ANALYSIS OF PRECIPITATION, STORM RUNOFF, AND SOIL LOSS IN DRYLAND FIELDS WITH CONSERVATION TILLAGE

by

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ABSTRACT

Conservation of storm precipitation and mitigation of storm runoff and soil loss are important for successful dryland production in the semi-arid Southern High Plains. Precipitation, runoff, and soil loss data was evaluated from six paired No-Till (NT) and Stubble-Mulch (SM) tillage fields maintaining a Wheat-Sorghum-Fallow (W-S-F) rotation at the USDA-ARS Conservation and Production Research Laboratory in Bushland, Texas. Our purpose was to evaluate data collected from 1984-2010 to explain why similar storms and field conditions produce variable runoff and soil loss amounts. Storm and field management factors of precipitation, tillage, and crop phase were analyzed to understand runoff and soil loss variation. Data was categorized by year, precipitation depth, field, and crop rotation phase to determine trends of precipitation, runoff and soil loss events. Parametric and non-parametric comparisons of means and medians were used to identify differences in datasets with comparable field conditions. Simple linear regression was used to correlate precipitation with runoff amounts. Multiple linear regression methods were used to correlate precipitation and runoff with soil loss amounts. Storms with depths in the 76.3-101.6 mm range caused the greatest variations in runoff and soil loss measurements. Twenty-seven year means and totals followed trends of increased precipitation in the summer months, increased runoff with No-Till management and increased soil loss with Stubble-Mulch. Fallow periods were shown to have increased runoff and soil loss with wheat residues providing better protection from storm precipitation than sorghum residues.

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CHAPTER I. INTRODUCTION

SEMI-ARID CROP PRODUCTION

The Southern High Plains (SHP) of the United States, termed Major Land Resource Area 77 by the United States Department of Agriculture National Resource Conservation Service (USDA-NRCS), is a physiological and geographic region which extends from the Panhandle of Northwest Texas to the Southern border of South Dakota (Baumhardt et al., 2017; Jones et al., 1985). The SHP region is characterized by a semi-arid climate and gently sloping topography containing 5.7 million hectares (ha) of rangeland and 6.5 million ha of cropland (Jones et al., 1995; Jones et al., 1985). Sparse or erratic rainfall patterns create precipitation constraints for intensive crop agriculture. In the Northern Texas panhandle, total annual precipitation from 1939 to 1997 averaged 475 millimeters (mm) and varied from a high of 828 mm in 1941 to a low of 240 mm in 1970 (Unger and Baumhardt, 1999). In Bushland, Texas, annual April through September pan evaporation measured 1270 mm, but annual precipitation accounts for only 25-30% of potential evaporation (Baumhardt and Brauer, 2018; Jones et al., 1994; Thappa et al., 2018). Baumhardt et al. (2017) reported 63% of annual rainfall in Bushland, TX occurred during the June to October growing season. Furthermore, greater than 130 mm of the total 285 mm of precipitation during the October to June winter wheat growing season occurred during May and June (Baumhardt et al., 2017).

The Ogallala Aquifer underlies 27% of all United States (U.S.) agricultural land within eight Great Plains states (Baumhardt et al., 2009). Crop irrigation accounts for 95% of total withdraws from the Ogallala, equating to 30% of all crop irrigation in the United States (Baumhardt et al., 2017; Baumhardt et al., 2013; Ouapo et al., 2014). Spatially weighted water table declines of 10.5 meters (m) and negligible recharge rates have reduced well yields and increased pumping cost for SHP producers, creating the need for conservation management practices (Baumhardt et al., 2013; Baumhardt et al., 2009; Stone and Schlegel, 2006). Since the 1990's, dryland crop production has expanded to encompass 45% of all crop value in the United States, allowing greater conservation of irrigation water for municipal and commercial demands (Baumhardt et al., 2016). However, the application of dryland production without regional considerations for crop rotations and conservation tillage can negatively impact environmental and economic sustainability.

Dryland cropping systems rely solely on rainfall and water storage in the soil profile for plant growth (Baumhardt et al., 2016). Dryland rainfed systems must be designed to capture, retain, and utilize all available precipitation in a semi-arid climate (Baumhardt et al., 2017). Farmers utilizing semi-arid dryland rotations typically avoid corn (*Zea mays L.*) because annual rainfall is less than production demands (Baumhardt et al., 2016). Traditional continuous wheat cropping systems place reliance on fall rains for crop establishment (Baumhardt et al., 2011; Hansen et al., 2012). Crop failure can occur when fall precipitation volumes are inadequate to permit crop establishment (Baumhardt et al., 2011; Hansen et al., 2012). The addition of fallow periods and conservation tillage can increase sustainable, continued production (Blanco-Canqui et al., 2010). The three-year wheat, sorghum, fallow rotation (W-S-F) in combination with stubble-mulch tillage (SM) and no-till (NT) management practices has increased water conservation while maintaining sustainable crop yields by providing added protection from wind and water erosion (Lascano and Baumhardt, 1996). The W-S-F rotation begins with the planting of winter wheat (*Triticum aestivum L.*) in October of the first year with harvest occurring in late June. The field then remains fallow for approximately 11 months until grain sorghum (*Sorghum bicolor (L.) Moench.*) is planted in June of the second year. After sorghum harvest in October, the field is fallowed for an additional 11-month period until the rotation repeats (Baumhardt et al., 2017). Wheat residues left on the soil surface during the first fallow period intercept the kinetic energy of rainfall during high precipitation summer months, decreasing splash erosion and increasing soil moisture for summer sorghum planting. Once established, the vegetative canopy cover of summer sorghum in the second-year increases albedo, lowering soil temperatures and reducing evapotranspiration (Baumhardt et al., 2011). Although less effective than wheat because of row planting with fewer and more concentrated stalks, sorghum residues provide protective soil cover during the final fallow period, increasing fallow efficiency and water storage for the next crop rotation (Baumhardt and Brauer, 2018; Baumhardt et al., 2016; Hansen et al., 2012; Hauser and Jones, 1991). Fallow efficiency is represented by the amount of precipitation stored in the soil profile during fallow periods and can be calculated by the ratio of stored soil water to fallow precipitation (Baumhardt et al., 2017; Baumhardt et al., 2011).

Modern herbicides and hybrid cultivars introduced in the 1970's increased the viability of conservation tillage (Unger and Baumhardt, 1999; Jones et al., 1995). Unger and Baumhardt (1999) resulted in a 46% average grain sorghum yield increase from 1977 to 1997 as a result of improved hybrids. Conservation practices accounted for an additional 93% sorghum yield improvement from 1958 to 1997 (Unger and Baumhardt, 1999). Conservation tillage is defined by the USDA-NRCS as any tillage that maintains 30% of residue surface cover after planting to reduce wind and water erosion (Baumhardt et al., 2015). Tillage is often used to bury perennial weed seeds and increase soil roughness, creating unfavorable conditions for weed seed germination (Jones et al., 1995). Conventional tillage disrupts soil at depths of 0.2 m or greater and does temporarily increase soil porosity and infiltration however, formation of surface crusts, exposure of soil to evaporation, and accelerated decomposition of organic matter result in increased storm runoff and soil erosion (Blanco-Canqui and Ruis, 2018; Baumhardt et al., 2008). Stubble-mulch conservation tillage uses sweeps with overlapping V-blades to undercut the top soil horizon by 0.1 m to 0.15 m, typically leaving 75-80% of previous crop residues on the soil surface (Baumhardt et al., 2008; Jones et al., 1995; Jones et al., 1994). Three to five SM tillage operations are needed during fallow phases to control weeds. Although herbicide applications are reduced with SM, tillage operations can increase soil compaction and diminish residue cover through soil incorporation of plant material (Jones et al., 1994). SM tillage also positions residues between plow shanks creating larger areas of exposed soil (Baumhardt et al., 2011). Jones et al. (1994) showed surface residue cover percentages in dryland plots of 86.1% for NT and 73.1% for SM at the end of fallow after wheat phases with 56.7% for NT and 25.0% for SM at the end of fallow after sorghum. No-till (NT) field management restricts soil modification to seed planting, retaining upright plant residues after grain harvest (Blanco-Canqui and Ruis, 2018). When compared with SM and conventional tillage, NT increases aggregate stability but increased water storage with NT can correlate to increased storm runoff especially in late fallow periods (Baumhardt and Brauer, 2018; Blanco-Canqui and Ruis, 2018; Kumar et al., 2012; Stone and Schlegel, 2006). Increased cost of herbicides can hinder adoption of NT management, while increased pesticide usage can contaminate off-site environments through storm runoff and sediment transport events (Hansen et al., 2012; Jones et al., 1995). In a study performed on NT and SM dryland plots in the SHP, Jones et al. (1995) showed concentrations of Atrazine in storm runoff were minimal with no soil accumulation or leaching below the root zone. However, pesticides have a greater potential to negatively impact the environment if applied at sorghum planting when the soil profile is wet, increasing runoff during storms (Jones et al., 1995).

RUNOFF AND EROSION PROCESSES

Soil loss from wind and water erosion can cause soil degradation and non-point source pollution, affecting on site productivity and off-site water and air quality (Nearing et al., 2017; USDA-NRCS, 2010). Soil erosion typically results from water and wind energy detaching and moving soil particles (USDA-NRCS, 2010). Historically, converting land from native vegetative cover to crop production causes periods of soil instability and increased erosion as illustrated by the Great Plains "Dust Bowl" of the 1930's (Baumhardt et al., 2015; Nearing et al., 2017). Dry aggregate instability in topsoil creates susceptibility to wind erosion. Van Pelt et al. (2016) found wind erosion to be responsible for approximately 75% of total net soil loss from the six dryland fields at Bushland, TX. Using results reported by Jones et al. (1985), Van Pelt et al. (2016) partitioned a mean gross water erosion rate of 1.9 Mg ha^{-1}, leaving a balance of 6.6 Mg ha^{-1} attributable to wind erosion on SM fields. Retention of plant residues however, can increase soil organic matter, increasing aggregate size and decreasing the number of smaller particles vulnerable to wind detachment (Baumhardt et al., 2015; Blanco-Canqui and Ruis, 2018; USDA-NRCS, 2010). Net soil loss by water erosion is measured by unit per area in a given time such as kilograms per hectare throughout the duration of a storm (Nearing et al., 2017). In semi-arid regions as few as 10% of rainfall events can generate 50% of soil loss (Baumhardt and Brauer, 2018; Gao et al., 2013). Soil's inherent erodibility is largely dependent on infiltration capacity and the soil's ability to resist detachment and transport by rainfall (Wischmeier and Mannering, 1969).

