TECHNICAL NOTE:

TRENDS IN PLANT AVAILABLE SOIL WATER ON PRODUCER FIELDS OF WESTERN KANSAS

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ABSTRACT. *Residual soil water after harvest and prior to planting was measured to a depth of 2.4 m with neutron attenuation techniques for approximately 45 irrigated corn and 45 dryland wheat fields annually from 2010 through 2012 in the western one-third of Kansas. The sampling locations were in three-county transects in northwest, west central and southwest Kansas with generally five fields for each crop type for each county. Residual plant available soil water (PASW) in corn fields was generally much greater than in wheat fields (150%-160% greater) for any given sampling period illustrating the residual influence of irrigation. Although weather conditions varied between regions and years there was not a strong effect on PASW in irrigated corn fields but there was an effect in dryland wheat fields. Annual differences in fall irrigated corn PASW for the 21 individual fields that were available for sampling in all three years varied less than 50 mm/2.4 m soil profile implying considerable stability in an individual producer's response (irrigation management and irrigation system capacity) to changing weather conditions as evidenced by the similar year-to-year PASW values. Drought conditions existed for much of the total period (fall 2010 through fall 2012) in southwest Kansas, yet the irrigated corn PASW was still relatively high (PASW value at approximately 62% of water stored at field capacity in a 2.4 m profile). So, the presence of drought may not be a good indicator of the amounts of residual soil water producers are leaving after irrigated corn harvest. Although differences in irrigated corn PASW varied greatly among producers (183% to 722% within a region), there were much smaller differences between regions and years with a variation from 8% to 22%. Irrigation system capacity (flowrate/area) had very little effect on residual fall PASW in the corn fields possibly indicating that producers with deficit capacity are pumping earlier and later into the season to help mitigate their lower irrigation capacity. Irrigated corn grain yields began to plateau when PASW reached a value of approximately 200 mm/2.4 m profile which would represent a water storage of approximately 56% of field capacity. The residual PASW in irrigated corn fields decreased about 1 mm for each 2 mm decrease in irrigation and cropping season precipitation illustrating the difficulties that can arise in managing for a target residual PASW. These results suggest that producers should be scheduling irrigation with science-based methods, rather than habits and previous experiences.*

Keywords. *Corn, Field capacity, Soil moisture content, Soil water, Volumetric water content, Wheat.*

Water shortage is the primary factor limiting crop production in the USA's west-central Great Plains, and agricultural sustainability depends on efficient use of water resources. Precipitation is limited and sporadic with mean annual precipitation ranging from 400 to 500 mm across the region, which is only 60% to 80% of the seasonal water use for corn. Precipitation increases from west to east in the Great Plains and in Kansas the average increase is approximately 0.9 mm for each kilometer (Flora, 1948). Yields of dryland crops are limited and variable and some producers have used irrigation to mitigate these effects. Continued declines within the Ogallala Aquifer will result in a further shift from fully irrigated to deficit or limited irrigation strategies or even a return to dryland production in some areas. As this occurs, producers will desire to maintain crop production levels as great as possible while balancing crop production risks imposed by constraints on water available for production. Efficient utilization of plant available soil water (PASW) reserves is important for both dryland and irrigated summer crop production systems.

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In western Kansas, dryland grain sorghum yield was linearly related to PASW at emergence and sorghum yields increased 22.1 kg/ha for each additional mm of PASW (Stone and Schlegel, 2006). When the experimental effects of tillage were considered, grain sorghum yield response to water supply (PASW at planting plus cropping season precipitation) was greater with no-tillage than with conventional tillage (18.4 vs. 12.9 kg/ha-mm). Grain sorghum yield with conventional tillage at Bushland, Texas, increased 17.0 kg/ha-mm of PASW at planting (Jones and Hauser, 1974). Careful management of soil water can make a great difference in crop production. Annual cropping of summer crops and oilseed crops with wheat, instead of using an 11-month fallow period prior to drilling wheat reduced crop water productivity by 31% (Aiken et al., 2013). The water productivity slope above the dry matter threshold (i.e., the total crop water use value at which crop yield is first attained) for corn and grain sorghum in western Kansas have been reported as great as 41.6 and 30.1 kg/ha-mm, respectively (Stone et al., 2006). Evaporative demands increase from north to south (i.e., decreasing latitude) in the Great Plains and this can reduce overall yield response to water (Musick et al., 1994; Nielsen et al., 2002).

Preseason irrigation (also referred to as preplant, dormant-season, off-season, or winter irrigation) is a common practice in central and southern sections of the western Great Plains on the deep soils with large water-holding capacity that are prevalent. The residual soil water left in irrigated corn fields has a strong effect on the amount of preseason irrigation and precipitation that can be stored during the dormant period (Lamm and Rogers, 1985). Although preseason irrigation is common, research has shown it is often an inefficient water management practice (Stone et al., 1987, 1994; Lamm and Rogers 1985; Musick and Lamm, 1990). Measured water losses from borderline insufficient preseason irrigation capacities during the 30 to 45 day period prior to planting in a Texas study were extremely high, ranging from 45% to 70% (Bordovsky and Porter, 2003). While several reasons are given by producers for the use of preseason irrigation, Musick et al. (1971) stated its primary purpose is to replenish soil water stored in the plant root zone. From an analysis of soil water data from producer fields with silt loam soils near Colby, Kansas, Rogers and Lamm (1994) concluded that irrigation above the amount required to bring soil water to 50% PASW would have a high probability of being lost or wasted. They found in a three-year study (1989-1991) of 82 different fields that on average producers were leaving residual PASW in the top 1.5 m of the soil profile at 70% of the PASW associated with field capacity water content (FCASW). Since that time, groundwater levels have continued to decline and more irrigation systems have marginally insufficient capacity and as a result producer fields currently may be drier than in this previous period. When soil profiles are less than 50% of field capacity there may be advantages in applying some preseason irrigation (Stone and Gwin, 1982; Stone et al., 1994, 2008). Corn grain yields in west central Kansas increased an average of 1 Mg/ha for preseason irrigation amounts of 75 mm with a decreasing positive response as irrigation capacity increased from 2.5 to 5 mm/day (Schlegel et al., 2012). A slow late season depletion of the water in the soil profile might be advantageous in allowing more overwinter accumulation and less nutrient leaching but this strategy is difficult to successfully implement without crop yield suppression. In a comparison in northwest Kansas of three irrigation regimes (75%, 100%, or 125% of crop evapotranspiration minus rain replacement), small daily deficits after tasseling (1 or 2 mm/day) decreased corn grain yields and did not increase crop water productivity (Lamm et al., 1994).

