Estimating Plant-Available Water Using the Simple Inverse Yield Model for Claypan Landscapes

Pingping Jiang,* Newell R. Kitchen, Stephen H. Anderson, E. John Sadler, and Kenneth A. Sudduth

ABSTRACT

Plant-available water (PAW) is one of the fundamental soil factors affecting crop yield, yet quantitative determination of plant-available water capacity (PAW_c) at a field scale has been challenging. A simple inverse yield model (SIYM) has been devised and shown to be successful in estimating PAW_c at a field scale for well-drained soils by matching simulated corn (*Zea mays* L.) yield with measured yield. For other soils, however, SIYM is yet to be tested. Our objective was to evaluate SIYM performance in estimating PAW_c for poorly-drained claypan-soil landscapes. Soil PAW_c to a depth of 1.2 m ($PAW_{1.2}$) was measured at 19 and 18 sampling locations for two claypan-soil fields, Fields 1 and 2, respectively. Corn yield maps of the two fields (nine site-years between 1993 and 2003) were used with the model to estimate PAW_c. Yield reduction associated with low precipitation and high vapor-pressure deficit during corn reproductive stages, and large yield variation in dry years were indications available water was the main yield-limiting factor. The regression r^2 values between SIYM-estimated PAW_c and the measured $PAW_{1.2}$ were 0.43 for Field 1 and 0.31 for Field 2 with estimating errors of 18 and 50 mm, respectively. In Field 2, SIYM estimated markedly lower PAW_c compared with the $PAW_{1.2}$ at the most-eroded backslope areas, where claypan characteristics were most prevalent. The SIYM-PAW_c estimates would be more informative in assessing soil productivity because they are based on crop-water relations and not solely on soil texture.

Plant-available water is one of the fundamental soil factors affecting crop yield. However, quantitative determination of PAW_c is not an easy task. Challenges in measurement include labor intensive activities such as permanent installation of soil moisture devices, repeated monitoring of water content, destructive sampling, and water extraction from soil samples. These difficulties prevent extensive assessment of the spatial variability of PAW_c at a field scale, information that would be useful for site-specific management and for crop growth modeling at high spatial resolution.

Several approaches have been proposed to estimate PAW_c for fields. One approach is to use terrain analysis and soil-landscape modeling (Moore et al., 1993). A range of soil properties related to PAW have been found to be correlated with topographic variables derived from terrain analysis. These soil properties include water storage (Tomer and Anderson, 1995), water retention at –33 kPa (Pachepsky et al., 2001), organic matter content, A horizon thickness (Moore et al., 1993; Gessler et al., 2000), and soil texture (Pachepsky et al., 2001). Even though these properties are related to PAW, the information they provide is indirect. A second approach is to use apparent soil electrical conductivity (EC_a). Following upon the relationships between soil water content and soil EC_a (Kachanoski et al., 1988, 1990; Sudduth et al., 2001; Reedy and Scanlon, 2003), some researchers also investigated relationships of EC_a with PAW (Morgan et al., 2000; Wong et al., 2006; Jiang et al., 2007b). Even though somewhat empirical, the EC_a approach provided a quick and reasonably accurate method to generate PAW information for a field. One shortcoming of the soil EC_a approach was that the root depth for PAW calculation was variable and arbitrary. Thus, the approach was not based on the real rooting depths in the field and hence was less germane to soil productivity.

Recent studies have presented a biophysical approach for estimating PAW for a field (Timlin et al., 2001a, 2001b; Morgan et al., 2003). In a SIYM devised by Morgan et al. (2003), profile PAW can be obtained by two model steps. The first step (forward step) is a corn yield simulating step, which uses a daily water-budget algorithm, and weather and a range of given PAW values typically encountered in the field as inputs. Thus, the daily amount of water taken up by a crop and stored in the soil can be evaluated. The baseline relationship for simulating yield is the transpiration efficiency equation given as follows:

$$Y/\mathrm{T} = k/\mathrm{VPD} \qquad [1]$$

where Y is the total plant biomass, T is the cumulative transpiration throughout the growing season, VPD is the mean daytime vapor-pressure deficit of the air for the growing sea-

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Abbreviations: EC_a, bulk soil apparent electrical conductivity; PAW, plant available water; PAW_c, plant available water capacity; $PAW_{1.2}$, plant available water capacity for a 1.2 m soil profile; VPD, vapor pressure deficit; SIYM, simple inverse yield model.