Storm runoff is rainfall precipitation that flows past the end of a field or hill slope and is no longer available to infiltrate the soil profile (Baumhardt et al., 2017; Unger et al., 1994). Surface evaporation, evapotranspiration from plants and weeds, and drainage below the root zone are additional losses of precipitation (Lascano and Baumhardt, 1996). Runoff rates are highly variable and dependent on storm intensity and infiltration rates (Goa et al., 2013). Greater storm intensity increases the kinetic energy of raindrop impacts, increasing turbulence and flow velocities of water. Additionally, raindrop impacts can detach soil particles causing sheet or inter-rill soil erosion, resulting in sediment entrainment and transport. Sheet erosion describes uniform soil erosion and water flow over a field while the presence of rills indicates preferred pathways of water travel (Marshall et al., 1999). Once soil particles are transported beyond field boundaries, soil erosion becomes soil loss. The deposition of soil particles in surface cracks can lead to the creation of seals on the soil surface (Marshall et al., 1999; Sadeghi and Tavangar, 2015). Surface seals, also termed crusts, are thin layers of consolidated soil aggregates that increase shear strength and penetration resistance of soil surfaces, decreasing infiltration and increasing runoff rates (Blanco-Canqui and Ruis, 2018; Baumhardt et al., 2011; Baumhardt et al., 1990; Wischmeier and Mannering, 1969). Pullman clay loam soil is susceptible to crusting because of its high silt content of 53% (Jones et al., 1994). Small silt soil particles are easily entrained by water. Larger silt particles are more likely to be redeposited in rills and cracks during the entrainment process while smaller, more buoyant and transportable silt particles have a higher likelihood of contributing to soil loss. Furthermore, soil that has been detached and redeposited can erode at higher rates due to inadequate formations of cohesive bonds with neighboring sediment (Marshall et al., 1999).

SITE SPECIFIC STUDIES

Rainfall simulation and infiltration tests have been conducted on dryland plots at Bushland, TX to examine relationships between field management, storm conditions, hydrological, and agronomic properties (Baumhardt et al., 2011; Jones et al., 1994; Unger and Pringle, 1981). Baumhardt et al. (2011) applied reverse osmosis water using a rotating-disk simulator to NT and SM fields with bare and residue covered surfaces under a W-S-F rotation 4 months after wheat harvest. NT management retained roughly 97% of wheat residue cover while SM provided 91-92%. Initial soil water content was 0.20 to 0.23 $m^3 m^{-3}$ and bulk densities remained ~1.0 ± 0.05 Mg m^{-3} across all rotations and tillage treatments. Sixty-minute rain simulations at rates of 78 mm h^{-1} produced raindrop impact energy of 22 J mm^{-1}, which is 80% of natural rainfall. Fifteen-minute infiltration amounts were identical for NT and SM at 19.1 ± 0.01 mm, however infiltration amounts increased to 72.7 ± 0.4 mm for SM at 60 minutes compared with 59.6 ± 3.5 mm for NT. The 60-minute infiltration rate was 70.7 ± 2.4 mm h^{-1} for SM and 26.1 ± 2.6 mm h^{-1} for NT. Although SM provided higher infiltration rates, soil loss from SM was 46.1 g m^{-2} h^{-1}, significantly greater than the 17.2 g m^{-2} h^{-1} for NT, probably resulting from increased residue coverage and aggregate size with NT. The NT calculated mean weight diameter (MWD) aggregate sizes measured 1.61 mm ± 0.22 compared to 0.86 mm ± 0.15 with SM. Jones et al. (1994) also conducted infiltration tests at the same site as Baumhardt et al. (2011). Jones et al. (1994) used a rotating-disk rainfall simulator applying cistern-stored rainwater at a rate of 48 mm h^{-1} at the end of fallow after wheat and fallow after sorghum periods on dryland fields under W-S-F rotations and NT or SM residue management practices. In the Jones et al. (1994) study, SM plots were plowed one week prior to testing to eliminate surface crusting conditions. Infiltration tests for dry-run and wet-run conditions were also conducted. Dry aggregate mean weight diameter was significantly greater on SM than NT resulting from increased organic matter incorporation during the recent tillage operation. The dry aggregate mean weight diameter in the fallow after wheat period was 7.75 mm for SM and 2.65 mm for NT. Dry aggregate MWD for fallow after sorghum was 14.67 mm for SM and 6.57 mm for NT. Wet run infiltration tests were conducted one day after dry soil surface tests to determine infiltration rates on moist soil (Jones et al., 1994). Thirty-minute infiltration rates with wet soil conditions were not significantly different between SM and NT but were substantially less than dry run conditions (Jones et al., 1994). For example, the mean cumulative one-hour infiltration rate in dry run conditions was 42.9 mm for SM and 26.5 mm for NT in the fallow after sorghum phase while thirty-minute wet run mean cumulative infiltration rates were 7.0 mm for SM and 9.1 mm for NT in the fallow after sorghum phase (Jones et al., 1994). Two-hour infiltration with SM was 90% greater than NT on dry run fallow after sorghum phase tests. The difference between infiltration amounts on SM and NT fallow after wheat plots was not as dramatic as the fallow after sorghum watersheds, indicating a higher effectiveness of wheat residues to improve infiltration. Although, after the 2-hour rainfall application, SM infiltration remained 26% higher than NT in fallow after wheat fields. Baumhardt et al. (2011) and Jones et al. (1994) demonstrate how tillage treatments and storm duration can affect water infiltration, storm runoff, and soil loss. Actual runoff and soil loss amounts have also been collected and studied in the dryland fields at Bushland, TX.

Actual runoff amounts have been collected at the USDA-ARS Bushland dryland plots from entire watersheds to determine variation between precipitation, crop phase, and tillage. Jones et al. (1985) first analyzed runoff amounts by crop phase and precipitation categories from 1958 to 1983. Soil loss amounts were analyzed after the installation of Chickasaw sediment samplers in 1978. Fields maintained a W-S-F rotation with SM tillage throughout the Jones et al. (1985) experiment. Average 26-year precipitation was 462 mm. The 26-year average storm runoff was 20.5 mm, 43.3 mm, and 40.5 mm for wheat, sorghum, and fallow phases respectively (Jones et al., 1985). Runoff during the sorghum growing season was 150% greater than the wheat growing season (Baumhardt and Brauer, 2018). Runoff from growing wheat is lower because many high intensity storms occur in May and June when wheat is mature and crop canopy protection is greatest. The numerous stalks and narrow row spacing in wheat production also provide increased surface cover (Hauser and Jones, 1991). Additionally, wheat root penetration is deeper than sorghum, improving drainage. Most importantly, in the late stages of the wheat growing season the soil profile is depleted of water from plant growth creating surface cracks up to 0.5 m in length, improving storage capacity and infiltration (Jones et al., 1994). In all, Jones et al. (1985) found runoff averaged 4.4% of total precipitation for wheat, 9.3% for sorghum, and 8.7% for fallow. Only 13 of 1,522 total storms from 1960 to 1979 measured in excess of 51 mm of rainfall. These 13 large, infrequent storms accounted for 10% of total rainfall and 36% to 41% of runoff volumes (Jones et al., 1985). Jones et al. (1994) evaluated precipitation and runoff amounts from 1984 to 1991 by crop phase with SM and NT distinctions. Building on the work of Jones et al. (1985), Jones et al. (1994) found that runoff from the sorghum growing season was higher than the wheat growing season. Runoff averages for the sorghum growing season were 17-18 mm for SM and NT while the wheat growing season averaged 3.5 with SM and 8.1 with NT. Average precipitation was similar for both growing seasons with 290 mm for sorghum and 280 mm for wheat (Jones et al., 1994). The two fallow periods showed the greatest difference between tillage treatments with average runoff of 27.5 mm for SM and 43.1 mm for NT fallow after wheat and 28.2 mm for SM and 51.1 mm for NT fallow after sorghum. Average precipitation for both fallow periods was the same at 501 mm and 502 mm (Jones et al., 1994). Baumhardt and Brauer (2018) analyzed precipitation and runoff data from 1990 to 2009 by crop phase, tillage, and precipitation category but explored successive rainfall events as possible runoff intensifiers. Total mean runoff was 2.2 ± 0.5 mm for SM but increased to 3.3 ± 0.6 mm for NT (Baumhardt and Brauer, 2018). As storm intensity increased, runoff and the disparity between runoff from SM and NT increased. For example, mean runoff from the 50.9 mm to 130.8 mm rainfall category was 13.6 ± 5.2 mm for SM and 19.4 ± 4.7 mm for NT (Baumhardt and Brauer, 2018). In the 6.4 mm to 12.5 mm rainfall category mean runoff was six times greater for events when a preceding storm occurred in the previous week (Baumhardt and Brauer, 2018). However, these frequent, small volume storms are not responsible for intense runoff events. Mean runoff from rainfall in excess of 50.9 mm with at least one rainfall event in the preceding week was 19.1 mm compared with 14.9 mm for independent storms. Although the difference is significant, it is only representative of 9 out of 129 runoff events (Baumhardt and Brauer, 2018). As with storm runoff, soil loss has been monitored and reported at USDA-ARS Bushland.

Jones et al. (1995) documented sediment losses from 1984-1992 under SM and NT management on the W-S-F dryland plots to determine nutrient and pesticide losses. Means for sediment loss were significantly different at $\rho \leq 0.05$ in fallow after wheat and fallow after sorghum phases between SM and NT plots. Sediment losses for fallow after wheat were 1.36 Mg ha^{-1} with SM and 500 kg ha^{-1} with NT. Fallow after sorghum was 1.83 Mg ha^{-1} with SM and 950 kg ha^{-1} with NT. Although runoff tends to be higher in NT, the consolidated surfaces which NT produces are resistant to water erosion (Jones et al., 1995). Means of soil loss in wheat and sorghum growing phases were not significantly different, however, sediment concentrations remained higher for SM compared with NT (Jones et al., 1995). Altogether, annual soil loss averages for the W-S-F rotation were 1.31 Mg ha^{-1} for SM tillage and 605 kg ha^{-1} with NT management (Jones et al., 1995). Still, with conservation practices in place, annual soil loss of less than 1.3 Mg ha^{-1} for both tillage systems are far below the annual soil loss tolerance of 11 Mg ha^{-1} (Jones et al., 1995). In a similar study, Jones et al. (1985) evaluated sediment losses on the same watersheds from years 1978 to 1983. Jones et al. (1985) showed the average six-year soil losses to be 1.15 Mg ha^{-1} from wheat, 2.66 Mg ha^{-1} from sorghum, and 1.76 Mg ha^{-1} from fallow after sorghum. Since wheat and fallow after wheat values are combined, the soil loss from these individual phases are substantially less. Increased values for sorghum could be indicative of high kinetic energy storms early in the growing season before canopy cover is established. For example, average soil loss for sorghum was affected by an unusually high value of 6.7 Mg ha^{-1} in 1982 when in other years values remain consistently proportional to the other crop stages. Precipitation in 1982 was 484 mm, reasonably close to the 26-year average of 462 mm (Jones et al., 1985). The

1978 soil loss values were high due to two storms totaling 152 mm of precipitation. Nevertheless, soil loss was below the field tolerance of 11 Mg ha^{-1} (Jones et al., 1985).