Research is needed to both assess the current amounts of residual PASW producers are leaving in the field after irrigated corn harvest and how much PASW is replenished during the period before spring planting of the next corn crop. The research results can be used to develop better cropping recommendations for producers based on their geographical location within western Kansas when used with information about their anticipated summer precipitation. The primary objectives of this project were 1) to characterize the fall residual profile PASW after irrigated corn production and in the subsequent spring, and 2) to characterize the PASW in dryland wheat stubble following early summer harvest and prior to the next summer's crop in producer fields in three distinct regions of western Kansas [southwest (SW), west central (WC) and northwest (NW)].

PROCEDURES

A three year study was initiated in the fall of 2010 and concluded in the winter of 2012 on the deep silt loam soils of western Kansas. Fifteen commercial producer fields from each of the three regions (southwest, SW; west central, WC; and northwest, NW) were sought (i.e., voluntary non-compensated agreement with producers) for each crop residue type (dryland wheat and irrigated corn) for sampling of PASW. In general, five fields of each residue type were selected in each county (fig. 1, the three westernmost counties of each region). In a few cases, additional fields (generally 1 or 2) were selected when it was deemed useful in gaining a better geographical distribution. Another selection criterion for the irrigated corn fields was irrigation system capacity. Attempts were made to find one or two fields in each county with irrigation capacities equivalent to <25, 25 to 38, and >38 L/s for a 50 ha field. Strip-tillage was the predominate tillage practice employed in the irrigated corn fields following harvest, but there were a few producers performing no tillage between harvest and subsequent harvest. A very few producers may have performed conventional disk tillage in the spring prior to planting but subsequent to our spring soil water measurements. All the dryland producers were practicing chemical fallow (i.e., using herbicides to control weed growth rather than tillage) for the after wheat harvest period through the following spring up through our spring soil water measurements. It is likely they continued with no tillage prior to planting since the wheat residue is managed relatively well with modern row planters.

Although a broad geographical representation was a primary desire (fig. 1), an attempt was made to select producers using good management practices and for which realistic

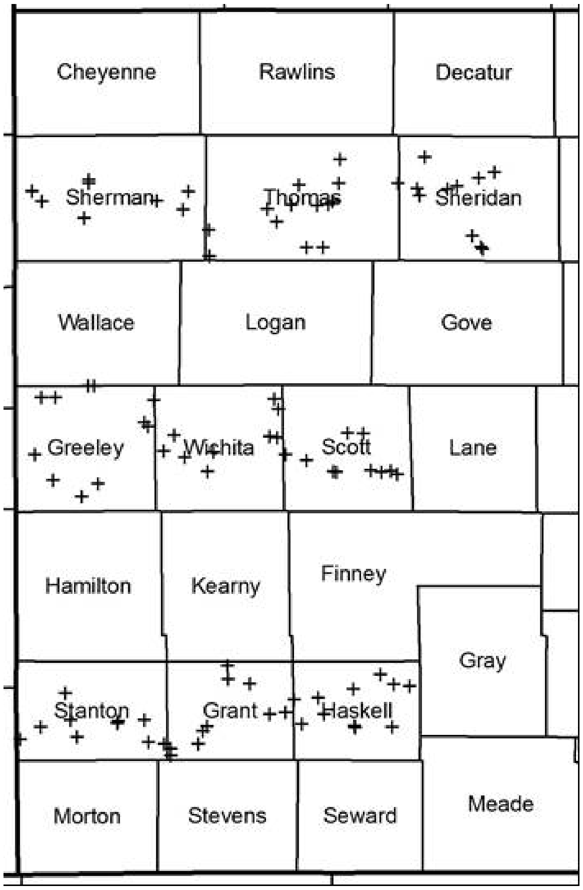

Figure 1. Example geographical distribution of soil water measurement location in producer fields for western Kansas in 2010. Each symbol represents a GPS-referenced producer field.

weather conditions could be obtained from public sources. Fields in NW Kansas were selected in Sheridan, Thomas, and Sherman counties (east to west counties). Fields in WC Kansas were selected in Scott, Wichita, and Greeley counties (east to west counties). There was increased difficulty finding producers with continuous (year-after-year) irrigated corn fields in WC Kansas, particularly in Wichita and Greeley Counties. The Ogallala aquifer in this region of Kansas is severely depleted, so producers appear to be using more crop rotation to better utilize residual soil water, thus maintaining crop productivity and conserving aquifer water for future years. Fields in SW Kansas were selected in Haskell, Grant, and Stanton counties (east to west counties). There were 96 total fields in the 2010 fall sampling and 91 fields in fall 2011. It was not possible to sample the same wheat residue fields in each year because there is little continuous annual cropping of wheat in this region of Kansas (i.e., typically a three-year rainfed rotation of wheat, summer crop, and fallow), so new fields were obtained each year. The dryland wheat field portion of the study was not conducted in the summer of 2012. There were 33 total irrigated corn fields sampled for soil water content in the fall of 2012. There were 31 irrigated corn fields that were sampled in both 2010 and 2011 and there were 21 fields that were made available for soil water sampling in all three years. The annual availability of previously-sampled continuous corn fields was negatively affected by persistent drought conditions during a large period of the study. For example, producers might choose to harvest the corn early as ensilage and then subsequently plant irrigated wheat for fall and spring livestock grazing.

GPS-referenced soil water access tubes (three per field) were installed in an equilateral triangular-shaped pattern (15 m sides) in a representative area of the field that also was easily accessible from nearby roads. Initial volumetric soil water content in 0.3 m increments to a depth of 2.4 m was determined by neutron attenuation techniques in the fields after installation of tubes and again in late spring prior to summer crop planting. The access tubes were removed from the fields prior to spring cropping. The same general sampling area (i.e., within 10 to 15 m) was selected for irrigated fields repeating in subsequent years. Published soil type and soil characteristics for the prevalent regional silt loam soils were used to estimate PASW in mm/2.4 m within the profile. These soils will hold approximately 440 mm of PASW in the 2.4 m profile at field capacity. The data from the three sampling points was examined for uniformity between readings and to remove any anomalies. A few tubes were lost due to damage by producer field operations between the fall and spring measurement periods. Less than 1% of the data was lost due to measurement anomalies or damaged tubes.

Annual irrigation amounts for the corn fields were obtained where possible from the Kansas Water Information Management and Analysis System (WIMAS, 2017). The reported water use values in this system are associated with a given parcel of land which in some cases was larger than the single field selected for the soil water sampling. In summarizing the irrigation amounts, the average amount for the whole parcel was used. However in some cases, data that appeared to be unrealistic and was excluded from analysis. It should be noted that this data set of annual values does not allow separation of in-season and dormant season irrigation amounts.