son, and k is the transpiration efficiency constant. The crop water budget algorithm used in yield simulation calculates soil evaporation and transpiration separately. The outcome of this first step simulates corn yield as a function of input PAW values. Then in the second step (inverse step) of the SIYM, the measured yield data, usually from a combine equipped with a yield monitoring system, are matched with the simulated yield, and when the closest match is found, PAW for a given location can be estimated from looking up the input PAW values. During the process, the SIYM is run for each individual year over a range of years whenever weather and yield data are available. Thus, a PAW value is estimated for each individual year (PAW_{year}) for each single yield value. Finally, PAW_c for a location can be estimated as an average of selected PAW_{year} over a range of years. The selected PAW_{year} were usually from water-stressed years when corn yield was highly reliant on stored profile PAW.

The SIYM successfully evaluated PAW_c for well-drained loam-based Alfisols and Mollisols in Wisconsin, where the model was first developed (Morgan et al., 2003). The main assumption of the SIYM is that PAW is the primary yield limiting factor. This assumption also lends rationality to the SIYM for not having a water routing routine, because runoff water is considered to be captured at lower slope positions, and this addition to the profile water storage would be reflected through a higher yield.

For claypan soils, the topsoil thickness above the claypan layer is highly related to PAW (Jiang et al., 2007b) and crop yield (Gantzer and McCarty, 1987; Kitchen et al., 1999). Prior experience indicated that low and unpredictable precipitation in July and August is mainly responsible for year-by-year yield variations (Hu and Buyanovsky, 2003). In addition, claypan characteristics such as low hydraulic conductivity, slow recharge, and poor drainage can affect plant–water relations (Jamison and Kroth, 1958; Thompson et al., 1991, 1992; Blanco-Canqui et al., 2002; Jiang et al., 2007a). If proven useful for claypan soils, the SIYM approach could provide a quick and economical way to map PAW at high resolution for a field, as yield monitor data have become increasingly commonplace. Further, PAW_c estimates obtained from SIYM were expected to be more relevant for assessing potential soil productivity, compared with other approaches, as the model used actual crop yield and was based on crop–water relationships.

The specific objective of this study was to evaluate SIYM performance in estimating PAW_c for poorly-drained claypan-soil landscapes.

MATERIALS AND METHODS

Study Sites

Study sites were two claypan-soil fields within a distance of 2 km from each other, near Centralia in central Missouri. Field 1 (39°38' N, 92°20' W) was 36 ha and Field 2 (39°38' N, 92°25' W) was 13 ha in size. Elevation ranged from 262 to 266 m in Field 1 and from 256 to 266 m in Field 2. The primary soil series found in the study fields include Mexico (fine, smectitic, mesic Vertic Epiaqualfs), Adco (fine, smectitic, mesic Vertic Albaqualfs), both with 1 to 5% slope, and Leonard (fine, smectitic, mesic, Vertic Epiaqualfs) with 2 to14% slope. All these soil series were somewhat-poorly or poorly drained. They were typical claypan soils characterized by an abrupt claypan horizon at varying depths, depending generally on slope position. The typical texture for topsoil was silt loam, and silty clay to clay for the claypan layer.

Both fields were managed in a corn–soybean [*Glycine max* (L.) Merr] rotation with mulch tillage for at least 10 yr prior to this study. For the years used in this research, Field 1 was managed in mulch tillage and Field 2 was managed in no-tillage. Both fields were under intensive management with a high yield goal for this region. Only in localized small areas in some years did we note plant growth negatively affected by soil compaction, weed pressure, insects, and disease. The mean annual temperature in the area was 12°C, and the mean annual precipitation was 96.9 cm (National Climate Data Center, 2002).

Yield Data

Five years (1993, 1997, 1999, 2001, and 2003) of corn yield data from Field 1 and 4 yr (1997, 2000, 2002, and 2005) from Field 2 were available for analysis. These yield data were collected using commercial yield monitors mounted on combine harvesters. During harvest, the combine usually traveled at approximately 5 to 8 km h^{-1}, and yield data were recorded every second. Thus, depending on swath width, a single yield data point represented an average yield for an area approximately 6 to 10 m^2. An automatic yield data processing program—Yield Editor (Sudduth and Drummond, 2007)—was used to remove questionable and unrealistic yield data points caused by operating errors such as abrupt changes of speed, partial swath, and combine stops and starts. Then, yield data were aggregated to a 10 by 10 m cell resolution using ArcGIS neighborhood analysis (ESRI, 2006). The yield averaged in a single cell typically included two harvest transects and two to three data points in each transect.

