate with delayed harvest, which was likely due to

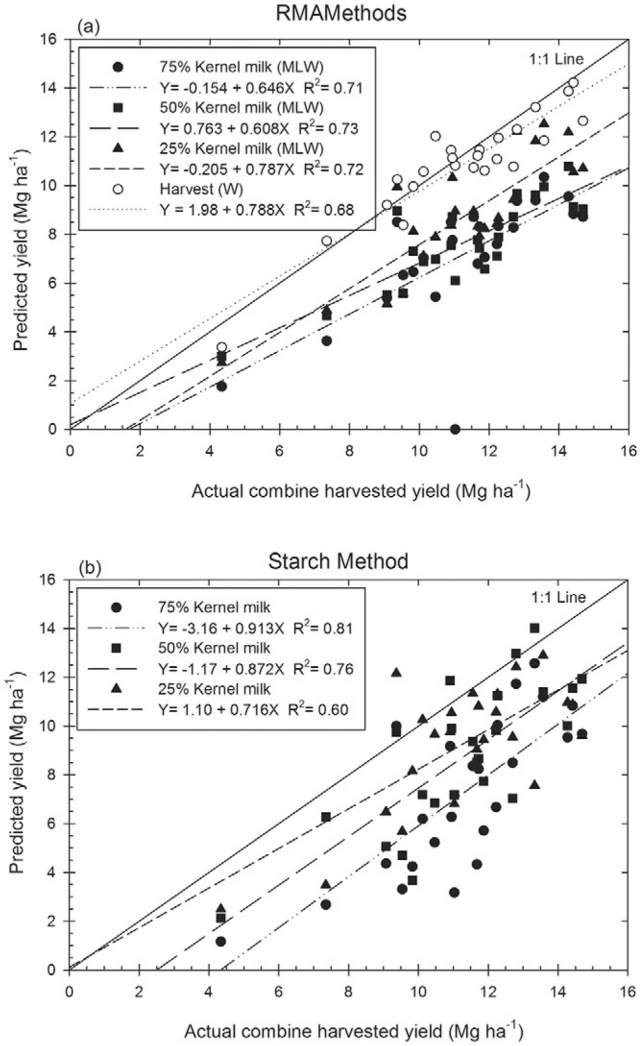

Fig. 1. The relationship between predicted yield and actual combine yield for a) the Risk Management Agency (RMA) maturity line weight (MLW) and weight (W) methods, and b) a starch content method. The MLW method estimated grain yield at 75%, 50% and 25% kernel milk. Each value represents the mean of a hybrid, planting date, and environment (*n* = 4).

a more rapid increase in starch content during grain fill (Nielsen et al., 2002; Roth and Yocum, 1997).

Yield and forage quality responses to planting date and harvest date in general followed expected patterns. Delaying planting by an average of 31 d reduced grain and forage yield by 21% (Table 3). Delayed planting decreased starch content by 29%, and increased NDF by 14% and ivNDFD by 3%. Similar planting date effects were observed by Darby and Lauer (2002a). Small hybrid differences were found for grain yield, starch content, NDF, and ivNDFD.(Table 3). As expected the longer season hybrid, NK Brand N58-D1, had greater forage moisture on each harvest date. As harvest date approached final combine harvest, grain yield estimates using RMA and starch-based methods provided similar results (Table 3). Delaying harvest resulted in an increase in silage yield of 9% and starch content of 49 g kg^{-1}, a decrease in NDF of 41 g kg^{-1} and a decrease in ivNDFD of 19 g kg^{-1}. Decreased fiber concentration is presumably due to increased grain fill during the grain development stages (Cox and Cherney, 2005; Darby and Lauer, 2002b).

The RMA methods underestimated final combine yield by 20 to 29% for early- and late-planting dates (Table 3). Likewise, RMA methods underestimated the prediction of final combine yield by 24% averaged across both hybrids. The RMA MLW method did not estimate final combine grain yield as well as the RMA weight method. The average final combine grain yield was 11.3 Mg ha^{-1}, however, at 75% KM, the RMA MLW method estimated grain yield at 7.2 Mg ha^{-1}, which was 36% lower than the final combine yield (Table 3). Predicting final combine grain yield on subsequent harvest dates improved, but was still 33, 23, and 4% for 50% KM, 25% KM, and the RMA weight method, respectively. A significant planting date × hybrid interaction was observed (Table 2) where RMA methods predicted similar yield for early planting dates, but under predicted yield to a greater extent for the full-season hybrid, NK Brand N58-D1, on later planting dates compared to the shorter-season hybrid, Pioneer 37R71 (Table 4).