County-wide monthly precipitation for the period January 1981 through December 2015 was obtained from the PRISM dataset maintained by Oregon State University (Daly et al., 2008). These data were used to examine soil water trends between the sampling years (2010-2012) as affected by precipitation and to determine the long-term (1981-2015) mean monthly values of precipitation. In addition, cumulative May through September precipitation amounts were added to annual irrigation amounts for correlation with the resultant fall PASW for the irrigated corn fields.

Corn grain yield samples at physiological maturity were hand-harvested from a 6 m length of row near the irrigated field soil water sampling points in 2011 and 2012 to examine the corn yield correlation to fall PASW. Some samples were not obtained due to earlier harvest prior to the site visit. Corn yield results from fields exhibiting heavy insect damage (i.e., spider mites) and for fields with low plant density (i.e., those fields with less than 64,300 plants/ha with typical fields having plant densities greater than 75,000 plants/ha) were excluded from analysis. As a result there were 25 and 17 corn yield samples in 2011 and 2012, respectively.

Statistical separation of means was conducted with pooled two-sample t-tests using Microsoft Excel (Redmond, Wash.) and linear regression in Microsoft Excel was used to determine functional relationships.

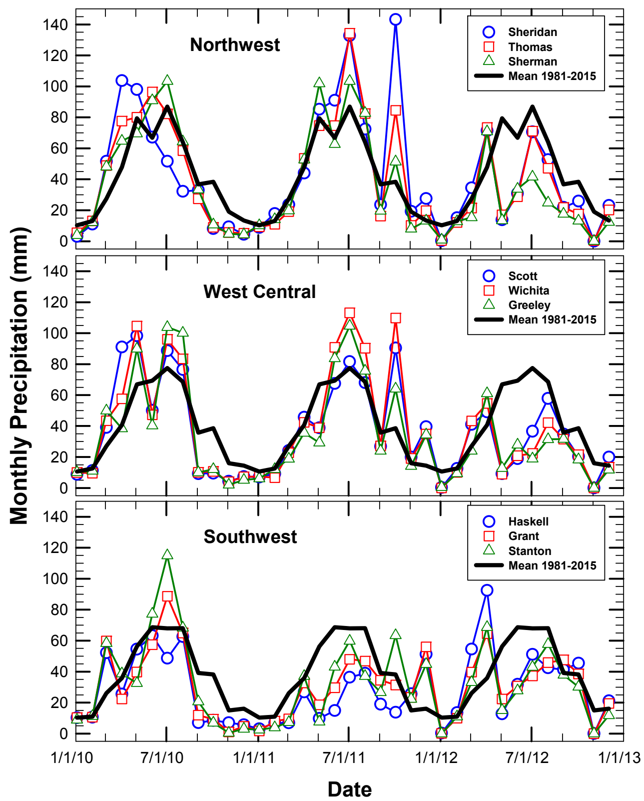

Figure 2. Monthly precipitation for the nine counties in the three western Kansas regions for 2010-2012 and the long term (1981-2015) mean monthly precipitation.

Results and Discussion

Precipitation Conditions

Weather conditions in nearly all of western Kansas were excessively dry from early August 2010 through mid-April 2011 (fig. 2). The western portion of WC and NW Kansas began to get more normal precipitation in late April 2011 and ended the cropping season with normal amounts of precipitation or greater. However, SW Kansas remained under severe drought conditions through the summer and much of the fall of 2011. For example, Grant County received less than 30% of normal annual precipitation for the period 1 September 2010 through 1 September 2011. In SW Kansas in 2011, dryland summer crops resulted in almost total failure and even many irrigated crops were severely stressed. The western edge of WC Kansas (Greeley County) and nearly all of NW Kansas experienced near- to above-normal precipitation for most of the 2011 summer period. A particularly wet multi-day weather period in early October 2011 tracked across some counties in WC Kansas and the eastern half of NW Kansas with those areas receiving between 50 and 100 mm of precipitation. Because of the multi-day nature of this precipitation, much of the water infiltrated into the soil profile. Precipitation amounts ranging from 49 to 93 mm occurred in April 2012 in the selected counties and this lessened the drought conditions temporarily and improved the potential for summer crop germination and establishment. However, the summer and fall periods of 2012 were generally excessively dry and even irrigated crop yields were negatively affected. The extended drought resulted in some producers performing some dormant season irrigation which may have increased some of the residual fall PASW values and may have further affected the spring PASW values. For this reason and the lack of field-to-field specificity for precipitation due to only having county-wide average precipitation, overwinter precipitation storage efficiency will not be reported here.

Soil Water as Affected by Location and Residue Type

In general, sprinkler irrigated corn fields had greater PASW than the dryland wheat fields (tables 1-4) as would be anticipated. Additionally, it should be noted that in some cases, some fall dormant season irrigation (all three falls) had been practiced prior to the soil water measurements to facilitate easier strip tillage operations. However, generally these amounts prior to strip tillage were between 25 and 40 mm.

Fall 2010 Results

Soil water was measured in the dryland wheat and irrigated corn fields between October and 30 December as producer preferences, weather conditions, and work schedules allowed. Some changes in soil water storage may have occurred between harvest and soil water measurement depending on weather conditions, particularly for the wheat fields since harvest was most likely in early July when precipitation amounts are greater than in the fall months (fig. 2). In 2010, NW Kansas had slightly more PASW (188 mm/2.4 m) in wheat fields (table 1) than in the other two regions (WC, 138 mm/2.4 m and SW, 167 mm/2.4 m, respectively). The coefficient of variation (CV) of PASW in wheat fields was least in NW Kansas and greatest in SW Kansas, probably reflecting the higher evaporative demand and worse drought conditions affecting SW Kansas.

The irrigated corn fields residual PASW averaged 160% that of the dryland wheat fields which was statistically significant at $P<0.0001$ (table 1) and also had less variability (CV of 0.31 and 0.48 for corn and wheat, respectively). The average PASW in irrigated corn fields for the three regions varied by only 21 mm (range of 254 mm in NW to 275 mm/2.4 m in SW) and with an average value of 262 mm/2.4 m that would approximate a profile at 60% of FCASW, which would suggest overall adequate irrigation management. However, there was a large amount of field to field variation. The greatest measured PASW for the irrigated corn fields of the three regions averaged 416 mm/2.4 m which would be very wet unless there was considerable late season precipitation or fall dormant season irrigation before sampling. At the other end of the spectrum, the lowest measured average PASW of the three regions was approximately 109 mm/2.4 m, which would be only about 25% of FCASW.