Simple Inverse Yield Model Inputs and Estimation of Plant-Available Water

The "forward step" of the SIYM was run for each available year to produce a corn yield vs. PAW relationship curve. Required weather inputs (i.e., mean maximum and minimum daily air temperature in °C, daily precipitation in millimeters, mean-season day-time hourly vapor pressure deficit (VPD) in kPa, and total daily radiation in MJ m^{-2} d^{-1}) were obtained from a weather station located adjacent to Field 1. The k value in Eq. [1] used to convert cumulative transpiration to yield was chosen to be 0.008 kPa for all years. This k value fulfilled the recommendation of Morgan et al. (2003) that the k value should be such that SIYM simulates 95% of the highest yield. Physiological inputs such as tasseling and maturity dates were also required but were not observed. Hence these dates were computed by a SIYM subroutine based on cumulative degree days required to reach each of the two dates. Several corn varieties were planted. For varieties whose cumulative degree days to maturity were not available, a value of 750 (10°C base), considered common in Missouri, was used. In the "inverse step" of the SIYM, the simulated yield values were matched with measured yield data for a given year to obtain the PAW_{year} for each cell.

To verify the effect of PAW on yield variation over the study period, average VPD values, as an indicator for water deficit,

Table 1. Descriptive statistics for corn grain yield.

Field	Year	Mean	SD	CV
		Mg ha^{-1}		%
Field 1				
	1993	7.5	1.40	0.19
	1997	7.2	1.10	0.15
	1999	2.6	0.68	0.26
	2001	6.1	0.92	0.15
	2003	2.1	1.10	0.66
Field 2				
	1997	6.3	2.50	0.31
	2000	9.0	1.40	0.11
	2002	3.2	1.30	0.42
	2005	3.7	1.60	0.50

calculated for three periods of each season (before tasselling, after tasselling, and season-long) were correlated with yield.

Field Measurements for Plant-Available Water

Profile samples were taken at 19 locations in Field 1 and 18 locations in Field 2 in October 2005 using a hydraulic soil coring probe (38.1 mm diam.). The sampling sites were distributed throughout the fields such that major land features were represented. Horizonation was determined during the sampling. Depth of each horizon was recorded, and then soil profiles were separated by horizon and each horizon sample was collected and sealed in a plastic bag. These horizon samples were left to air-dry for 2 wk before an air-dry weight was obtained. A subsample of about 50 g was oven-dried to determine water content for the air-dry horizon samples. Thus, bulk density for each horizon was calculated using air-dry soil mass, water content of the oven-dried subsample, and sample volume. Bulk density was used to convert gravimetric water content to volumetric water content.

Sample material passed through a 2-mm sieve was used to determine water retention at –1500 kPa, which was used as the lower limit. Profile samples were taken again at the same locations on 29 Mar. 2006, following wintertime profile recharge, to determine field capacity. Volumetric water content was determined for each horizon sample using the gravimetric method and bulk density. Plant-available water was determined by the difference between the field capacity and –1500 kPa water content. Profile PAW_c was then determined by summing horizon PAW to a 1.2-m depth ($PAW_{1.2}$).

RESULTS AND DISCUSSION

Yield Variation, Weather, and Plant-Available Water

In Central Missouri, highly variable weather patterns during the growing season gave rise to large year-by-year variation in yield. As presented in Table 1, during the study period, average corn yield ranged from 2.1 Mg ha^{-1} (2003) to 7.5 Mg ha^{-1} (1993) for Field 1 and from 3.2 Mg ha^{-1} (2002) to 9.0 Mg ha^{-1} (2000) for Field 2. The cumulative daily precipitation of the growing season (Fig. 1) indicated severe water deficit during the critical development stages (usually during the period from July to mid-August) in 1999, 2002, 2003, and 2005, and resulted in serious yield loss in 4 yr, similarly to that documented by Hu and Buyanovsky (2003) for claypan soils. The large yield coefficients of variation (CV) for 3 of these 4 yr (2002, 2003, and 2005) was indicative of the role of topsoil in supplying PAW to corn plants under dry conditions. Measured topsoil thickness ranged from 11 to 120 cm with an average of 34.8 cm for Field 1 and from 0 to 120 cm with an average of 40.1 cm for Field 2 (Jiang et al., 2007b). For a 1.2 m soil profile, the amount of PAW stored could change from 276 mm, assuming all topsoil with silt loam texture, to 144 mm, assuming the claypan occurred at the surface. In water-stressed years, areas with greater topsoil depth, hence a greater amount of profile PAW, supported high yield; while areas with shallow topsoil depth, especially highly-eroded backslopes, only produced very low, sometimes nil, grain yield.