RUNOFF AND EROSION PREDICTION

Runoff from storm events can be predicted using runoff curves developed in the Eastern U.S. (Kent, 1973). Accumulated direct runoff "Q" can be mathematically derived with the below equation. Factors include accumulated rainfall "P", initial abstraction "I_a" (surface storage, interception, and infiltration prior to runoff), and potential maximum rainfall retention "S" (Kent, 1973).

$$Q = (P - 0.2S)^2 / (P + 0.8S)$$

Equation 1. Accumulated Direct Runoff.

The relationship for I_a and S was developed experimentally and assumes 0.2 to eliminate estimation (Kent, 1973). S values are transformed into curve number (CN) values to be illustrated graphically by the below equation, assuming S in cm:

$$CN = 1000 / (10 + S/2.54)$$

Equation 2. Runoff Curve Number Values.

However, because runoff in the SHP west of the 100th meridian drains into playas, stream flow estimates of runoff are not applicable. Therefore, studies have been conducted in the SHP to extrapolate data for regional application (Hauser and Jones, 1991). Regional rainfall isohyets and storm runoff curve models were developed and published by the United States Department of Agriculture Soil Conservation Service (USDA-SCS) in technical paper (TP) 149 titled "A Method of Estimating Volume and Rate of Runoff in Small Watersheds" (Kent, 1973). In the USDA-SCS handbook Pullman soils are classified as hydrological group "D" (very slow infiltration rate) with corresponding curve numbers of 80 for wheat and sorghum and 90 for fallow (Hauser, 1991; Kent, 1973). In Bushland, TX ~86% of the 1522 total storm events from 1960-

1979 were less than 12.7 mm (Baumhardt et al., 2011). Hauser and Jones (1991) showed that runoff approximations for small and frequent one-day storm events derived from the USDA-SCS technical report are underestimated for the sorghum growing season and slightly over-estimated for wheat growing seasons. Over-estimations for fallow after wheat and fallow after sorghum were even higher. These differences can be attributed to the use of conservation bench terracing at Bushland, TX to conserve storm runoff and differences in residue yield produced by dryland fields (Hauser and Jones, 1991). Hauser and Jones (1991) found the implementation of dryland conservation methods produced CNs of 77 for fallow after wheat, 82 for fallow after grain sorghum, 79 for the wheat growing season, and an increase of 80 to 82 for sorghum growing season. For instance, without the revision of curve numbers, runoff depth prediction for fallow after wheat would be 97% greater than observed amounts (Hauser and Jones, 1991).

Annual soil loss can be predicted for a watershed using the Universal Soil Loss Equation (USLE) described by Wischmeier and Smith (1978) in the USDA handbook "Predicting Rainfall Erosion Losses." The USLE is calculated by the formula:

$$A = R\ K\ L\ S\ C\ P$$

Equation 3. Universal Soil Loss Equation.

where "A" is the computed average annual soil loss in tons per acre year, "R" is the rainfall erosivity index, "K" is the soil erodibility factor for a particular soil as measured on the unit plot, "L" is the slope length, "S" is slope gradient, "C" is the cover management factor, and "P" is the support practice factor for conservation methods such as contouring (Baumhardt et al., 1985; McGregor et al., 1996; Nearing et al., 2017). At the USDA-ARS Bushland site "R" values are interpolated from the rainfall erosivity index as 125. The soil erodibility factor "K" is 0.26 for pullman clay loam with 1% organic matter. The slope, length factor at Bushland uses an average contour slope of 1.5% and a length of 660 m or 722 yards (Hauser et al., 1962). The following equation can be used to calculate LS:

$$LS = (\lambda / 72.6)^{m} (65.41 \, sin^{2} \theta + 4.56 \, sin \, \theta + 0.065)$$

Equation 4. Length, Slope Calculation of the Universal Soil Loss Equation.

where λ is the slope length in feet and θ is the angle of slope. The value 0.3 is substituted for "m" when the field slope gradient is 1 to 3% (Wischmeier and Smith, 1978). With given data the LS factor is equal to 0.18. The cover management factor is broken into the crop phases rough fallow (F), seedbed (SB), establishment until 50% canopy cover (1), development until 75% canopy cover (2), maturing crop (3), and residue (4) (Wischmeier and Smith, 1978). Coefficient C is the product of all pertinent regional and management subfactors. During the third year of the W-S-F rotation under SM tillage, fields remain in the fallow after sorghum phase and are more susceptible to soil loss due to sparse sorghum residue cover and time of exposure to summer rainfall events. The suggested crop stage 4 values for residue retaining fallow at 80% coverage decreasing to 60%, 40%, and 20% with each tillage treatment were used for calculations. USLE handbook values are weighted to correct for duration of each stage in an annual 12-month cycle. Grain after summer fallow with 30% residue cover values for wheat planting and establishment from October to December were also used. The weighted calculated value of "C" is 0.315 (Wischmeier and Smith, 1978). The practice factor "P" is 0.6 for contoured fields with 1-2% slope but the maximum length available for calculation is 121 m. The calculated "A" or soil loss value for the third year of the SM W-S-F rotation using the previous values is:

$$1.1 \text{ tons per acre } (2.5 \text{ Mg ha}^{-1}) = 125 \times 0.26 \times 0.18 \times 0.315 \times 0.6$$

Equation 5. Annual USLE Calculated Soil Loss in Mg ha^{-1} in the Fallow after Sorghum Phase with SM Tillage at Bushland, TX.

(Foster & McCool 1981)

Jones et al. (1995) determined mean sediment losses for fallow after sorghum to be 1.8 Mg ha^{-1} with SM. The variation could be attributed to absent terrace construction inputs (Jones et al. 1985). The seedbed and crop establishment wheat phase could also contribute to increased soil loss when sorghum residues are low and crop canopy is underdeveloped. Although, precipitation amounts can be small during the late fall and winter.

CHAPTER II. MATERIALS AND METHODS

RESEARCH OBJECTIVES

The purpose of this research project is to evaluate precipitation, storm runoff, and soil loss data to understand variation between crop phases and tillage practices. The first effort was to organize data for comparison with previous site-specific observations and topic related research. Evaluation of data collected from 1984-2010 can possibly explain why similar storms and conditions produce variable runoff and soil loss amounts. This project will also document hydrological trends in the USDA-ARS Bushland, TX dryland graded terraces to create a continuous record of data from 1958-2010.

SITE DESCRIPTION

All data collection was conducted at the USDA Agricultural Research Service, Conservation and Production Laboratory located 1.5 km West of Bushland, Texas in Randall County approximately 12 km west of Amarillo, TX (Hauser and Jones, 1991). Site coordinates are 35° 11' N Latitude, 102° 5' W Longitude at 1170 m above sea level (Baumhardt et al., 2017). Dryland wheat-fallow rotations began at the Bushland site in 1927 with the W-S-F rotation implemented in 1949 (Baumhardt and Brauer, 2018; Baumhardt et al., 2017). Data was collected on six fields designated as follows with corresponding sizes: 10A (4.1 ha), 10B (3.3 ha), 11A (2.8 ha), 11B (2.6 ha), 12A (2.3 ha), 12B (2.0 ha) (Jones et al., 1995). Fields were under uniform SM management until 1981 when they were divided into SM and NT pairs with the letter "A" representing NT and "B" SM (Baumhardt et al., 2017; Van Pelt et al., 2016). Fields are arranged in adjacent contoured order with 10A furthest west. The fields are positioned lengthwise from North to South. All field lengths are greater than 630 m with a combined width of 307 m (Jones et al., 1994). Field construction is a graded terrace system with an average West to East slope of 1.5% (Van Pelt et al., 2016). Each watershed is bounded by terraces built at 0.76 m vertical intervals with a uniform terrace channel slope of 0.05% draining into grassed waterways (Hauser and Jones, 1991; Jones et al., 1995). Earthen berms located at the ends of each field contain water flow, terminating the watershed (Hauser and Jones, 1991).

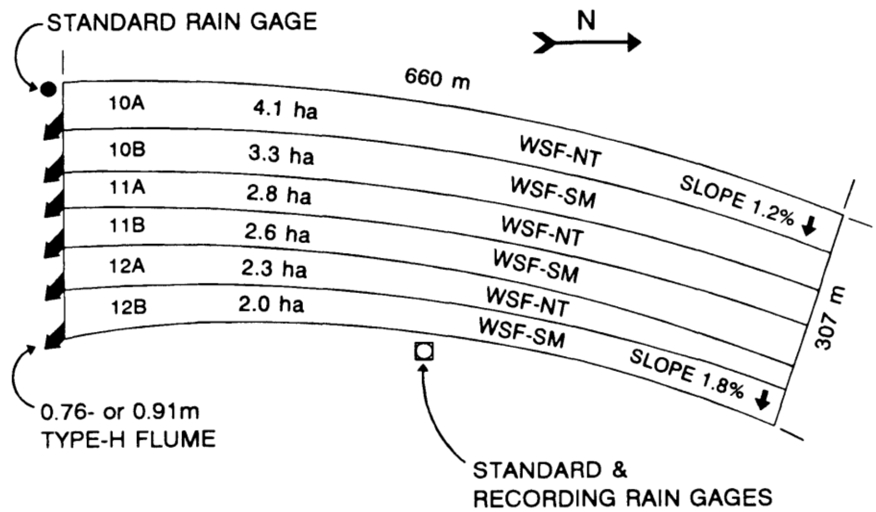

Figure 1. Schematic of dryland plots at USDA-ARS Bushland, TX with field size, rain gage locations, and flume positions (Jones et al., 1994).

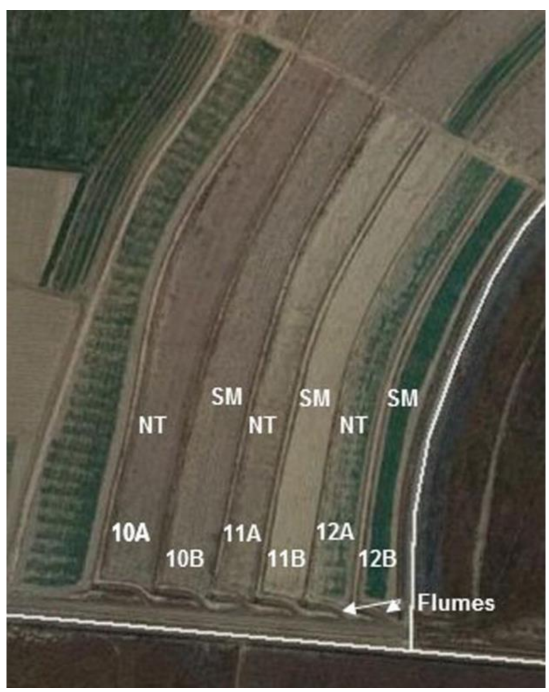

Figure 2. Aerial photograph of dryland plots at USDA-ARS Bushland, TX with field and tillage labels (Van Pelt et al., 2016).