Spring 2011 Results

There was on average slight losses or very small accumulations in the dryland wheat residue fields by late spring 2011 (table 2), with the exception of NW Kansas which saw

Table 1. Plant available soil water (mm/2.4 m) in producer fields in western Kansas in fall 2010 (30 October-30 December sampling period).

Residue Type	County and No. of Fields	Average	Greatest	Least	CV[a]
Northwest Kansas, Sheridan, Thomas, and Sherman Counties					
Dryland Wheat	Sheridan (5)	194	290	114	0.33
	Thomas (7)	218	281	156	0.19
	Sherman (5)	139	210	98	0.31
	All 3 Ctys (17)	188	290	98	0.30
Irrigated Corn	Sheridan (5)	267	282	218	0.06
	Thomas (7)	274	395	172	0.22
	Sherman (5)	212	296	167	0.24
	All 3 Ctys (17)	254	395	167	0.24
Irrigated to Dryland Ratio	Sheridan	1.37	0.97	1.91	0.19
	Thomas	1.26	1.40	1.10	1.12
	Sherman	1.52	1.41	1.70	0.77
	All 3 Ctys	1.35	1.36	1.70	0.79
West Central Kansas, Scott, Wichita, and Greeley Counties					
Dryland Wheat	Scott (5)	130	228	63	0.50
	Wichita (6)	130	236	77	0.48
	Greeley (5)	156	281	53	0.53
	All 3 Ctys (16)	138	281	53	0.48
Irrigated Corn	Scott (5)	304	421	208	0.27
	Wichita (5)	236	299	166	0.20
	Greeley (5)	223	270	101	0.32
	All 3 Ctys (15)	255	421	101	0.29
Irrigated to Dryland Ratio	Scott	2.34	1.85	3.31	0.54
	Wichita	1.83	1.27	2.16	0.42
	Greeley	1.43	0.96	1.91	0.60
	All 3 Ctys	1.85	1.50	1.91	0.60
Southwest Kansas, Haskell, Grant, and Stanton Counties					
Dryland Wheat	Haskell (5)	137	259	38	0.72
	Grant (5)	87	154	43	0.50
	Stanton (5)	276	366	188	0.29
	All 3 Ctys (15)	167	366	38	0.66
Irrigated Corn	Haskell (6)	249	433	60	0.61
	Grant (5)	230	352	160	0.37
	Stanton (5)	351	424	292	0.14
	All 3 Ctys (16)	275	433	60	0.41
Irrigated to Dryland Ratio	Haskell	1.82	1.67	1.58	0.84
	Grant	2.64	2.28	3.69	0.74
	Stanton	1.27	1.16	1.56	0.47
	All 3 Ctys	1.65	1.18	1.58	0.62

[a] Coefficient of variation is defined as the standard deviation of PASW divided by the mean PASW.

Table 2. Plant available soil water (mm/2.4 m) in producer fields in western Kansas in spring 2011 (15 March-27 May sampling period).

Residue Type	County and No. of Fields	Average	Greatest	Least	CV[a]
Northwest Kansas, Sheridan, Thomas, and Sherman Counties					
Dryland Wheat	Sheridan (5)	245	319	198	0.19
	Thomas (7)	246	291	186	0.13
	Sherman (4)	223	274	180	0.20
	All 3 Ctys (16)	240	319	180	0.16
Irrigated Corn	Sheridan (5)	285	309	271	0.05
	Thomas (7)	280	399	209	0.22
	Sherman (5)	222	301	162	0.24
	All 3 Ctys (17)	264	399	162	0.21
Irrigated to Dryland Ratio	Sheridan	1.16	0.97	1.37	0.26
	Thomas	1.14	1.37	1.12	1.69
	Sherman	1.00	1.10	0.90	1.21
	All 3 Ctys	1.10	1.25	0.90	1.28
West Central Kansas, Scott, Wichita, and Greeley Counties					
Dryland Wheat	Scott (5)	159	277	95	0.46
	Wichita (5)	129	183	92	0.30
	Greeley (5)	164	289	62	0.50
	All 3 Ctys (16)	150	289	62	0.43
Irrigated Corn	Scott (5)	369	510	246	0.27
	Wichita (5)	282	352	191	0.23
	Greeley (5)	269	345	114	0.34
	All 3 Ctys (15)	307	510	114	0.30
Irrigated to Dryland Ratio	Scott	2.32	1.84	2.59	0.58
	Wichita	2.20	1.92	2.07	0.78
	Greeley	1.65	1.20	1.84	0.67
	All 3 Ctys	2.04	1.77	1.84	0.70
Southwest Kansas, Haskell, Grant, and Stanton Counties					
Dryland Wheat	Haskell (5)	159	280	53	0.64
	Grant (5)	102	176	58	0.45
	Stanton (5)	223	303	134	0.34
	All 3 Ctys (15)	161	303	53	0.54
Irrigated Corn	Haskell (5)	307	474	145	0.43
	Grant (5)	292	400	179	0.30
	Stanton (5)	346	410	260	0.18
	All 3 Ctys (15)	315	474	145	0.31
Irrigated to Dryland Ratio	Haskell	1.94	1.69	2.73	0.67
	Grant	2.86	2.28	3.10	0.67
	Stanton	1.56	1.35	1.94	0.53
	All 3 Ctys	1.95	1.56	2.73	0.56

[a] Coefficient of variation is defined as the standard deviation of PASW divided by the mean PASW.

an average increase of 52 mm of PASW in the soil profile. This reflects some appreciable late April 2011 precipitation events in NW Kansas that the other regions had missed or had lesser amounts (fig. 2).

In contrast, NW Kansas had only minimal increase in PASW in the irrigated corn fields while PASW in the WC and SW Kansas fields increased approximately 45 mm/ 2.4 m (table 2). This reflects that many of the WC and SW Kansas fields had received additional dormant season irrigation to better cope with the drought before spring planting. The greatest measured PASW for the sprinkler-irrigated corn fields averaged 399, 510, and 474 mm/2.4 m for NW, WC, and SW Kansas, respectively. These values in WC and SW Kansas would be considered extremely wet (i.e., both values were above the field capacity water content) and would be subject to considerable losses from deep percolation. Close examination of the individual field data revealed that these high PASW values in spring 2011 also were very wet on the same fields in fall 2010 (data not shown), suggesting that these irrigators should cut back on late and/or dormant season irrigation. In contrast, the lowest values of PASW in spring 2011 on the producer fields averaged only 140 mm in the 2.4 m profile (approximately 30% of the FCASW). These producers with such low values of PASW might have greatly benefited had they used more dormant season irrigation, particularly prior to dry summers.