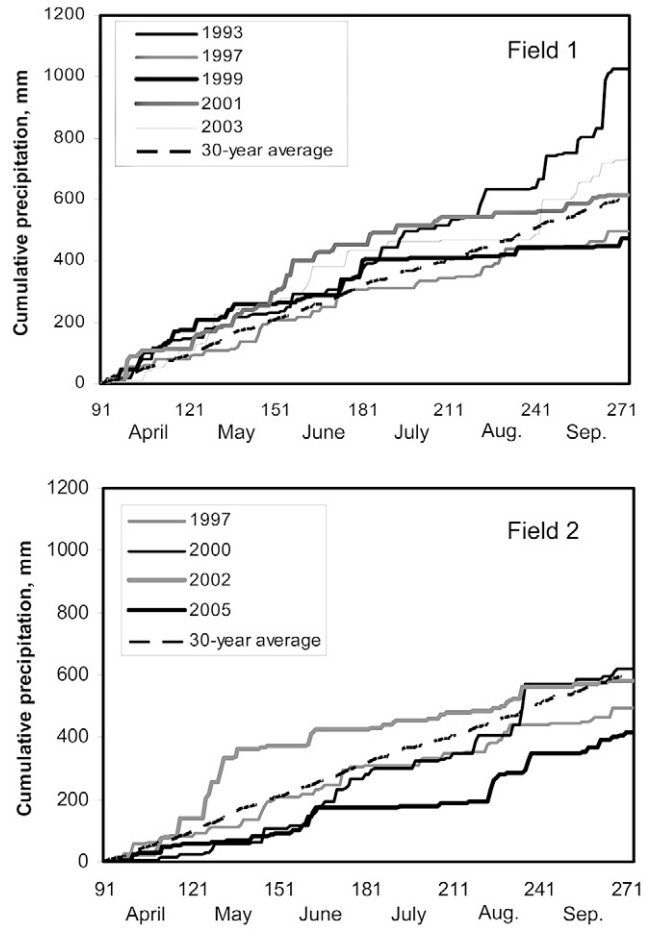

Fig. 1. Cumulative daily precipitation from April to September, along with 30-yr cumulative daily averages (1975–2004) obtained near the study site. The x-axis labels are day of year.

The relationships of the mean VPD for the periods of "before tasseling", "after tasseling", and "season-long" to yield were plotted in Fig. 2. Tasseling dates simulated by SIYM ranged from day of year 194 to 205 (results not shown). The mean VPD after tasseling was significantly correlated with corn yield for both fields pooled together, with a correlation coefficient of 0.80 (P value < 0.01), and the mean VPD before tasseling did not affect yield. This result indicated the high evaporative demand coupled with low precipitation during the reproductive stages was correlated with (and likely the cause of) yield reduction, consistent with Hu and Buyanovsky (2003).

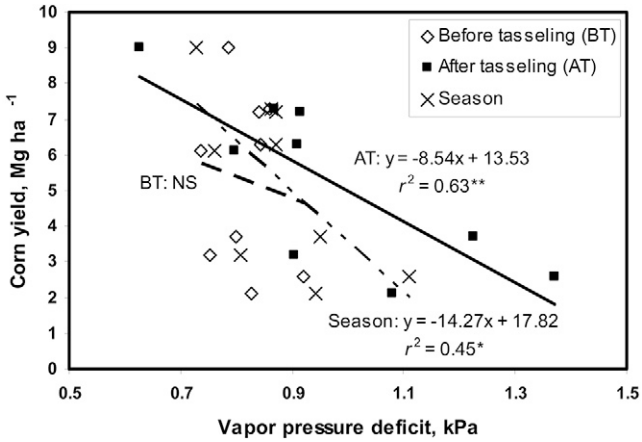

Fig. 2. Corn grain yield as a function of mean day-time vapor pressure deficit (VPD) before tasseling, after tasseling, and for the whole growing season, during the study period.