SITE SOIL CHARACTERISTICS

Pullman clay loam is the predominant soil of the SHP, representing 4.8 million ha of cropland and rangeland in the SHP (Jones et al., 1985). Pullman soil is classified as a fine, mixed, thermic family of Torrertic Paleustolls with a composition of 30% clay, 53% silt, 17% sand, and 1% organic matter throughout the profile (Schwartz et al., 2015; Unger and Pringle, 1981). Approximate depth of the Pullman is 1.8 m (Baumhardt et al., 2017; Jones et al., 1995; Unger and Pringle, 1981). Pullman soil developed from fine textured eolian sediments under dense short grasses such as blue grama (*Bouteloua gracilis*) and buffalograss (*Buchloe dactyloides*) (Unger and Pringle, 1981). The following Pullman soil profile descriptions were provided by Moroke et al. (2005) and Unger and Pringle (1981) and are typical of the soil horizons found at USDA-ARS Bushland and Randall County, TX. The surface plow horizon (Ap) has a depth of 0.18 m with a weak fine granular surface structure to 0.05 m and medium subangular blocky structure below consisting of brown silty clay loam. The Ap horizon is hard, friable, and neutral with few fine roots and pores and an abrupt, smooth boundary. The total Argillic surface horizon (Bt) is a very slowly permeable montmorillonitic illuvial subsoil having a depth of 0.18 m to 1 m consisting of silty clay to clay (Baumhardt et al., 2008; Moroke et al., 2005). Unger and Pringle (1981) further detailed the components of the B21t to B24t layers. The B21t horizon can begin from 0.15 m to 0.4 m with moist, moderate to medium dark brown clay blocky structures. The B21t contains firm wedge shaped peds with vertical cracking and a gradual smooth boundary. Depths of 0.4 m to 0.7 m are termed the B22t horizon consisting of dark brown silty clay moderate medium blocky structures with wedge shaped peds and 0.05 m to 0.1 m wide slickensides. Slickensides indicate shrinking and swelling of Smectite clays that can facilitate water movement and deep percolation (West et al., 2017). The B22t has thin clay and calcium carbonate films. The B23t layer begins at 0.7 to 1.12 m with a reddish-brown silty clay consistency. Structure is similar to B22t with a mildly alkaline pH. The B24t horizon reaches depths of 1.5 m with moderate medium subangular blocky structures of yellowish-red aggregates. It has a clear smooth boundary transitioning to the Calcic horizon (Btk). The Btk horizon spans 1.5 m to 2.3 m under the soil surface containing pink to reddish-yellow clay loam textures with up to 50% calcium carbonates (Moroke et al., 2005). The Ap surface plow horizon was shown to have organic matter of 2.06% with decreasing values at lower layers combining to give a weighted mean of 1.03% organic matter throughout the profile (Unger and Pringle, 1981). Potential of Hydrogen values were 6.70 at the surface rising to 7.29 at the B24t horizon. Unger and Pringle (1981) assumed bulk densities to be 1.26 g cm^{-3} at the Ap horizon based on previous studies, accounting for variability dependent on tillage type and frequency. Weighted mean bulk densities for the Pullman profile were 1.55 g cm^{-3} with increasing measurements of 1.48 g cm^{-3} to 1.55 g cm^{-3} throughout the Bt subsoil. Water content potential at field capacity (~33kPa) was calculated at 25% in the Ap layer. Plant available water was 9.0%, 10.3%, 8.6%, 9.1%, 7.7% from Ap to B24t respectively (Unger and Pringle, 1981). The Pullman soil at Bushland, TX can retain 430 mm of total water and 200 mm of plant available water when filled to capacity at 1.2 m depths. Terminal water intake rate is 1.3 mm h^{-1} (Hauser and Jones, 1991).

SITE CROP MANAGEMENT

All following rotation, planting, harvest, and pesticide management practices are described by Baumhardt et al. (2017) which is the most current publication related to the research site. All planting, harvest, and maintenance operations are conducted on the field contour (Hauser and Jones, 1991). Field organization and crop rotations are managed to represent each phase of the system every year (Hauser and Jones, 1991). Planting dates can vary because adequate rainfall is needed to increase soil moisture, permitting crop establishment. Rainfall events can also delay harvest operations (Baumhardt et al., 2017). For a 32-year period of the W-S-F rotation at USDA-ARS Bushland, mean growing and fallow season dates were given by Hauser and Jones (1991) as follows:

Growing Wheat:	6 October to 24 June
Fallow after Wheat:	25 June to 15 June
Growing Grain Sorghum:	16 June to 29 October
Fallow after Sorghum:	30 October to 7 October

The W-S-F rotation on the six dryland plots at USDA-ARS Bushland begins in September or October by sowing hard red winter wheat of various cultivars at 45 kg ha^{-1} to achieve 200 plants m^{-2} in rows spaced 0.3 m apart using a high clearance hoe opener grain drill. Wheat growing season broadleaf weeds are controlled using a spring time application of 0.6 kg active ingredient (a.i.) ha^{-1} 2, 4-D [(2,4-dichlorophenoxy) acetic acid] (Baumhardt et al., 2017). Wheat is usually harvested in July. Tillage operations are conducted using a 4.6 m wide Richardson sweep-plow (Sunflower Man. Co., Inc.) to a depth of 0.10 m to control weeds throughout the 11-month fallow after wheat phase on

SM fields (Baumhardt et al., 2017). In NT fields a combination of 0.84 kg a.i. ha^{-1} 2,4-D and 1.1 kg a.i. ha^{-1} atrazine [6-chloro-N-ethyl-N'-(1-methylethyl)-1,3,5-triazine-2,4-diamine] is applied for fallow after wheat weed growth (Baumhardt et al., 2017). During June of year two, various cultivars of grain sorghum are planted in rows spaced 0.75 m apart at 8.0 seeds m^{-2} using a 6-row 'Max-Emerge' planter (John Deere Co.). Initially, sorghum growing season weed control consists of pre-emergence June application of 1.7 kg a.i. ha^{-1} propazine [6-chloro-N-ethyl-N'-(1-methylethyl)-1,3,5-triazine-2,4-diamine], then 1.3 kg a.i. ha^{-1} atrazine, and 1.0 kg a.i. ha^{-1} metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl) acetamide]. Sorghum seeds are treated with fluxofenim [1(4-chlorophenyl)-2,2,2-trifluoroethanone O-(1,3-dioxolan-2-ylmethyl) oxime] before planting to permit the use of commercial atrazine and metolachlor mixtures. Grain sorghum is harvested at maturity in November of year three and followed by an additional 10-month fallow period. SM fields are tilled with the same method as the fallow after wheat period with NT fallow after sorghum spring herbicide applications of 0.37 kg a.i. ha^{-1} 2,4-D, 0.045 kg a.i. ha^{-1} chlorosulfuron [2-chloro-N[[(4-methoxy-6-methyl-1,3,5-triazin-2yl)amino]carbonyl] benzenesulfanomide], and 0.009 kg a.i. ha^{-1} metsulfuron-methy [Methyl 2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl) amino]carbonyl] amino]sulfonyl]benzoate). Pre-plant burn down and fallow weed escapes are controlled using 0.56 kg a.i. ha^{-1} glyphosate, [N-(phosphonomethyl) glycine], and 0.37 kg a.i. ha^{-1} 2,4-D (Baumhardt et al., 2017). Pullman soil is inherently fertile (Jones et al., 1994). The needed 50 kg ha^{-1} of Nitrogen (N) for grain production is supplied through mineralization during fallow periods and deep profile nitrates. Pullman soil also provides adequate Phosphorus (P) and Potassium (K) (Baumhardt et al., 2017).

In June of 1990 NT fields were strategic-tilled with V-blades to control tumblegrass (*Schedonnardus paniculatus* (Nutt.) Trel.) and pricklypear (*Opuntia sp*.) (Jones et al., 1995). Fields are tilled for wind erosion control as needed.

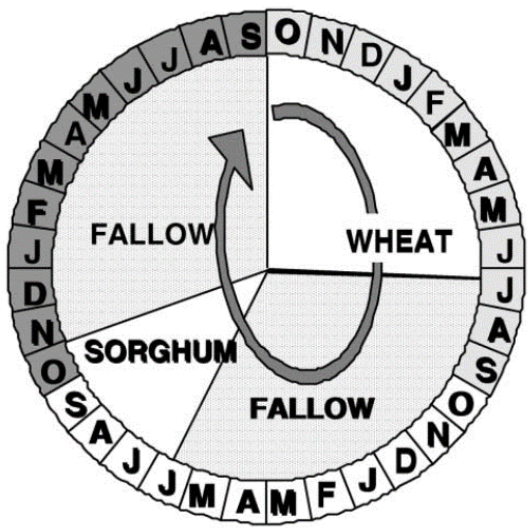

Figure 3. *Illustration of the Wheat-Sorghum-Fallow rotation at USDA-ARS Bushland, TX (Baumhardt and Jones, 2002).*

DATA COLLECTION METHODS

Total storm precipitation is measured using a combination of weighing and standard rain gages. The weighing rain gauge is stationed just east of the plot area to provide continuous rainfall volumes. The research site provides two additional 20 cm diameter standard manual rain gages with one located adjacent to the weighing gage and the second located immediately south of field 10A (Baumhardt and Brauer, 2018; Baumhardt et al., 2017; Brakensiek et al., 1979). Among the total 11 rainfall gages located at USDA-ARS Bushland, Baumhardt and Brauer (2018) concluded that as total event precipitation increased the coefficient of rainfall variation decreased from 17.9% to 8.9% throughout the research station. Storm runoff is measured using calibrated 0.91 m (Fields 10A, 11A, 12A) and 0.76 m (Fields 10B, 11B, 12B) type-H flumes equipped with Belfort FW-1 stage recorders located at the southeast corner of each watershed where the grassed terrace channels end (Baumhardt et al., 2017; Hauser and Jones, 1991; Jones et al., 1995; Jones et al., 1985). Flumes were constructed using concrete with steel crests (Hauser and Jones, 1991). During a runoff event, water samples are automatically pumped and analyzed for sediment concentrations (Jones et al., 1995). FW-1 Stage Recorders use a curvilinear chart with a designated time scale to calculate runoff amounts. Watershed areas less than 121 ha use a 6-hour chart with each stage increment correlating to runoff flow amounts in cubic feet per second (Gwinn et al., 1979). Using horizontal summation analysis, hydrograph chart data can be converted to cubic feet of runoff per stage which is then summed and converted to total acre inches of runoff for a given watershed during a runoff event (Gwinn et al., 1979; Jones et al., 1994). Modified Chickasha sediment samplers were installed in 1978 to measure soil loss (Jones et al., 1985). In 2003, the system was augmented with back-up Sigma portable samplers. Chickasha samplers can collect 28-0.47 L samples in a 12-hour period (Allen et al., 1976). To determine sediment concentrations the 0.47 L bottles are collected, weighed, and flocculated with 0.4 mm of 0.2 molar solution aluminum ammonium sulfate [Al NH_4 $(SO_4)_2 \cdot 12H_2O$] per liter of sample (Dendy et al., 1979). Sediment samples are then allowed to settle for 12-hours. Once settled, excess fluid is vacuumed from the sample container leaving 30 mL of effluent. The remaining sample is then place in an evaporating dish and oven-dried overnight at 105° C to 110° C (Dendy et al., 1979). A composite mixture of vacuumed effluent is also oven-dried to determine the amount of dissolved sediment in the samples (Dendy et al., 1979). Evaporation dishes are then removed from the oven and placed in a desiccator until cool (Dendy et al., 1979). All sediment samples are weighed and converted from g L^{-1} to kg ha^{-1} to be representative of soil loss from the entire watershed for a given runoff event (Dendy et al., 1979).