The irrigated corn fields had approximately 160% of the PASW of wheat fields which was statistically significant at $P<0.0001$, somewhat similar to the results from fall 2010, and again with less variability in PASW.

Fall 2011 Results

Fall soil water measurements were conducted between 30 September and 12 December. In fall 2011, because of the continuing drought in SW Kansas, it was anticipated that producer fields would be much drier than in 2010 (tables 3 and 1, respectively). Although this turned out to be true for SW Kansas for dryland wheat fields (42 mm/2.4 m drier), overall the irrigated corn fields were wetter (approximately 11% greater PASW) in 2011, with only SW Kansas having slightly drier irrigated fields in fall 2011 (approximately 6% lower PASW). The wetter summer period in portions of WC Kansas (Greeley County) and NW Kansas no doubt had some effects on the amounts of residual PASW. The October 2011 multi-day wet period resulted in some very wet wheat residue fields in Sheridan County in northwest Kansas (table 3). The irrigated corn fields were significantly wetter than the wheat fields (P<0.0001) having approximately 150% of the PASW of the wheat fields, similar to the results from the fall of 2010 and again with less variability in PASW.

Spring 2012 Results

Spring 2012 soil water measurements were conducted between 29 February and 8 May. The improvement in spring precipitation in 2012 as compared with 2011 resulted in an average fall 2011 to spring 2012 PASW increase in the dryland wheat fields of 48 mm/2.4 m profile across the three regions with the SW region having an average increase of 73 mm (table 4).

Table 3. Plant available soil water (mm/2.4 m) in producer fields in western Kansas in fall 2011 (30 September-12 December sampling period).

Residue Type	County and No. of Fields	Average	Greatest	Least	CV[a]
Northwest Kansas, Sheridan, Thomas, and Sherman Counties					
Dryland Wheat	Sheridan (5)	354	452	179	0.29
	Thomas (5)	181	232	157	0.16
	Sherman (5)	174	221	96	0.31
	All 3 Ctys (15)	236	452	96	0.46
Irrigated Corn	Sheridan (6)	350	396	265	0.14
	Thomas (5	332	428	227	0.22
	Sherman (5)	211	297	151	0.28
	All 3 Ctys (16)	301	428	151	0.28
Irrigated to Dry-land Ratio	Sheridan	0.99	0.88	1.49	0.49
	Thomas	1.84	1.84	1.44	1.32
	Sherman	1.21	1.34	1.58	0.89
	All 3 Ctys	1.27	0.95	1.58	0.61
West Central Kansas, Scott, Wichita, and Greeley Counties					
Dryland Wheat	Scott (5)	205	278	138	0.25
	Wichita (5)	212	255	164	0.20
	Greeley (5)	218	273	168	0.18
	All 3 Ctys (15)	212	278	138	0.20
Irrigated Corn	Scott (5)	330	453	248	0.23
	Wichita (5)	320	361	273	0.11
	Greeley (5)	298	311	279	0.04
	All 3 Ctys (15)	316	453	248	0.16
Irrigated to Dryland Ratio	Scott	1.61	1.63	1.79	0.90
	Wichita	1.50	1.41	1.66	0.57
	Greeley	1.37	1.14	1.66	0.22
	All 3 Ctys	1.49	1.63	1.79	0.80
Southwest Kansas, Haskell, Grant, and Stanton Counties					
Dryland Wheat	Haskell (5)	152	262	69	0.46
	Grant (5)	83	171	4	0.90
	Stanton (5)	141	207	118	0.26
	All 3 Ctys (15)	125	262	4	0.52
Irrigated Corn	Haskell (5)	264	396	75	0.59
	Grant (5)	223	419	80	0.66
	Stanton (5)	282	363	220	0.20
	All 3 Ctys (15)	258	419	75	0.46
Irrigated to Dryland Ratio	Haskell	1.74	1.51	1.08	1.30
	Grant	2.69	2.45	19.02	0.74
	Stanton	2.00	1.75	1.87	0.76
	All 3 Ctys	2.06	1.60	17.84	0.88

[a] Coefficient of variation is defined as the standard deviation of PASW divided by the mean PASW.

Table 4. Plant available soil water (mm/2.4 m) in producer fields in western Kansas in spring 2012 (29 February-8 May sampling period).

Residue Type	County and No. of Fields	Average	Greatest	Least	CV[a]
Northwest Kansas, Sheridan, Thomas, and Sherman Counties					
Dryland Wheat	Sheridan (5)	356	477	125	0.32
	Thomas (5)	211	304	166	0.19
	Sherman (5)	202	346	90	0.33
	All 3 Ctys (15)	254	477	90	0.41
Irrigated Corn	Sheridan (6)	368	433	268	0.13
	Thomas (6)	356	478	248	0.18
	Sherman (5)	245	314	163	0.17
	All 3 Ctys (17)	326	478	163	0.23
Irrigated to Dryland Ratio	Sheridan	1.03	0.91	2.14	0.41
	Thomas	1.69	1.57	1.49	0.95
	Sherman	1.21	0.91	1.81	0.52
	All 3 Ctys	1.28	1.00	1.81	0.56
West Central Kansas, Scott, Wichita, and Greeley Counties					
Dryland Wheat	Scott (5)	277	377	166	0.26
	Wichita (5)	257	404	144	0.29
	Greeley (5)	262	320	156	0.17
	All 3 Ctys (15)	265	404	144	0.24
Irrigated Corn	Scott (6)	399	526	244	0.18
	Wichita (4)	391	475	350	0.10
	Greeley (5)	342	372	284	0.07
	All 3 Ctys (15)	377	526	244	0.15
Irrigated to Dryland Ratio	Scott	1.44	1.40	1.47	0.69
	Wichita	1.52	1.17	2.43	0.34
	Greeley	1.30	1.16	1.82	0.41
	All 3 Ctys	1.42	1.30	1.69	0.63
Southwest Kansas, Haskell, Grant, and Stanton Counties					
Dryland Wheat	Haskell (5)	223	378	119	0.33
	Grant (5)	132	216	65	0.47
	Stanton (5)	226	328	145	0.28
	All 3 Ctys (15)	198	378	65	0.39
Irrigated Corn	Haskell (5)	391	523	214	0.30
	Grant (5)	332	521	217	0.35
	Stanton (6)	363	492	235	0.18
	All 3 Ctys (16)	362	523	214	0.28
Irrigated to Dryland Ratio	Haskell	1.76	1.38	1.79	0.91
	Grant	2.52	2.41	3.36	0.74
	Stanton	1.61	1.50	1.62	0.64
	All 3 Ctys	1.83	1.38	3.31	0.72

[a] Coefficient of variation is defined as the standard deviation of PASW divided by the mean PASW.