The Pearson's correlation coefficients between corn yield and PAW depth-weighted at 30-cm increments are given in Table 2. There was no general pattern found as to which soil depth was most significantly and consistently correlated with yield. However, stronger correlations seemed to occur at deeper depths (i.e., from 60–120 cm) in water-stressed years for Field 1, suggesting root activity within and below the claypan layer, which supports previous observations that crop roots were able to penetrate into and through the claypan layer (Grecu et al., 1988; Myers et al., 2007), and that root growth may increase within the claypan layer (Myers et al., 2007), as a result of plant adaptation to water-limited soil layers.

Correlation coefficients for corn grain yield vs. the measured profile $PAW_{1.2}$ are also given in Table 2. For both fields, $PAW_{1.2}$ was significantly correlated with yield only in water-stressed years (1997, 1999, 2002, 2003, and 2005), and not in the years when sufficient rainfall resulted in optimal PAW for crop growth, or when rainfall was in excess (1993 and 2000). In fact, a negative trend between corn yield and PAW, with statistical significance at two depths for 1993, began to show when rainfall was in excess. For dry years, the correlation coefficients between profile PAW and corn yield found for our study sites were weaker than for well-drained soils in Maryland and Wisconsin (Timlin et al., 1998; Morgan et al., 2003). The average correlation coefficient (r) between corn yield and the measured $PAW_{1.2}$ for our dataset was 0.65 across both fields, excluding the years when no significant correlations were found (Table 2), while an average $r = 0.82$ for water-stressed years ($r = 0.76$ for both stressed and nonstressed years) was reported in Morgan et al. (2003). The interactions between PAW and yield could have shown better had we monitored PAW variations for each growing season. Nonetheless, these results suggested that crop–water relationships are more complex for claypan soils than for well-drained soils. On similar claypan soils, Thompson et al. (1992) also reported that topsoil depth (which was correlated with PAW) was not the sole factor responsible for yield reduction as the crop experienced similar yield loss in both water-stressed and nonstressed conditions regardless of topsoil depth (from 0–375 mm). For the poorly-drained claypan soils, once water is depleted in the immediate environment around the root surface, movement of water toward roots may be highly impeded because of the high clay content and associated slow transport of water (Blanco-Canqui et al., 2002; Jiang et al., 2007a). As a result, PAW may not be taken up efficiently, even though it was still measurable using the conventional method.

Table 2. Pearson's correlation coefficients (r) for corn grain yield vs. the measured plant-available water by 30-cm increments and weighted to a 1.2-m depth ($PAW_{1.2}$).

Year	Soil depth, cm 0–30	30–60	60–90	90–120	$PAW_{1.2}$
	r				
			Field 1		
1993	−0.43†	−0.13	−0.23	−0.49*	−0.38
1997	0.54*	0.69**	0.73***	0.39	0.74***
1999	0.37	0.46*	0.67**	0.39†	0.60**
2001	−0.05	−0.23	−0.02	−0.16	−0.15
2003	0.02	0.51*	0.77***	0.70***	0.64**
			Field 2		
1997	0.51*	0.58*	0.46†	0.40†	0.59**
2000	0.37	−0.11	0.04	0.15	0.10
2002	0.56*	0.62**	0.39	0.54*	0.63**
2005	0.54*	0.61**	0.47*	0.61**	0.68**

* Significant at the 0.05 level.

** Significant at the 0.01 level.

*** Significant at the 0.001 level.

† Significant at the 0.10 level.

Estimating Plant-Available Water Using Simple Inverse Yield Model

Simulated corn grain yield as a function of input PAW values from the "forward-step" of the SIYM are shown in Fig. 3. Yield was most responsive to PAW in the range from about 125 to 250 mm in water-stressed years. At PAW values smaller than 125 mm, the yield increase with PAW was minor and at PAW values >250 mm, yield began to level off. In years when rainfall was not limiting (i.e., 1993 and 2000), the modeled yield started high at low PAW, but quickly leveled off after a rapid increase over a short range of PAW, also suggesting yield was not limited by PAW in those years.