Once precipitation, storm runoff, and sediment concentrations were collected they were entered into a Microsoft Excel spreadsheet titled "Storm Runoff 1983-2013-Data collected, processed, and complied by Grant L. Johnson USDA-ARS" (Baumhardt, 2018). The spreadsheet is organized into eight categories consisting of storm date, field, sequence, tillage, storm precipitation in inches, storm runoff in inches, and storm soil loss in kg ha^{-1}. The following abbreviations were used to denote tillage types, crop stage characteristics, sample characteristics, and sample malfunctions:

WSF	Wheat-Sorghum-Fallow
NT	No Tillage
SM	Stubble Mulch Tillage
Wheat	Wheat Crop Phase
Sorghum	Sorghum Crop Phase
Fal/sor	Fallow after Sorghum Crop Phase
NI	Sampler Not Installed
NS	No Sample Collected
RM	Storm Runoff Recorder Malfunction
Smalf	Sediment Sampler Malfunction

Figure 4. Original data sheet abbreviations.

DATA ANALYSIS

Storm precipitation and storm runoff amounts were first converted from inches to metric millimeter units using a multiplication factor of 25.4. The data measurements were then organized by year, crop phase, field, tillage, and storm precipitation categories. The following abbreviations were used separately and in combination for collections of measurements with the same tillage management and within the same crop phase:

W	Wheat Crop Phase
FW	Fallow after Wheat Crop Phase
S	Sorghum Crop Phase
FS	Fallow after Sorghum Crop Phase
NT	No-Till
SM	Stubble-Mulch Tillage
P	Storm Precipitation
RO	Storm Runoff
SL	Soil Loss

Figure 5. Data analysis abbreviations.

Data collected in 1983 was excluded from analysis because runoff and sediment samplers were not fully operational until 1984 (Jones et al., 1985). Data recorded from the NT continuous wheat field termed G5 was also omitted from analysis to ensure accurate comparisons. Unlike the W-S-F fields, the G5 field crop sequence and tillage combination is not replicated. Furthermore, previous research shows field G5 has significantly different runoff and soil loss amounts than the W-S-F fields. Jones et al. (1995) showed G5 runoff amounts to be one-quarter of the annual average runoff from fields with W-S-F sequences. Field G5 soil loss amounts were one-tenth of the annual average soil loss from W-S-F fields (Jones et al., 1995).

The fallow after wheat phase was not included in the in the sequence column of the data sheet. The wheat growing season and fallow after wheat phases were both labeled as wheat in the sequence description. Therefore, wheat sequence data was separated into wheat and fallow after wheat categories. Because actual planting and harvest dates for each year were unavailable, the mean dates of each phase provided by Hauser and Jones (1991) were used for crop phase organization. Careful consideration was given to conflicting planting and harvest dates, especially during the summer rainfall months of June and July when wheat is harvested and sorghum is planted.

The occurrence of runoff recorder and sediment sampler malfunctions were evaluated for detrimental effects in the reporting process. Because the presence of NS (no-sample) soil loss entries were common, an analysis on mean runoff amounts between crop phases and tillage practices was performed to understand the volume of runoff that must be present to produced soil loss.

Total storm precipitation, storm runoff, and soil loss amounts were separated by tillage and crop phases, then summed for each year from 1984 to 2010. Twenty-seven-year totals and averages were then calculated. Nine-year averages with ranges of 1984 to 1992, 1993 to 2001, and 2002 to 2010, were also calculated for comparison to previous literature. For example, Baumhardt and Brauer (2018) studied runoff data from 1990 to 2010, Jones et al. (1995) studied runoff and soil loss data from 1984 to 1992, and Jones et al. (1994) studied runoff and soil loss data from 1984 to 1991. Nine-year averages were first analyzed by the Shapiro-Wilk normality test. The Shapiro-Wilk test was chosen for analysis because each dataset consisted of three values ($n = 3$). The Shapiro-Wilk normality test is more sensitive for small datasets (Laerd, 2015). Student's t-test mean comparison analysis was then conducted to determine significant differences between the nine-year precipitation, runoff, and soil loss averages.

All statistical analysis was performed using IBM SPSS version 25.0 (IBM Corp. 2017). After data organization, the Kolmogorov-Smirnov test for normality was used to determine the need for parametric or non-parametric procedures of larger datasets (Laerd, 2015). If data was found to be not normally distributed, the Kruskal-Wallis H test was performed to compare two or more data groups. If the Kruskal-Wallis test proved the probability distributions between datasets were significantly different, a Post-Hoc analysis was conducted to compare median scores between groups. Significance levels of 0.05 were used for all statistical analysis methods unless otherwise specified.

Data was organized by precipitation amounts similar to previous site research for ease of comparison. For example, data was organized by year and crop phase with corresponding precipitation, runoff, and soil loss amounts as shown in Jones et al. (1985). The 13 highest intensity storms were also evaluated for comparison to figures in Jones et al. (1985). Storm precipitation was arranged by storm size categories described in Jones et al. (1985) and Baumhardt and Brauer (2018). Storm runoff and soil loss with means and percentages of 27-year totals were calculated to illustrate varying runoff and soil loss volumes between crop phase, tillage, and storm volume. Additionally, data was organized by field for plot assessments with NT and SM tillage.

Simple linear regression was used to understand the relationship between precipitation and runoff amounts. Two trendline equations were created for each tillage practice. Stepwise, Removed, Forward, and Backward multiple linear regression analyses were conducted using precipitation and runoff amounts as independent variables and soil loss amounts as dependent variables. Multiple linear regression was also separated by NT and SM tillage.

CHAPTER III. RESULTS

MALFUNCTIONS AND NO SAMPLE ANALYSIS

Throughout the 27-year study period, a total five storm runoff recorder malfunctions were documented. A recorder malfunction describes errors in producing a readable hydrograph chart and results in the non-reporting of runoff amounts for a storm event. Because all data collection and sampling equipment is battery operated, cold weather can hinder its functionality. The highest precipitation amount recorded for any recorder malfunction was 49.5 mm on fields 10A and 10B in the fallow after wheat phase. The highest runoff recorded on neighboring fields during the August 15, 1995, 49.5 mm storm event was 0.05 mm. Fields 11A-B were in the fallow after sorghum phase and fields 12A-B were in the sorghum phase. No soil loss was recorded for any field during the 49.5 mm storm. The second highest precipitation amount recorded during a recorder malfunction was on July 7, 2006 at 35.1 mm on field 12B with SM tillage in the fallow after wheat phase. Although, field 12A with NT recorded 10.2 mm of runoff and 1.11 Mg ha^{-1} of soil loss during the 35.1 mm storm event, SM fields 11B and 10B produced no soil loss. All smaller storm events with recorder malfunctions produced no soil loss. The complete list of runoff recorder malfunctions is listed below in Table 1, with specific fields affected, the applicable crop phase, and corresponding precipitation amounts.

	Runoff Recorder Malfunction Analysis (RM)				
Date of Malfunction	Fields Affected	Phase	Tillage	Precipitation Amount (mm)	Soil Loss Amount (kg ha^{-1})
Oct. 4, 1984	10A	Sorghum	NT	22.1	No Sample
Aug. 15, 1995	10A	Fallow after Wheat	NT	49.5	No Sample
Aug. 15, 1995	10B	Fallow after Wheat	SM	49.5	No Sample
Mar. 23, 2000	11B	Fallow after Wheat	SM	26.7	No Sample
Jul. 7, 2006	12B	Fallow after Wheat	SM	35.1	No Sample

Table 1. Runoff Recorder Malfunctions 1984-2010.

A total of ten sediment sampler malfunctions occurred from 1984-2010 resulting in the non-reporting of soil loss for several intense storms including the largest recorded storm of 131 mm on October 30, 1998. The sample malfunction for the 131 mm storm was recorded on field 12B with SM tillage. Soil loss from the NT field 12A was 1.82 Mg ha^{-1}. Following soil loss trends, it is possible 12B soil loss was consistent with or higher than 12A due to differences in tillage management within the same fallow after sorghum phase. Two sampler malfunctions were recorded for fields 11A and 12B during the July 15, 1993 72.9 mm storm event. During July 1993 field 11A was in the fallow after wheat phase while field 12B was in the fallow after sorghum phase. Field 11A produced 3.66 mm of runoff while the 11B SM pair produced 0.15 mm of runoff and no sediment sample. Field 12B produced 17.1 mm of runoff while the 12A NT field pair recorded 29.4 mm of runoff and 341 kg ha^{-1} of soil loss. Sample malfunctions during the two described storm events could have possibly contributed to an additional 2.5% or greater recorded soil loss during the 27-year study period. Each sediment sampler malfunction is listed in Table 2, with corresponding sampler field, precipitation, and runoff amounts.

	Sediment Sampler Malfunction Analysis (Smalf)				
Date of Malfunction	Fields Affected	Phase	Tillage	Precipitation Amount (mm)	Runoff Amount (mm)
Oct. 10, 1984	12A	Wheat	NT	23.6	9.99
Aug. 6, 1989	10B	Fallow after Wheat	SM	35.1	2.35
Jun. 21, 1992	11A	Fallow after Sorghum	NT	18.8	9.19
Aug. 26, 1992	11A	Fallow after Sorghum	NT	23.9	4.58
Aug. 26, 1992	12A	Sorghum	NT	23.9	2.23
June 19, 1993	10A	Sorghum	NT	39.1	3.11
Jul. 15, 1993	11A	Fallow after Wheat	NT	72.9	3.66
Jul. 15, 1993	12B	Fallow after Sorghum	SM	72.9	17.1
April 25, 1997	12A	Wheat	NT	64.5	18.7
Oct. 30, 1998	12B	Fallow after Sorghum	SM	131	49.4

Table 2. Sediment Sampler Malfunctions 1984-2010.

On eight occasions throughout the study, sediments samplers were not installed (NI) during storm events resulting in the non-reporting of soil loss amounts. In each case all fields were affected. The highest volume storm event without installation of sediment samplers was 77.7 mm on March 24, 2007. The highest runoff amount resulting from this storm event was 35.2 mm for field 11A during the fallow after sorghum phase. Average soil loss for storms in the 76.3 to 101.6 mm category was 634 kg ha^{-1} across all fields and crop phases although soil losses ranged from a minimum of 90.3 kg ha^{-1} with NT to a 3.85 Mg ha^{-1} maximum with SM. An 80.0 mm storm on July 10, 1999 produced soil loss samples ranging from 0 with SM in the fallow after wheat phase to 256 kg ha^{-1} for SM in the sorghum phase. The seven remaining storm events without installed sediment samplers ranged from 25.4 mm to 29.5 mm. Storms in the 20-30 mm category can have widely varying storm runoff and soil loss amounts dependent highly on crop phase and tillage. For example, SM tillage fields in the fallow after wheat phase had an average precipitation of 25.0 mm with a standard error of ± 1.23 mm resulting in no sediment sample recording 68.4% of the time. All uninstalled sediment sampler events are listed below in Table 3, with corresponding precipitation amounts and the highest runoff amount for each event recorded.