Overwinter PASW profile increases in the irrigated corn fields averaged 63 mm across the three regions with the resulting PASW averaging 355 mm/2.4 m in the spring, which would be approximately 80% of FCASW. Profile PASW values were greater in WC and SW as compared with the NW region (table 4), probably reflecting both greater spring precipitation (fig. 2) and prevalence of more dormant season irrigation due to the drought conditions of 2011. The greatest PASW for the sprinkler irrigated corn fields averaged 478, 526, and 523 mm/2.4 m for NW, WC and SW Kansas, respectively, which indicate soil water contents greater than field capacity and the likelihood of considerable deep percolation. In contrast, the lowest values of PASW in spring 2012 on the producer fields averaged 207 mm in the 2.4 m profile (approximately 47% of FCASW) and were 47% greater PASW than spring 2011.

The irrigated corn fields were significantly wetter ($P<0.0001$) having approximately 150% of the PASW of the wheat fields, slightly less than the results from spring 2011 and again with less variability in PASW.

Fall 2012 Results

Fall 2012 soil water measurements were conducted 19-26 October. Despite the widespread severe drought in 2012 in all of western Kansas, residual PASW in the 2.4 m profile still averaged 275 mm (table 5) or approximately 62% of FCASW for the irrigated corn fields. The wettest profiles were located in the SW region which received greater than normal precipitation in late-summer and early fall (fig. 2) near the time of the fall soil water sampling (19-26 October). Fall 2012 soil water profiles across the three regions averaged 275 mm/2.4 m of PASW, 22% drier ($P<0.0001$) than the spring 2012 profiles probably reflecting the prevalent inability of marginally insufficient irrigation system capacities to match the evaporative demands of the severe drought. In contrast, fall 2011 PASW and spring 2011 PASW values were not significantly different ($P<0.05$) and were nearly equal at approximately 295 mm/2.4 m.

Table 5. Plant available soil water (mm/2.4 m) in producer irrigated corn fields in western Kansas in fall 2012 (19-26 October sampling period).

Residue Type	County and Number of Fields	Average	Greatest	Least	CV[a]
Northwest Kansas, Sheridan, Thomas, and Sherman Counties					
Irrigated Corn	Sheridan (6)	281	418	187	0.33
	Thomas (6)	261	421	182	0.33
	Sherman (3)	206	304	112	0.47
	All 3 Ctys (15)	258	421	112	0.34
West Central Kansas, Scott, Wichita, and Greeley Counties					
Irrigated Corn	Scott (3)	319	408	255	0.25
	Wichita (3)	259	275	241	0.07
	Greeley (3)	201	276	151	0.33
	All 3 Ctys (9)	260	408	151	0.28
Southwest Kansas, Haskell, Grant, and Stanton Counties					
Irrigated Corn	Haskell (4)	313	494	130	0.54
	Grant (3)	332	485	131	0.55
	Stanton (2)	262	316	209	0.29
	All 3 Ctys (9)	308	494	130	0.46

[a] Coefficient of variation is defined as the standard deviation of PASW divided by the mean PASW.

Annual Differences in Corn Residual PASW

Although record or near-record drought conditions existed in southwest Kansas for the entire period from the middle of summer 2010 through fall 2011 and for all of western Kansas in 2012, there were only minimal annual differences in fall irrigated corn PASW for the 21 individual fields that were available for sampling in all three years (fig. 3). The slope of the lines in figure 3 are not significantly different from unity, nor is the intercept significantly different from zero ($P<0.05$) Overall, 2012 averaged less than 25 mm greater PASW than 2010, and 2011 averaged approximately 50 mm greater PASW than 2010. It appears there was considerable stability in an individual producer's response (irrigation management and irrigation system capacity) to changing weather conditions as evidenced by the similar year-to-year values. Part of the rationale might be that drought conditions existed for much of the total period (fall 2010 through fall 2012). However, the irrigated corn residual soil water was still relatively high on the average for SW Kansas (approximately 62% of FCASW). So, the presence of drought may not be a good indicator of the amounts of residual soil water left after irrigated corn harvest. Sometimes, crop yield reductions are caused by system capacity (L/s-ha) at the critical stages, rather than what total irrigation amount can be applied during the season. Insect damage, such as from spider mites, is exacerbated by high canopy temperatures and drought. Producers recognizing the drought and anticipating crop damage may have continued irrigating hoping to mitigate further crop damage and this sometimes increases profile PASW as the damaged crop is no longer transpiring typical amounts of water. One caveat, in some cases the PASW results are probably reflecting the effects of some fall dormant season irrigation that occurred before the PASW sampling. However, in most cases the fall irrigation amounts were not large.

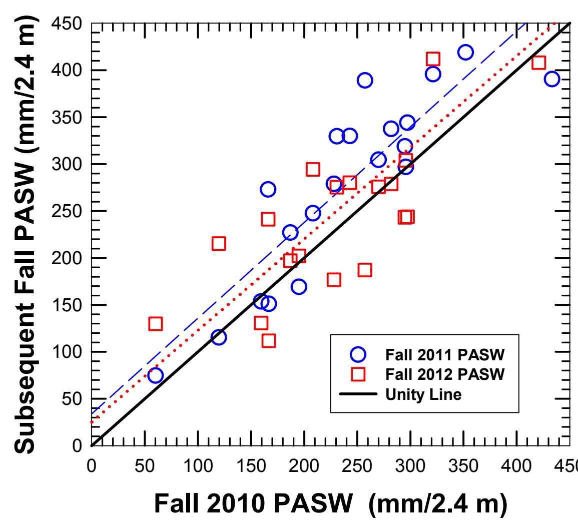

Figure 3. Similarity of fall residual plant available soil water (PASW) in the 2.4 mm soil profile in irrigated corn fields after harvest for the years 2010, 2011, and 2012 in western Kansas producer fields. These data represent 21 fields that producers made available for PASW measurements in all three years of the study. The solid line is the unity line, the dashed line is the Fall 2011 data and the dotted line is the Fall 2012 data.