Inverse SIYM PAW estimates for each year (SIYM PAW_{year}) vs. the measured $PAW_{1.2}$ are given in Fig. 4. Mean SIYM PAW_{year} were 65, 200, 176, 161, and 116 mm for 1993, 1997, 1999, 2001, and 2003 in Field 1, and 177, 66, 138, and 139 mm for 1997, 2000, 2002, and 2005 in Field 2, respectively. The SIYM PAW_{1993} and SIYM PAW_{2000} values were underestimated because the water needed for growth was met by seasonably-distributed rainfall, and the final yield did not depend on stored PAW. This result was consistent with the weak correlation between PAW and yield for these 2 yr (Table 2). For dry years, the simulated yield potential for 2003 was higher than that for 1999 in Field 1 (Fig. 2), and the measured grain yield for 2003, however, was lower (Table 1). As a result, SIYM PAW_{2003} was noticeably lower than SIYM PAW_{1999}. A probable reason for this result was that the soil profile was poorly recharged before the 2003 growing season. There was an 88 mm deficit in precipitation during the recharge months from October of 2002 to April of 2003, in addition to the severe drought in the previous season of 2002 (data not shown). Thus, with the soil profile not fully recharged, potential corn yield was further reduced in 2003.

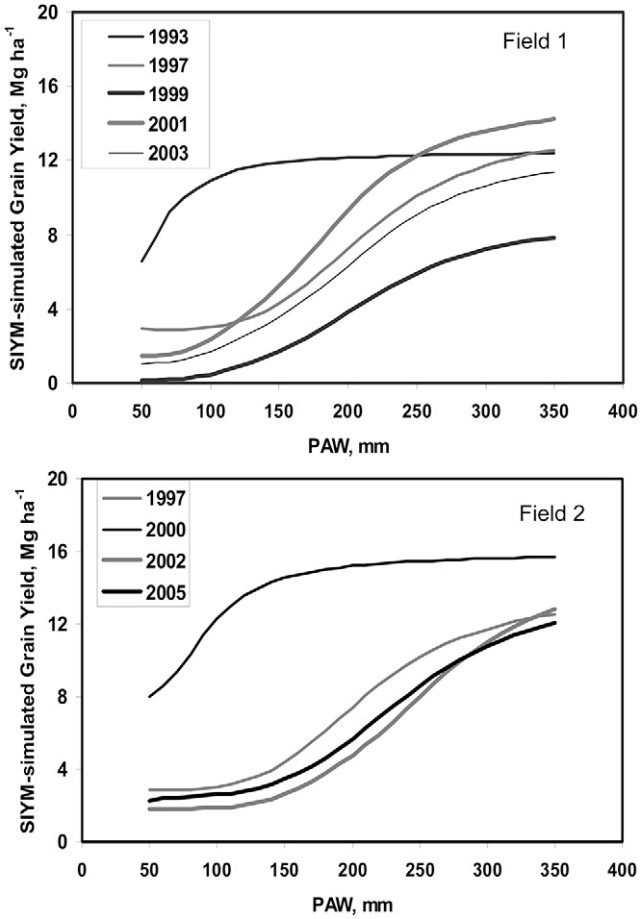

Fig. 3. Simulated corn grain yield using the simple inverse yield model (SIYM) as a function of profile plant-available water (PAW) for each individual year.

Table 3. Regression equations for plant-available water (mm) estimated by the simple inverse yield model (SIYM-PAW$_{year}$) vs. measured plant-available water to a 1.2-m soil depth (PAW$_{1.2}$).

SIYM-PAW$_{year}$	Regression equation	r^2	RMSE†
	Field 1		
1993	NS‡	–	–
1997	155.9 + 0.24 PAW$_{1.2}$	0.59	11
1999	140.2 + 0.19 PAW$_{1.2}$	0.34	15
2001	NS	–	–
2003	28.9 + 0.48 PAW$_{1.2}$	0.35	35
	Field 2		
1997	105.0 + 0.41 PAW$_{1.2}$	0.26	42
2000	NS	–	–
2002	12.6 + 0.72 PAW$_{1.2}$	0.32	62
2005	4.6 + 0.77 PAW$_{1.2}$	0.39	57

† RMSE = root mean square error.

‡ Not significant.

The regression r^2 values between SIYM PAW$_{year}$ and the measured PAW$_{1.2}$ ranged from 0.01 for the nonstressed years to 0.59 for the stressed years (Table 3). When compared, the SIYM PAW$_{year}$ estimates did not agree with the measured PAW$_{1.2}$ for claypan soils as well as for well-drained soil in Wisconsin, where the reported r^2 values ranged from 0.41 for nonstressed years to 0.69 for stressed years (Morgan et al., 2003). The poorer agreement between the PAW$_{1.2}$ and SIYM PAW$_{year}$ found for claypan soils can be directly linked back to