	Sediment Sample Loss Due to No Instillation (NI) Analysis		
Not Installed Date	Fields Affected	Precipitation Amount (mm)	Highest Event Runoff (mm)
Nov. 22, 1991	All Fields	26.9	12.0
Mar. 16, 1998	All Fields	29.2	17.5
Jan. 30, 1999	All Fields	27.9	4.57
Nov. 24, 2004	All Fields	26.9	9.01
Oct. 9, 2006	All Fields	26.4	2.26
Dec. 20, 2006	All Fields	25.4	0.28
Mar. 24, 2007	All Fields	77.7	35.5
Jan. 30, 2010	All Fields	29.5	3.08

Table 3. Storm events without functioning sediment samplers.

Soil loss is dependent on runoff to entrain and transport soil particles. Many medium size precipitation events produced minimal runoff and no soil loss. Therefore, an analysis was conducted to determine the minimum amount of rainfall and runoff needed to produce soil loss in both tillage practices and within each crop phase of the W-S-F rotation. All No Sample (NS) recordings were evaluated and organized by tillage and crop phase. Average precipitation and average runoff with standard error was included for each category as listed in Table 4. The average runoff amount that produced no soil loss was highest for SM fields during the fallow after wheat phase at 0.42 mm due to added soil protect with wheat residues. However, standard error was also highest for the SM fallow after wheat category at 0.34 indicating a high variability of soil loss volumes resulting from decreased residue cover with each tillage operation. The next highest runoff average resulting in no soil loss was for NT fallow after sorghum fields at 0.27 mm ± 0.06. Overall, average precipitation tolerances were lower for NT fields across all phases while runoff tolerances were higher, following trends of increased runoff and decreased soil loss with NT management.

	Soil Loss No Sample (NS) Analysis			
	No-Till		Stubble-Mulch	
Phase	Average Precipitation (mm) ± Standard Error	Average Runoff (mm) ± Standard Error	Average Precipitation (mm) ± Standard Error	Average Runoff (mm) ± Standard Error
Wheat	22.1 ± 1.34	0.16 ± 0.06	22.6 ± 1.45	0.12 ± 0.05
Fallow after Wheat	22.6 ± 0.97	0.21 ± 0.06	25.0 ± 1.23	0.42 ± 0.34
Sorghum	23.8 ± 1.16	0.25 ± 0.11	24.1 ± 1.27	0.07 ± 0.03
Fallow after Sorghum	20.6 ± 0.91	0.27 ± 0.06	23.4 ± 0.99	0.09 ± 0.02

Table 4. Analysis of runoff events without recorded soil loss.

Total occurrences of No Sample (NS) events were summed for each tillage treatment and phase and percentages were calculated. NT fields during the sorghum phase had the highest percentage of NS soil loss events in relation to total storm events at 68.6%. Total NS events and percentages to total storms remained relatively the same between tillage treatments and crop phases with the exception of the NT fallow after sorghum category. Only 42.9% of storm events produced no soil loss in the NT fallow after sorghum category compared with 64.3% with SM fallow after sorghum. However, 27-year averages of soil loss with NT in the fallow after sorghum phase were 524 kg ha^{-1} compared to 642 kg ha^{-1} with SM. Table 5 shows NS totals and percentages for each tillage and phase.

	Occurrence of No Sample (NS) Soil Loss Events by Phase			
	NT		SM	
	Number of NS	Percent of Total Storm Events	Number of NS	Percent of Total Storm Events
Wheat	60	63.2	62	65.3
Fallow after Wheat	120	62.2	132	68.4
Sorghum	96	68.6	84	60.0
Fallow after Sorghum	84	42.9	126	64.3

Table 5. Further analysis of runoff events without recorded soil loss.

1984-2010 YEARLY DATA ANALYSIS

The full original dataset was separated by the two tillage treatments to establish documented trends. The average 27-year storm volume for both NT and SM was 26.7 mm with a standard error of 1.4 mm and a standard deviation of 19.4 mm within the dataset. The average of all storm runoff values was 5.24 mm for NT with a standard error of 0.73 mm and standard deviation of 10.0 mm compared with an average storm runoff value of 3.79 mm for SM tillage with a standard error of 0.67 mm and standard deviation of 9.20 mm. These values follow trends of greater rainfall infiltration on SM fields due to the elimination of surface crusting with each tillage treatment (Appendix C; Jones et al., 1994). Conversely, total average soil loss with NT management was 132 kg ha^{-1} with a standard error of 19.3 kg ha^{-1} and standard deviation within the data of 266 kg ha^{-1}. SM fields recorded a soil loss average of 282 kg ha^{-1} with a standard error of 44.2 kg ha^{-1} and standard deviation of 609 kg ha^{-1}. Complete precipitation, runoff, and soil loss datasets were found to be not normally distributed based on Kolmogorov-Smirnov results (Appendix C).

Only precipitation amounts that resulted in runoff events were recorded in the datasheet. Average precipitation within the W-S-F phases from 1984-2010 totaled 101 mm for wheat, 203 mm for fallow after wheat, 139 mm for sorghum, and 199 mm for fallow after sorghum. Twenty-seven-year runoff event averages by phase for NT plots were 11.5 mm, 26.0 mm, 12.5 mm, 37.7 mm for wheat, fallow after wheat, sorghum, and fallow after sorghum respectively. Twenty-seven-year runoff event averages by phase for SM plots were 7.3 mm for the wheat phase, 15.8 mm for fallow after wheat, 12.2 mm for sorghum, and 19.7 mm for fallow after sorghum. These figures not only further demonstrate increased runoff volume with NT but also follow trends of crop stage and residue retention effects on runoff and infiltration capacity. Average wheat phase soil loss was 152 kg ha^{-1} for NT and 170 kg ha^{-1} for SM. Fallow after wheat was 322 kg ha^{-1} for NT and 598 kg ha^{-1} for SM. Soil loss averages for sorghum were 189 kg ha^{-1} for NT and 576 kg ha^{-1} for SM. Average fallow after sorghum soil loss was 524 kg ha^{-1} for NT and 642 kg ha^{-1} in SM fields.

Precipitation, storm runoff, and soil loss nine year means for each crop phase and tillage were found to be normally distributed with all ρ values being greater than the significance level of 0.05 (Appendix D). T-test comparison of means showed nine-year means of NT runoff were significantly greater ($\alpha = 0.05$) than SM fields in the wheat, fallow after wheat, and fallow after sorghum phases (Table 6). Nine-year NT average runoff amounts were consistently greater than SM except in the 1993-2001 year range for the sorghum phase when NT runoff averaged 8.6 mm while SM was 12.5 mm. This deviation could be explained by two storm events early in the sorghum growing seasons of July 1993 and 1995 when fields were still in the seedbed phase of plant growth providing little canopy cover. Greater wheat residues left on the NT field surface from the fallow after wheat period could allow decreased runoff amounts for NT.

T-test comparison analysis of nine-year soil loss means revealed SM was significantly greater ($\alpha = 0.05$) than NT in the sorghum crop phase. Although soil loss amounts were higher for SM than NT in all three, nine-year ranges (Appendix A; Appendix B).

	NT and SM Runoff Nine Year Means Student's t-test Comparison by Phase			
	Wheat	Fallow after Wheat	Sorghum	Fallow after Sorghum
H_o: α (0.05) < ρ	Means of datasets are not significantly different.			
H_a: α (0.05) > ρ	Means of datasets are significantly different.			
ρ value (determination)	0.002	0.046	0.898	0.016
results	α (0.05) > ρ (0.002)	α (0.05) > ρ (0.046)	α (0.05) < ρ (0.898)	α (0.05) > ρ (0.016)
conclusion	Reject H_o; Means are significantly different	Reject H_o; Means are significantly different	Fail to reject H_o; Means are not significantly different	Reject H_o; Means are significantly different
interpretation	NT > SM	NT > SM	SM > NT	NT > SM

Table 6. NT and SM Runoff Nine Year Means Student's t-test Comparison by Phase.

Means of nine-year runoff averages were significantly greater in NT than SM fields in the wheat, fallow after wheat, and fallow after sorghum phases. Means of nine-year runoff averages were greater for SM than NT in the sorghum phase but were not significantly different.

	NT and SM Soil Loss Nine Year Means Student's t-test Comparison by Phase			
	Wheat	Fallow after Wheat	Sorghum	Fallow after Sorghum
H_o: α (0.05) < ρ	Means of datasets are not significantly different.			
H_a: α (0.05) > ρ	Means of datasets are significantly different.			
ρ value (determination)	0.663	0.346	0.034	0.594
results	α (0.05) < ρ (0.663)	α (0.05) < ρ (0.346)	α (0.05) > ρ (0.034)	α (0.05) < ρ (0.594)
conclusion	Fail to reject H_o; Means are not significantly different	Fail to reject H_o; Means are not significantly different	Reject H_o; Means are significantly different	Fail to reject H_o; Means are not significantly different
interpretation	SM > NT	SM > NT	SM > NT	SM > NT

Table 7. NT and SM Soil Loss Nine Year Means Student's t-test Comparison by Phase.

Means of nine-year soil loss averages were greater for SM than NT but were only significantly different in the sorghum phase.

DATA ANALYSIS BY FIELD

Comparisons by year could be misleading because fields are grouped solely by crop phase. Grouping by year could exclude influencing and intensifying factors such as field differences and large storms. Furthermore, all crop phases except the sorghum phase extend from one calendar year to the next. Since the dryland plots at USDA-ARS Bushland are arranged in NT and SM pairs that experience the same rainfall events and crop rotation, the effects of tillage treatments on runoff and soil loss can be easily compared when measurements are separated by field. Twenty-seven year totals for each field, phase, and category are listed in Tables 8 and 9. Fallow periods are longer than crop growing phases and precipitation is higher in the summer months. Therefore, precipitation totals were highest for fallow after wheat and fallow after sorghum periods with rainfall during the sorghum crop growing phase higher than the wheat growing phase. Storm runoff amounts were also consistently higher for NT fields across all phases while soil loss was higher for SM fields. The only exception is a higher soil loss volume for 12A during the wheat phase when compared with 12B. Field 12A recorded a total soil loss amount of 611 kg ha^{-1} while 12B totaled 413 kg ha^{-1}. A portion of the difference in soil loss can be contributed to a single 22.9 mm storm event which occurred on October 14, 2008 creating total soil loss of 126 kg ha^{-1} in field 12A and 86.4 kg ha^{-1} in field 12B.