Effect of Regional Characteristics on Corn Residual PASW

Although intuition might suggest that less saturated thickness of the Ogallala and more marginally insufficient irrigation system capacities (L/s-ha) would result in less average residual PASW and lower PASW values in the irrigated corn fields of WC Kansas, there was no strong evidence from the data of 2010 through 2012 that would support that theory (fig. 4). This might be because producers with lower capacity irrigation systems have adjusted to their limitation by using longer pumping periods. Their goal, by pumping later into the crop season, would be to minimize crop yield loss, but sometimes those later irrigation events also increase residual PASW. There was greater variation in PASW values in SW Kansas (i.e., fig. 4 CV values) as compared with the other two regions probably reflecting greater evaporative demand to some extent and also more variation in producer irrigation management.

Effect of Field Type on Overwinter Change in PASW

Overwinter accumulation or loss of PASW could be affected by precipitation, initial PASW, residue type, and any applied dormant season irrigation, so the following results are being discussed in terms of field type, rather than just crop residue type.

During the overwinter period 2010 through 2011, corn fields on average accumulated approximately 50 mm of soil water overwinter when the fall PASW was very low and less than 25 mm of accumulation when the fall PASW was high (fig. 5). The slope of the corn data line was not significantly different from unity (P<0.05). In contrast, the wheat fields accumulated only about 40 mm of soil water overwinter when the fall 2010 PASW was very low and tended to lose approximately 40 mm of PASW when fall 2010 PASW was higher (fig. 5). Additionally, the slope of the wheat line was significantly different from unity (P<0.05). These small differences are probably due to dormant season irrigation slightly increasing PASW in the corn fields while the drought conditions were not favorable for much overwinter accumulation in the dryland wheat fields. Overwinter accumulation of PASW was greater for the fall 2011 through spring 2012 period for both field types (fig. 6) and the slopes of both the wheat and corn data lines were significantly different from unity (P<0.05). Normal to wetter than average April conditions in the region (fig. 2) contributed to increased spring 2012 PASW for many of the fields. In addition, many irrigated producers had practiced some dormant season irrigation due to the persistent, continuing drought.

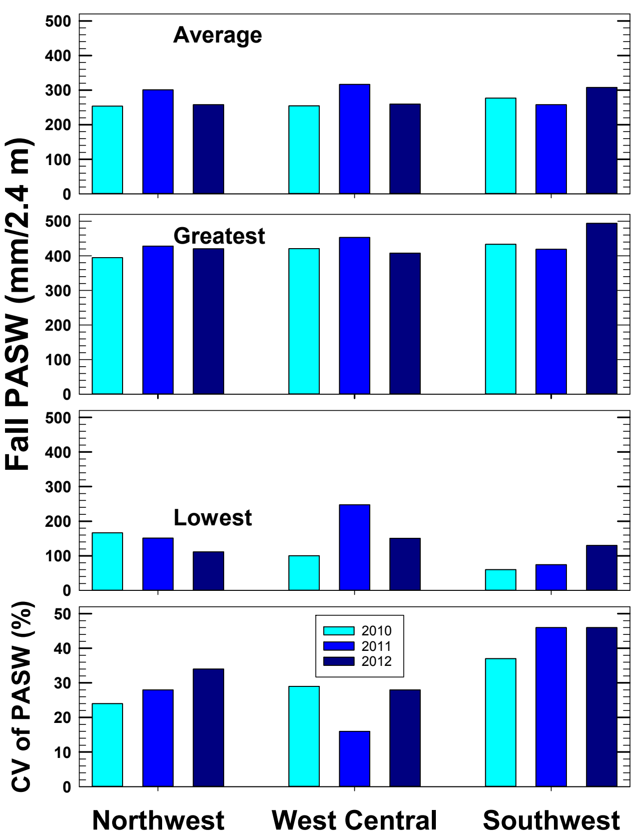

Figure 4. Effect of western Kansas region on average, greatest, lowest, and coefficient of variation of measured plant available soil water (PASW) in the 2.4 m soil profile in irrigated corn fields after harvest for the fall periods in 2010-2012.

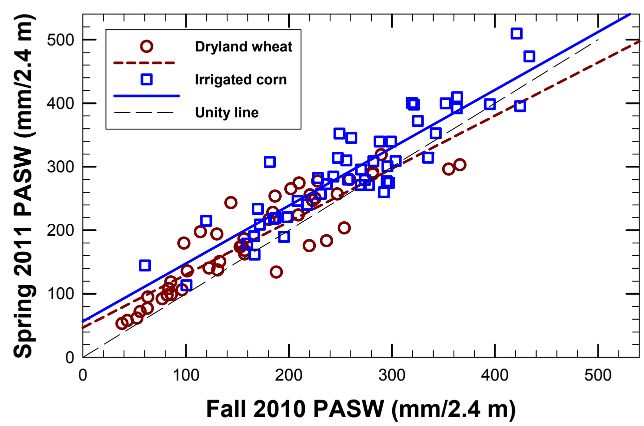

Figure 5. Effect of field type (dryland wheat or irrigated corn) on accumulation of plant available soil water (PASW) in the 2.4 m soil profile for the period fall 2010-spring 2011 for producer fields in western Kansas.

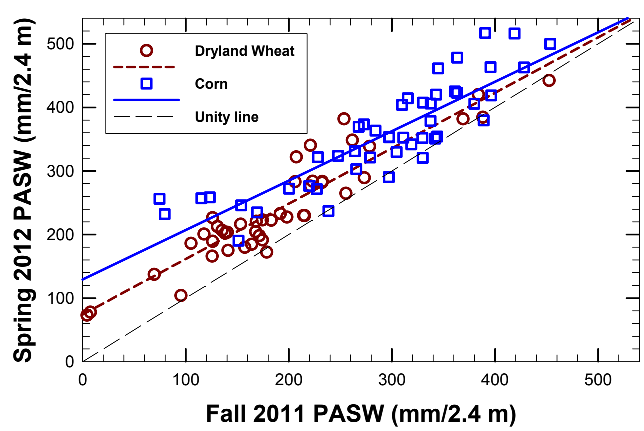

Figure 6. Effect of field type (dryland wheat or irrigated corn) on accumulation of plant available soil water (PASW) in the 2.4 m soil profile for the period fall 2011 through spring 2012 for producer fields in western Kansas.

Irrigated corn and dryland wheat fields had 130 and 80 mm/2.4 m greater spring PASW when soil profiles were very dry in the fall. However when fall soil profiles were on the wetter range (i.e., >400 mm/2.4 m), overwinter PASW accumulation for both field types was approximately 20 mm/2.4 m. Less overwinter PASW accumulation when soil profiles are wetter is consistent with the soil water recharge model of Lamm and Rogers (1985).