The effect of planting date on the prediction of final combine yield using the starch method was underestimated by 16 to 38% for early- and late-planting dates (Table 3). Depending on hybrid the starch method underestimated final combine yield by 22 to 24%. The starch method better estimated final combine grain yield than the RMA MLW method at 50 and 25% KM. At 75% KM,

Table 2. Significance of analysis of variance for experiments conducted in Pennsylvania and Wisconsin environments during 2006, 2007, and 2008. Grain yield estimates used (1) a combine at harvest, (2) Risk Management Agency (RMA) line weight and weight methods, and (3) a starch content method. Grain equivalents were calculated for each estimate method using forage yield and quality measurements.

	Grain yield			Grain equivalents			Forage yield and quality					
Source	Combine	RMA methods	Starch-based	Combine	RMA methods	Starch-based	Forage yield	Starch content	Kernel milk	Forage moisture	NDF	NDFD
Planting date (P)	***	***	***	ns†	***	***	***	***	***	***	***	***
Hybrid (H)	***	***	***	***	***	***	ns	***	***	***	***	ns
P × H	***	***	**	*	**	***	**	***	ns	**	ns	ns
Harvest timing (T)	–	***	***	**	**	***	***	***	***	***	***	***
P × T	–	ns	***	**	*	***	**	***	**	ns	***	ns
H × T	–	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
P × H × T	–	ns	**	ns	**	ns	*	ns	ns	ns	ns	ns

* Significant at the $P \leq 0.05$ probability level.
** Significant at the $P \leq 0.01$ probability level.
*** Significant at the $P \leq 0.001$ probability level.
† ns, no significant differences at $P \leq 0.05$.

both the starch method and RMA method estimated grain yield at 7.2 Mg ha^{-1}, which was 36% lower than the final combine yield. This result was similar to Afuakwa and Crookston (1984) and Thornton et al. (1969) who found that grain yield increased 34 to 43% following the fully dented stage. A significant planting date × hybrid interaction was observed (Table 2) where the starch-based method predicted similar yield for early planting dates, but under predicted yield to a greater extent for the full-season hybrid, NK Brand N58-D1, on later planting dates compared to the shorter-season hybrid, Pioneer 37R71 (Table 4).

A set of regression equations describing the relationship of final combine grain yield to the RMA and starch methods are shown in Fig. 1. Accurate determination of KM is required to use these equations (Crookston and Kurle, 1988). Underestimating grain yield using RMA methods (Fig. 1a) and the starch method was the typical result for nearly all harvest dates (Fig. 1b). Slopes for the regression between predicted yield using RMA methods and actual combine yield were less than one for all RMA methods (Fig. 1a) indicating that as combine grain yield increased RMA methods underestimated grain yield more

Table 3. Corn grain yield measured using (1) a combine at harvest, (2) risk management agency (RMA) line weight and weight methods, and (3) a starch content method. Values are averaged across all environments.

Factor	Grain yield: Combine	Grain yield: RMA methods	Grain yield: Starch based	Forage yield and quality: Dry matter yield	Starch content	Kernel milk	Forage moisture	NDF	ivNDFD†
	Mg ha^{-1}			Mg ha^{-1}	g kg^{-1}	%	g kg^{-1}		
Planting date									
Early	12.6	10.1	10.6	19.3	333	36	601	436	554
Late	10.0	7.1	6.2	15.3	238	76	699	498	569
LSD (0.05)	0.9	0.5	0.7	1.0	15	4	9	10	7
Hybrid									
Pioneer 37R71	11.8	9.0	9.3	17.3	321	49	623	440	560
NK Brand N58-D1	10.8	8.2	7.5	17.3	250	64	676	494	564
LSD (0.05)	0.5	0.3	0.4	ns‡	9	4	9	8	ns
Harvest timing									
75% Kernel milk	–	7.2	7.2	16.4	256	70	693	491	573
50% Kernel milk	–	7.6	8.7	17.6	296	55	632	461	559
25% Kernel milk	–	8.7	9.2	17.9	305	43	625	450	554
Grain yield	11.3	10.9	–	–	–	–	–	–	–
LSD (0.05)	–	0.4	0.5	0.8	11	5	11	10	6

† ivNDFD, in vitro neutral detergent fiber digestibility.
‡ ns, not significant.

Table 4. Planting date and hybrid effects on grain yield (Mg ha^{-1}) and equivalents (Mg grain Mg^{-1} forage) as measured using (1) a combine at harvest, (2) Risk Management Agency (RMA) line weight and weight methods, and (3) a starch content method.