	27 Year Precipitation, Storm Runoff (SR), and Soil Loss (SL) Totals for NT Fields by Phase										
		10A-NT				11A-NT				12A-NT	
	Precip.	SR	SL		Precip	SR	SL		Precip.	SR	SL
	mm	mm	Mg ha^{-1}		mm	mm	Mg ha^{-1}		mm	mm	Mg ha^{-1}
Wheat	1240	75.0	0.47	**Wheat**	711	166	3.04	**Wheat**	769	68.3	0.61
FW	1636	207	1.74	**FW**	1846	151	1.69	**FW**	1989	343	5.27
Sorghum	1439	88.9	1.09	**Sorghum**	1182	96.5	1.31	**Sorghum**	1128	151	2.69
FS	1467	182	2.39	**FS**	2043	324	2.63	**FS**	1895	512	9.14
Precip. -Precipitation											

Table 8. 27-Year Precipitation causing runoff, Storm Runoff, and Soil Loss Totals for NT Fields by Phase.

	27 Year Precipitation, Storm Runoff (SR), and Soil Loss (SL) Totals for SM Fields by Phase										
		10B-SM				11B-SM				12B-SM	
	Precip.	SR	SL		Precip	SR	SL		Precip	SR	SL
	mm	mm	Mg ha^{-1}		mm	mm	Mg ha^{-1}		m	mm	Mg ha^{-1}
Wheat	1240	47.0	0.57	**Wheat**	711	136	3.61	**Wheat**	769	13.1	0.41
FW	1636	162	3.04	**FW**	1846	60.8	3.58	**FW**	1989	204	9.53
Sorghum	1439	115	6.07	**Sorghum**	1182	103	2.84	**Sorghum**	1128	110	6.62
FS	1467	116	4.70	**FS**	2043	154	3.31	**FS**	1895	262	9.32
Precip. -Precipitation											

Table 9. 27-Year Precipitation causing runoff, Storm Runoff, and Soil Loss Totals for SM Fields by Phase.

Kolmogorov Smirnov tests for distribution normality were conducted for each field, phase, and for each dataset of precipitation, storm runoff, and soil loss. The only dataset that resembled normal distribution was field 12A wheat phase soil loss. In all other fields and categorical datasets α (0.05) was greater than ρ, indicating non-normal distributions (Appendix E). With the consistent absence of normal distributions, non-parametric statistical methods were employed for further data comparisons. After completion of Kolmogorov-Smirnov analysis, Kruskal-Wallis H-Tests for one-way analysis of variance were performed to compare probability distributions for precipitation, storm runoff, and soil loss between fields with the same tillage treatment for each crop phase. Probability distributions were the same between most "A" NT fields and "B" SM fields with exceptions being SM wheat phase runoff, NT sorghum phase runoff, and NT wheat phase soil loss. Pairwise comparisons were performed using Dunn's procedure with a Bonferroni correction for multiple comparisons (Dunn, 1964; Laerd, 2015). Pairwise Post-Hoc analysis revealed significantly different median scores between fields 10B-11B and 11B-12B for SM wheat phase runoff. After further examination, median values for SM wheat phase runoff were very low and not indicative of large variations or volumes. With the same methods employed for SM wheat phase runoff, NT sorghum phase runoff and NT wheat phase soil loss revealed statistical differences between their respective probability distributions. Post-Hoc pairwise analyses are shown below in Tables 11, 13, and 15. For NT fallow after sorghum phase runoff there was significant differences between fields 10A-12A and 11A-12A. The median for NT fallow after sorghum runoff was 3.93 mm for 12A compared with 0.7 mm for 11A and 0.34 mm for 10A. These differences are likely attributed to field 12A frequently being in the fallow after sorghum phase when large rainfall events occurred creating increased runoff volumes. For example, field 12A was in the fallow after sorghum phase for two of the three largest storms on record. Like field 12A, NT wheat phase soil loss totals for field 11A were highly influenced by two large soil loss events resulting from the 131 mm storm on October 30, 1998 and the 96.5 mm storm on June 12, 1984.

Kruskal-Wallis H Test for Stubble-Mulch Wheat Phase Runoff (Fields 10B, 11B, 12B)	
H_o: α (0.05) < ρ	The three probability distributions are the same.
H_a: α (0.05) > ρ	The three probability distributions are not the same.
α (significance level)	0.05
H_{stat} (2)	8.22
ρ value (determination)	0.016
results	α (0.05) > ρ (0.016)
conclusion	Reject H_o; The three probability distributions are not the same.

Table 10. Kruskal-Wallis H Test for Stubble-Mulch Wheat Phase Runoff.

Post Hoc Analysis for Stubble-Mulch Wheat Phase Runoff (Fields 10B, 11B, 12B)			
H_o: α (0.05) < ρ	Median scores are not significantly different between datasets.		
H_a: α (0.05) > ρ	Median scores are significantly different between datasets.		
Field comparisons	10B-11B	12B-11B	12B-10B
α (significance level)	0.05	0.05	0.05
ρ value	0.031	0.029	0.999
results	α (0.05) > ρ (0.031)	α (0.05) > ρ (0.029)	α (0.05) < ρ (0.999)
conclusion	Reject H_o	Reject H_o	Fail to reject H_o*

Table 11. Post Hoc Analysis for Stubble-Mulch Wheat Phase Runoff.

Kruskal-Wallis H Test for No-Till Fallow after Sorghum Phase Runoff (Fields 10A, 11A, 12A)	
H_o: α (0.05) < ρ	The three probability distributions are the same.
H_a: α (0.05) > ρ	The three probability distributions are not the same.
α (significance level)	0.05
H_{stat} (2)	17.6
ρ value (determination)	0.001
results	α (0.05) > ρ (0.001)
conclusion	Reject H_o; The three probability distributions are not the same.

Table 12. Kruskal-Wallis H Test for No-Till Fallow after Sorghum Phase Runoff.

Post Hoc Analysis for No-Till Fallow after Sorghum Phase Runoff (Fields 10A, 11A, 12A)			
H_o: α (0.05) < ρ	Median scores are not significantly different between datasets.		
H_a: α (0.05) > ρ	Median scores are significantly different between datasets.		
Field comparisons	10A-11A	12A-11A	12A-10A
α (significance level)	0.05	0.05	0.05
ρ value	0.999	0.001	0.001
results	α (0.05) < ρ (0.999)	α (0.05) > ρ (0.001)	α (0.05) > ρ (0.001)
conclusion	Fail to reject H_o	Reject H_o	Reject H_o
		12A > 11A	12A > 10A

Table 13. Post Hoc Analysis for No-Till Fallow after Sorghum Phase Runoff.

Kruskal-Wallis H Test for No-Till Wheat Phase Soil Loss (Fields 10A, 11A, 12A)	
H_o: α (0.05) < ρ	The three probability distributions are the same.
H_a: α (0.05) > ρ	The three probability distributions are not the same.
α (significance level)	0.05
H_{stat} (2)	10.194
ρ value (determination)	0.006
results	α (0.05) > ρ (0.006)
conclusion	Reject H_o; The three probability distributions are not the same.

Table 14. Kruskal-Wallis H Test for No-Till Wheat Phase Soil Loss.

Post Hoc Analysis for No-Till Wheat Phase Soil Loss (Fields 10A, 11A, 12A)			
H_o: α (0.05) < ρ	Median scores are not significantly different between datasets.		
H_a: α (0.05) > ρ	Median scores are significantly different between datasets.		
Field comparisons	10A-11A	12A-11A	12A-10A
α (significance level)	0.05	0.05	0.05
ρ value	0.007	0.999	0.221
results	α (0.05) > ρ (0.007)	α (0.05) < ρ (0.999)	α (0.05) < ρ (0.221)
conclusion	Reject H_o	Fail to reject H_o	Fail to reject H_o
	11A > 10A		

Table 15. Post Hoc Analysis for No-Till Wheat Phase Soil Loss.

STORM INTENSITY ANALYSIS

Storm intensity is a significant contributor to runoff and soil loss. Characterization of storms at USDA-ARS Bushland was first accomplished by the categorization of storm precipitation events in the size categories described by Jones et al. (1985). A total of 208 storm events that caused runoff occurred in the study period from 1984-2010. The highest number of storms occurred in the rainfall category of 12.8 mm to 25.4 mm with a total of 92 storm events accounting for 30.8% of total precipitation. Seventy-six storms in the 25.5-50.8 mm category accounted for 44.4% of total precipitation during the study period. All storm categories with total storms, precipitation amounts, and percentages of total precipitation are listed in Table 16.

Characteristics of precipitation at Bushland, Texas 1984-2010			
Storm Size	**Number of storms**	**Total Precipitation**	**Percent of**
mm		**mm**	**27-year total**
.3-2.5	0	0	0.0
2.6-6.4	1	4.32	0.1
6.5-12.7	23	244	4.2
12.8-25.4	92	1783	30.8
25.5-50.8	76	2568	44.4
50.9-76.2	10	614	10.6
76.3-101.6	5	437	7.6
101.7-127.0	0	0	0.0
>127.0	1	131	2.3
Total	208	5782	

Table 16. Characteristics of precipitation at Bushland, Texas 1984-2010.

Although frequent, medium size storms are not indicative of large runoff and soil loss events. Thirteen of the highest rainfall events with completely operational monitoring equipment were evaluated for their effects on storm runoff and soil loss for each crop phase and tillage treatment. The thirteen storms ranged in size from 52.3 mm to 131 mm with storm dates spanning May to October. Out of the total 208 storms in the 27-

year period these thirteen storms account of 16.7% of total rainfall and caused 23.3% to 49.0 % of total runoff. Total soil loss percentages resulting from these intense storms ranged from 22.1% to 67.6% (Appendix G).

Runoff and soil loss were further analyzed by storm category by developing means and frequency percentages for each phase and tillage. The storm category 12.8-25.4 mm accounted for 42.2% of runoff events and 20.9% of runoff volumes. The NT wheat phase had the highest average runoff in this category with 3.07 mm while the NT fallow after sorghum phase accounted for 19% of total runoff events. The 25.5-50.8 mm storm category caused 35.8% of runoff events and 31.5% of total runoff with the NT fallow after sorghum phase contributing the highest average runoff at 5.79 mm and the highest percentage of events at 18.9%. Wheat residues provide more surface coverage than sorghum residues to protect against storms in the 25.5-50.8 mm category (Baumhardt et al., 2011; Jones et al., 1994). The fallow after sorghum period extends through an entire summer when large storms normally occur. Additionally, tillage on SM fallow after sorghum fields can increase rainfall infiltration. Decreased residue cover, intense summer storms, and slower infiltration rates explain why NT fields in the fallow after sorghum phase are most vulnerable to runoff events (Blanco-Canqui et al., 2011; Jones et al., 1994). Storms ranging from 50.9-76.2 mm resulted in 6.6% of runoff events and 18.1% of total runoff volumes. In the 50.9-76.2 mm storm category NT fallow after sorghum had the most recorded runoff events of all phases at 18.2%. While the 76.3-101.6 mm storm category accounted for only 3.5% of total events, these 29 runoff events resulted in 20% of total 27-year runoff.