Effect of System Capacity on Fall PASW in Irrigated Corn Fields

There was very little correlation of residual PASW with irrigation system capacity (fig. 7) despite the hypothesis that lower capacities would result in drier fall soil profiles. In two years (2011 and 2012), the greatest capacity (> 0.76 L/s-ha) had slightly greater average PASW (difference <35 mm/2.4 m) while in 2010 the greatest capacity was 22 mm/2.4 m drier than the lowest capacity (<0.5 L/s-ha). The rationale for these results is probably similar to the rationale for results from west central Kansas where low saturated thickness did not have a large effect on PASW relative to the other regions. In both cases, producers may have increased the length of the irrigation season in attempting to mitigate irrigation deficiencies and ended up with similar PASW to the systems where irrigation was less restrictive. There tended to be less variability for the lower capacity systems and this probably just reflects less variance in producer management when capacity is low.

Relationship of Corn Grain Yield to Fall PASW

Corn grain yield was somewhat correlated (R^2 = 0.40 and Standard Error = 2 Mg/ha) with the fall PASW, increasing sharply up until about 200 mm and nearing a plateau at about 250 mm. Although a fall PASW of 250 mm corresponds to a water storage value approximately 56% of field capacity, which is greater than most current extension publication recommendations (Rogers and Sothers, 1996; Yonts et al., 2008) for an after harvest residual PASW of around 40%, this greater value corresponds well with results from Lamm and Aboukheira (2012) who found corn yields beginning to decrease at PASW values corresponding to less than 55% of field capacity. Corn yields varied greatly across a wide range of fall PASW values suggesting that irrigation scheduling for good crop yields, while targeting a lower residual fall PASW, in practice has not been easy for irrigators to achieve.

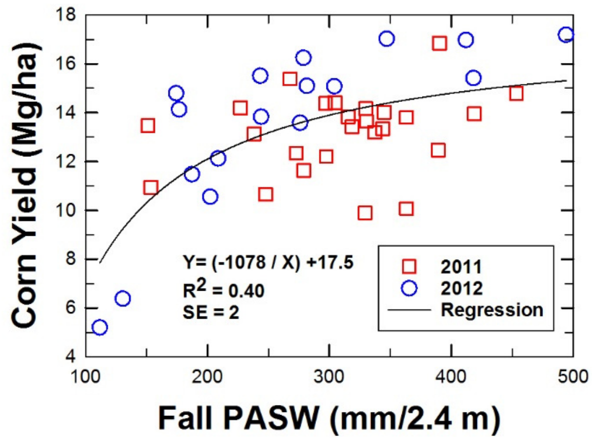

Figure 8. Relationship of corn grain yield to residual plant available soil water (PASW) in the 2.4 m soil profile for 2011 and 2012 for producer fields in western Kansas.

Effect of Cumulative Irrigation and Crop Season Precipitation on Fall PASW in Irrigated Corn Fields

The residual fall PASW was reasonably well correlated (R^2 = 0.54 and Standard Error = 62) with the total of May through September precipitation and applied irrigation (fig. 9). The slope of relationship was 0.49 which means that to decrease fall PASW by one mm it was necessary to decrease seasonal precipitation and irrigation by over two mm. In an earlier research study in western Kansas, Lamm et al. (1994) found that to reduce fall PASW by one unit, irrigation had to be reduced four units. This further emphasizes that targeted management of fall PASW is not easily achieved.

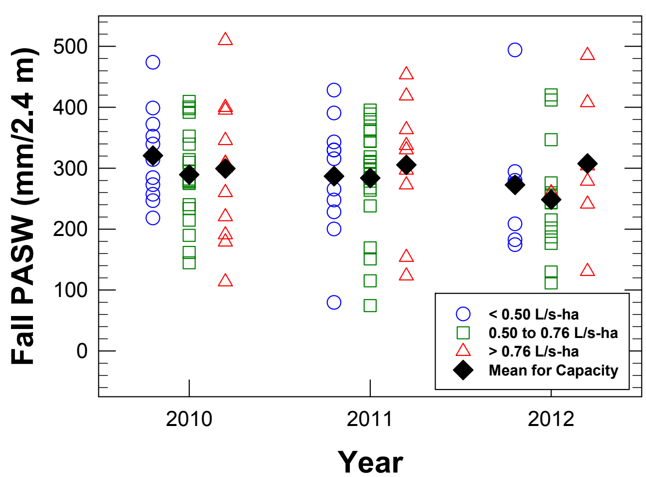

Figure 7. Effect of irrigation system capacity (flow rate/area) on residual plant available soil water (PASW) in the 2.4 m soil profile for the period fall 2011-spring 2012 for producer fields in western Kansas.

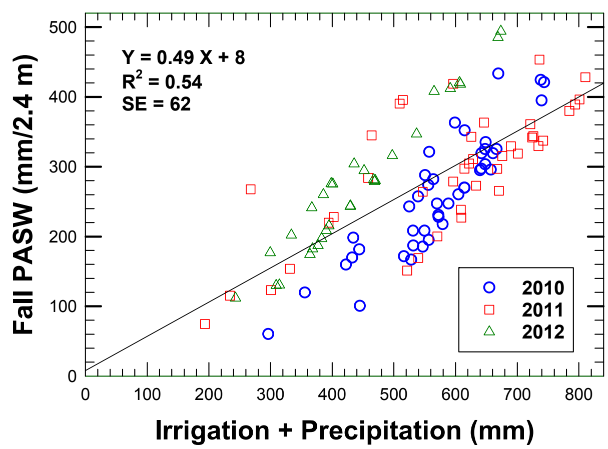

Figure 9. Effect of cumulative irrigation and precipitation amount on residual plant available soil water (PASW) in the 2.4 m soil profile for 2010-2012 for producer fields in western Kansas.

CONCLUSIONS

These results suggest a few very important aspects for irrigated crop production in western Kansas and the central Great Plains. Irrigation not only increases the water available for crop production, but also reduces the variability in profile available soil water in the field. An average residual available soil water value may not be indicative of an individual field, so it is wise for producers to check each field prior to the next crop year to plan water use strategies for that year. Each year is different, so irrigating to average conditions is risky and will likely be less profitable. Science-based irrigation scheduling (i.e., irrigation decisions based on weather, soil, or plant measurements) should be able to help producers better manage water resources in-season and between seasons. There was considerable stability in annual values of residual soil water in western Kansas corn fields with relatively little effect of weather differences and irrigation system capacity. Considerable amounts of residual soil water are left in producers' fields annually reducing the need for dormant season irrigation to replenish the soil profile.

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