Planting date	Hybrid	Grain yield: Combine	Grain yield: RMA methods	Grain yield: Starch method	Grain equivalents: Combine	Grain equivalents: RMA MLW† method	Grain equivalents: Starch method
		Mg ha^{-1}			Mg Mg^{-1}		
Early	Pioneer 37R71	12.3	10.0	11.1	0.237	0.179	0.208
	NK Brand N58-D1	12.8	10.1	10.0	0.230	0.171	0.178
Late	Pioneer 37R71	11.2	8.1	7.2	0.257	0.166	0.164
	NK Brand N58-D1	8.9	6.2	5.0	0.214	0.126	0.111
LSD (0.05)		0.9	0.6	0.7	0.021	0.014	0.009

† MLW, maturity line weight method.

Table 5. Planting date and harvest timing effects on grain yield (Mg ha^{-1}) and equivalents (Mg grain Mg^{-1} forage) as measured using (1) a combine at harvest, (2) Risk Management Agency (RMA) line weight and weight methods, and (3) a starch content method.

Planting date	Harvest timing	Grain yield: Combine	Grain yield: RMA methods	Grain yield: Starch method	Grain equivalents: Combine	Grain equivalents: RMA MLW† method	Grain equivalents: Starch method
		Mg ha^{-1}			Mg Mg^{-1}		
Early	75% KM‡	–	8.8	9.8	0.240	0.170	0.184
	50% KM	–	8.9	11.1	0.227	0.162	0.199
	25% KM	–	10.3	10.8	0.235	0.193	0.197
	Harvest	12.7	12.1	–	–	–	–
Late	75% KM	–	5.5	4.6	0.257	0.137	0.114
	50% KM	–	6.3	6.3	0.237	0.150	0.143
	25% KM	–	7.1	7.6	0.214	0.150	0.157
	Harvest	10.0	9.6	–	–	–	–
LSD (0.05)		0.9	0.7	0.8	0.021	0.017	0.010

† MLW, maturity line weight method.
‡ KM, kernel milk.

at high combine yield levels than at low yield levels. Slopes for the regression between predicted yield using the starch-based method and actual combine yield were less than one (Fig. 1b) indicating that as combine grain yield increased the starch-based method underestimated grain yield more at high yield levels than at low yield levels. The relationship between the RMA MLW method and the starch method at 75 and 50% KM has a slope of 1.01 and 0.98 with R^2 values of 0.82 and 0.75 indicating that both methods predict similar values at those stages and validates the RMA method with the more quantitative starch-based method. At 25% KM, the slope of the relationship between the RMA MLW method and the starch method was 0.65 (R^2 = 0.60) indicating that the starch method overestimated the RMA MLW method in low yielding environments, while in high yield environments the estimates were similar. At 25% KM, the starch method estimated final combine yield better than the RMA MLW method (Tables 3 and 5).

Both RMA methods and the starch-based method underestimate combine grain yield at various silage harvest stages (Tables 3 and 5, Fig. 1a and 1b). The RMA weight method was the best predictor of final combine grain yield, however, this method was applied post silage harvest and just before grain harvest (Fig. 1a). The accuracy of these methods has an important application when corn fields are sold at harvest. The forage price settled on between a seller and buyer is influenced by the opportunity grain price. Often a ratio of 0.196 Mg grain Mg forage^{-1} (ratio of grain at 155 g kg^{-1} moisture to corn forage at 650 g kg^{-1} moisture, that is, 0.196 Mg grain Mg forage^{-1} = seven bushels grain per ton of forage) is used to predict the amount of grain in the forage (Jorgensen and Crowley, 1972).

Grain equivalents change with advancing maturity (Table 5). So to be accurate a sliding scale would be needed for predicting grain equivalents. Depending on environment, harvest date, planting date and hybrid, grain equivalents ranged from 0.126 to 0.179 Mg Mg^{-1} for the RMA MLW method and 0.111 to 0.208 Mg Mg^{-1} for the starch method (Tables 4 and 5). All methods were substantially below the final combine grain equivalents that ranged from 0.214 to 0.257 Mg Mg^{-1}.

CONCLUSIONS

The RMA methods underpredict grain yield at grain harvest. Both RMA and starch methods can predict grain content at silage harvest equally well. Grain yields increase during grain fill, so some adjustment is necessary to accurately predict final grain yield. This may vary depending on factors that affect grain fill such as planting date, late season disease, etc. The relationship also is influenced by KM stage, so careful documentation of growth stage is necessary for accurate estimates. Current appraisal methods have the adjuster determine the stage of grain development based on KM line. The adjuster must determine the weight based on the various stages of maturity and then apply a factor to convert the determined weight to an estimated weight of mature corn at 155 g kg^{-1} moisture. These factors contribute to the underestimation of the actual accumulation of yield as the plants develop. With careful assessment a starch-based method or a silage based crop adjuster system could produce equitable estimates of grain yield.

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