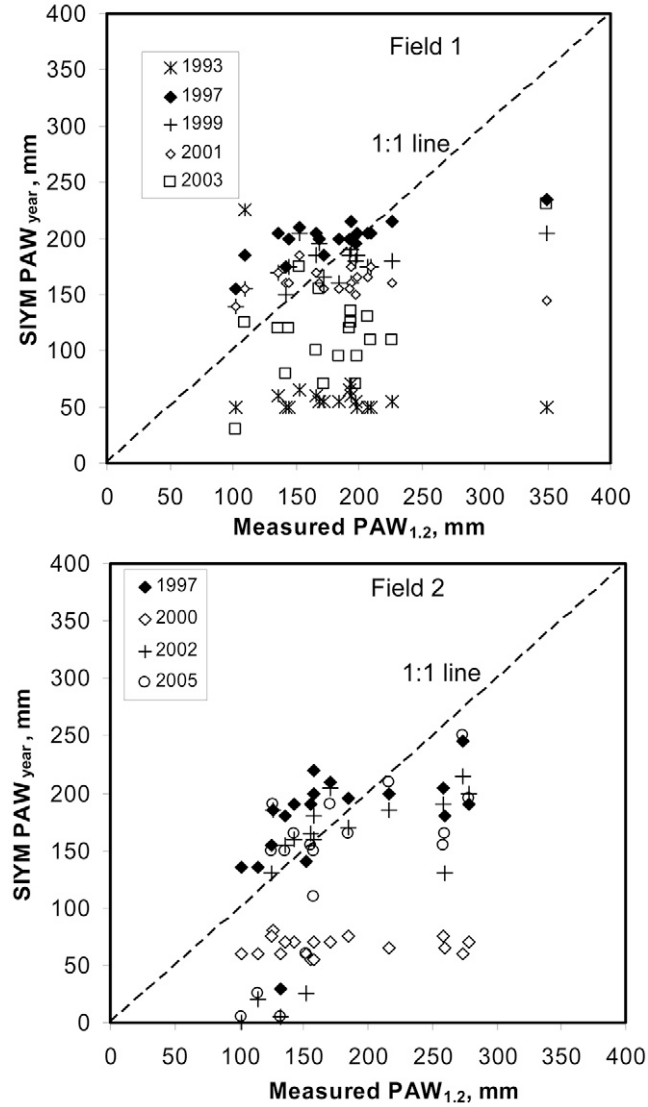

Fig. 4. Estimated plant-available water (PAW) for each individual year using the simple inverse yield model (SIYM PAW$_{year}$) vs. measured profile plant-available water for a 1.2-m soil profile (PAW$_{1.2}$).

the weaker relationships between corn yield and the measured PAW$_{1.2}$ that were discussed previously.

Selected SIYM PAW$_{year}$ values were averaged to obtain SIYM PAW$_c$. The selected years included those when corn plants experienced some level of water stress during the critical development stages (based on field observations) and final grain yield was significantly correlated with the measured profile PAW$_{1.2}$. The SIYM PAW$_{1997}$, PAW$_{1999}$, and PAW$_{2003}$ for Field 1, and SIYM PAW$_{1997}$, PAW$_{2002}$, and PAW$_{2005}$ for Field 2 were selected for averaging.

Relationships between SIYM PAW$_c$ and the measured PAW$_{1.2}$ are plotted in Fig. 5, along with a 1:1 reference line. Compared with the value of 0.78 reported in Morgan et al. (2003), the r^2 values between SIYM PAW$_c$ and the measured PAW$_{1.2}$ for our dataset were 0.43 and 0.31 for Fields 1 and 2, respectively. The root mean square errors (RMSE) were 18 and 50 mm for the two fields. In Field 2, SIYM estimated markedly lower PAW values compared to the measured PAW$_{1.2}$ for a group of four locations (circled in Fig. 5). This occurred because observed grain yields were consistently lower than values simu-

lated by SIYM based on the measured $PAW_{1.2}$ at these sites. For example, at the level of the measured $PAW_{1.2}$, SIYM simulated an average of 3.0 Mg ha^{-1} for these four sites over the two driest years of 2002 and 2005; the actual average yield, however, was only about 1.5 Mg ha^{-1}. These four sites were located in the most-eroded and lowest-yielding backslope areas of Field 2, where the topsoil depth was the shallowest or the claypan was mixed into the surface soil. Crop production in such areas was especially prone to water stress and yield loss because of the following claypan characteristics: (i) the likely not-well-recharged soil profile before the growing season; and (ii) the high soil resistance (i.e., low conductivity) to water movement to roots during the growing season. Under such conditions, the crop could be "hydraulic property limited" and experience irreversible stunting before profile PAW was completely depleted, as water was not available for uptake in a timely manner. These results suggested that claypan soil characteristics caused additional yield variability, which cannot be readily explained by profile PAW measured using conventional methods.

CONCLUSIONS

Frequent drought and erratic weather patterns during the growing season are constant risks for corn grown on claypan-soil areas of the U.S. southern cornbelt. From the data used in this study, grain yield was severely reduced by drought in four (1999, 2002, 2003, and 2005) out of a total of nine site-years; and the yield goal set at the current management level was achieved only in one site-year (2000). The high correlation between corn yield and mean VPD, and the low precipitation during the reproductive stages of corn plant development implied depletion of PAW which resulted in water stress and subsequent reductions in yield. During the dry years, significant yield loss was experienced. Thus, under the management level employed, the assumption of SIYM (i.e., PAW is the primary yield limiting factor) held for claypan soils under Missouri climatic conditions for dry years.

Besides the precipitation deficit in July and August, the large CV of corn yield in dry years can be explained by the unique physical and hydraulic properties of the claypan, such as low hydraulic conductivity, slow recharge, poor drainage, and high soil resistance for water movement to roots. These properties further reduced yield potential where topsoil thickness was shallow; while with greater topsoil thickness, a relatively high yield was maintained. For this reason, the correlation between yield and the measured $PAW_{1.2}$ was lower for our study field than for well-drained soils because the measured $PAW_{1.2}$ did not account for the additional yield variability.

The SIYM-PAW_c estimates showed that the largest disagreement with the measured $PAW_{1.2}$ occurred in areas where topsoil thickness was shallow and the claypan characteristics were most prevalent close to the soil surface. At these positions, yield was consistently lower than the SIYM-simulated yield based on the level of the measured $PAW_{1.2}$, therefore SIYM–PAW_c estimates were considerably lower than the measured $PAW_{1.2}$. Using the conventionally-measured $PAW_{1.2}$ as the benchmark, SIYM–PAW_c estimates did not agree with the measured $PAW_{1.2}$ values as well as for well-drained soils. However, for claypan soils, it is questionable whether the conventionally-measured PAW represents the "true" amount of soil water

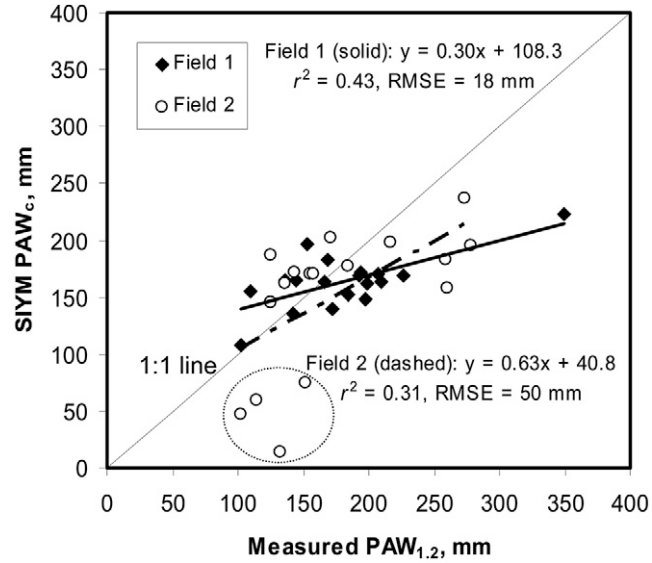

Fig. 5. Plant available water capacity estimated by the simple inverse yield model (SIYM PAW_c) vs. measured plant available water to a 1.2-m depth ($PAW_{1.2}$). The SIYM PAW_c for Field 1 was obtained by averaging SIYM PAW estimates for 1997, 1999, and 2003. The SIYM PAW_c for Field 2 was obtained by averaging SIYM PAW estimates for 1997, 2002, and 2005. The dashed circle indicates the data points with the largest underestimation errors.

that can be used by the crop. On the other hand, the SIYM estimates would be more useful in assessing soil productivity and making site-specific management decisions because SIYM is based on yield measurements and crop water use, and less strongly on soil and conventional measurement techniques (e.g., pressure chamber or soil moisture probe sensors), which do not take crop–soil–water interactions into account. This may be more important for claypan soils because recharge is difficult and conventionally-measured PAW may be less representative of the amount of stored water that can be taken up by plants for these soils.

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