Soil loss categorized by storm intensity followed similar trends of storm runoff. The 12.8-25.4 mm precipitation category accounted for 40.1% of soil loss events and 23.4% of total soil loss. The 25.5-50.8 mm storm group accounted for 40.2% of soil loss events and 29.2% of the 27-year total. Higher rainfall volumes increased soil loss totals. Storms greater than 50.9 mm caused 15.9% of total soil loss events and 46.6% of total soil loss volumes. Average wheat phase soil loss varied between NT and SM tillage but wheat phase soil loss events only accounted for 7.7% of total events across all storm categories. Soil loss averages for fallow after wheat, sorghum, and fallow after sorghum were normally higher for SM tillage compared to NT except in the 76.3-101.6 mm storm category where NT had higher averages for all phases except fallow after sorghum. Higher soil loss for NT was found in four large storms with no rainfall occurring during the previous week before each storm. The absence of consecutive storms rules out moist soil conditions as a contributing factor to greater runoff and soil loss volumes (Baumhardt and Brauer, 2018). Runoff was higher for NT in all storm events for the 76.3-101.6 mm storm category except the June 12, 1984, 96.5 mm storm when runoff was 32.5 mm for NT and 43.7 mm for SM in the fallow after wheat phase. This 96.5 mm storm caused 218 kg ha^{-1} of soil loss for NT and no soil loss for SM. The July 7, 1999, 80 mm storm caused 118 kg ha^{-1} soil loss for NT and no soil loss for SM early in the fallow after wheat phase. Soil crusting between tillage treatments in an SM field could cause increased runoff while the consolidate surfaces a crust creates could protect topsoil from erosion. The September 11, 1985, 84.3 mm storm caused 192 kg ha^{-1} soil loss for NT and 38 kg ha^{-1} for SM in the fallow after wheat phase. Although NT normally has greater residue cover and aggregate stability that creates resistance to soil erosion, prolonged rainfall could cause ponding on the soil surface. As rainfall continues, greater water flow turbulence is created (Marshall et al., 1999). Cracks in the soil surface created during the previous wheat phase allow greater water storage for NT but when the profile reaches storage capacity or terminal infiltration rates, runoff increases (Jones et al., 1994; Marshall et al. 1999). Increased runoff and turbulence could generate sediment entrainment and transport. Jones et al. (1994) showed greater dry aggregate mean weight diameter for SM than NT in the fallow after wheat phase following a tillage operation. Jones et al. (1994) also found 26% greater two-hour infiltration rates for SM compared with NT. Larger aggregates and greater infiltration rates could make SM fields more resistant to erosion in the fallow after wheat phase with recent tillage and extended rainfall periods. The September 15, 1988, 98.0 mm storm event resulted in soil losses of 381 kg ha^{-1} for NT field 11A and 99.0 kg ha^{-1} for SM field 11B in the sorghum phase. September is late in the sorghum season. Sorghum growing season precipitation in 1988 remain consistent with 1984-1992 averages making crop failure or low growth an unlikely cause of increased soil loss. Baumhardt et al. (2017) showed greater water storage and leaf area indexes with NT sorghum compared to SM. Vegetative leaves of a sorghum plant in the hard dough or physiological maturity stage can remain green or die and brown rapidly because plant moisture is used for grain production (Vanderlip, 1993). Leaves can also be lost entirely (Vanderlip, 1993). Loss of leaf area could create variable canopy coverage in fields, leaving soil surfaces unprotected from the kinetic energy of rainfall. Less canopy coverage during an intense storm event could be responsible for greater soil loss in NT during the September 15, 1988 storm.

SIMPLE AND MULTIPLE LINEAR REGRESSION ANALYSIS

Precipitation and runoff data from NT fields was regressed using precipitation as the independent variable and runoff as the dependent variable. An R-square value of 0.495 was found between precipitation and runoff amounts. The following equation for NT runoff was calculated.

$$\text{NT Runoff} = -5.77 + (0.344 \times \text{precipitation, mm})$$

Equation 6. NT Runoff Simple Linear Regression.

The regression of precipitation and runoff amounts in SM fields produced an R-square value of 0.394 and the following trendline equation.

$$\text{SM Runoff} = -4.77 + (0.261 \times \text{precipitation, mm})$$

Equation 7. SM Runoff Simple Linear Regression.

The higher slope coefficient of 0.344 in the NT equation indicates a stronger positive relationship between precipitation and runoff in NT fields. Less rainfall is needed to create higher runoff amounts with NT residue management.

Using multiple linear regression methods, the relationship of precipitation and runoff volumes as independent variables and soil loss as the dependent variable was assessed. Stepwise, Removal, Forward, and Backward multiple linear regression methods produced the same adjusted R-square values, independent variable coefficients, and Pearson correlation coefficients for NT and SM soil loss datasets. Precipitation and runoff were found to significantly predict soil loss at $p < \alpha$ (0.05) in both models. The NT soil loss model produced an adjusted R-square value of 0.717. The Pearson correlation coefficient between NT precipitation and soil loss was 0.555. The Pearson correlation coefficient for NT runoff and soil loss was 0.844. The multiple linear regression equation produced for NT soil loss was:

$$\text{NT Soil Loss kg ha}^{-1} = 11.0 - (1.23 \text{ x precipitation, mm}) + (19.8 \text{ x runoff, mm})$$

Equation 8. NT Soil Loss Multiple Linear Regression.

Using the same methods as NT data, SM soil loss produced an adjusted R-square value of 0.689 with Pearson correlation coefficients of 0.400 for precipitation and soil loss and 0.817 for runoff and soil loss. The regression equation for SM soil loss was:

$$\text{SM Soil Loss kg ha}^{-1} = 106.3 - (4.97 \text{ x precipitation, mm}) + (51.9 \text{ x runoff, mm})$$

Equation 9. SM Soil Loss Multiple Linear Regression.

A higher slope coefficient for runoff in the SM soil loss equation shows a greater susceptibility of SM fields to soil loss.

The comparison of actual runoff and soil loss volumes with predicted values for the regression models could explain sources of variation. Casewise diagnostics for residuals greater than three standard deviations revealed variation of runoff and soil loss for both NT and SM fields in the fallow after wheat and fallow after sorghum phases. Additionally, fields 12A and 12B were consistent outliers. In the NT soil loss regression model field 12A produced the three highest residuals. In all three cases the regression equation underestimated actual soil loss amounts. In the SM soil loss model, field 12B generated the three highest positive residuals. The June 12, 1984, 96.5 mm storm accounted for 50% of the highest residual events from all regression equations. This 96.5 mm storm was the third largest rainfall event recorded in 27 years. Field 12B had the highest residual in the SM soil loss model for a 3.85 Mg ha^{-1} soil loss event resulting from a 54.1 mm storm on June 11, 1992 in the fallow after wheat phase. Since both of these large storms occur late in the fallow periods, increased runoff and soil loss could be attributed to residue decomposition and soil profile water storage (Baumhardt and Brauer, 2018). Both factors could increase runoff and soil loss due to less soil protection and decreased infiltration (Baumhardt et al., 2011). Anomalies in fields 12A and 12B could be attributed to increased slope, accelerating water turbulence and sediment entrainment and limiting opportunities for sediment redeposition (Marshall et al., 1999). Field slope of the six dryland plots gradually increases moving west to east. Field 12B has a 1.8% slope compared to field 10A with a 1.2% slope (Jones et al., 1994).

CHAPTER IV. DISCUSSION

COMPARISON OF RESULTS TO PREVIOUS RESEARCH

Annual precipitation averages were calculated from rainfall events that caused storm runoff. The 27-year annual precipitation resulting in runoff was 214 mm. Jones et al. (1985) found a 26-year total annual rainfall average of 462 mm. Therefore, 46% of annual rainfall can contribute to runoff events. Similar to Jones et al. (1985), rainfall followed trends of higher summer precipitation volumes (Fig. 6). When compared with the combined wheat and fallow after wheat phases with SM, runoff averages from 1984-2010 were 23.1 mm, similar to the 20.5 mm recorded from 1958-1983 in Jones et al. (1985). Runoff from sorghum and fallow after sorghum phases with SM tillage measured 12.2 mm and 19.7 mm compared with 43.3 mm and 40.5 mm in Jones et al. (1985). Soil loss was also consistently lower with SM wheat and fallow after wheat averages totaling 768 kg ha^{-1} in contrast to 1.15 Mg ha^{-1} in Jones et al. (1985). SM sorghum soil loss was 576 kg ha^{-1} with fallow after sorghum averages of 642 kg ha^{-1} compared to 2.66 Mg ha^{-1} and 1.76 Mg ha^{-1} for the years 1958-1983. The nine-year 1984-1992 soil loss averages were consistently different from those recorded in Jones et al. (1995). Runoff means for NT and SM tillage treatments remained similar between this study and Jones et al. (1995), but soil loss averages were much lower. Trends of deceased soil loss with NT and higher soil loss for the fallow after sorghum phase were still present (Fig. 6, Fig. 7, Fig. 8).

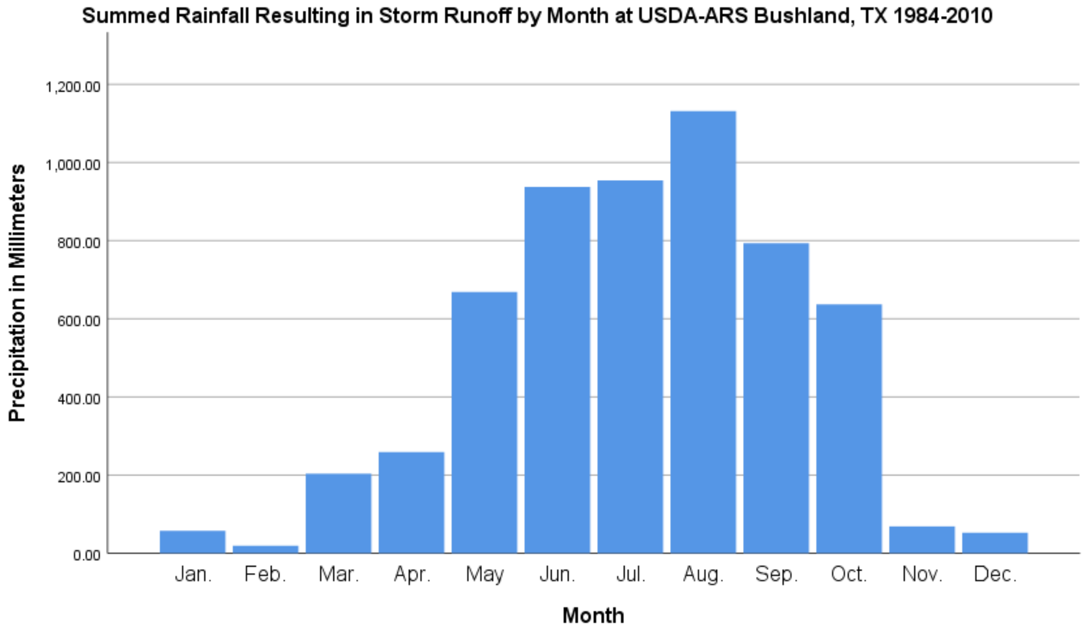

Figure 6. Total summed rainfall by month in (mm) 1984-2010.

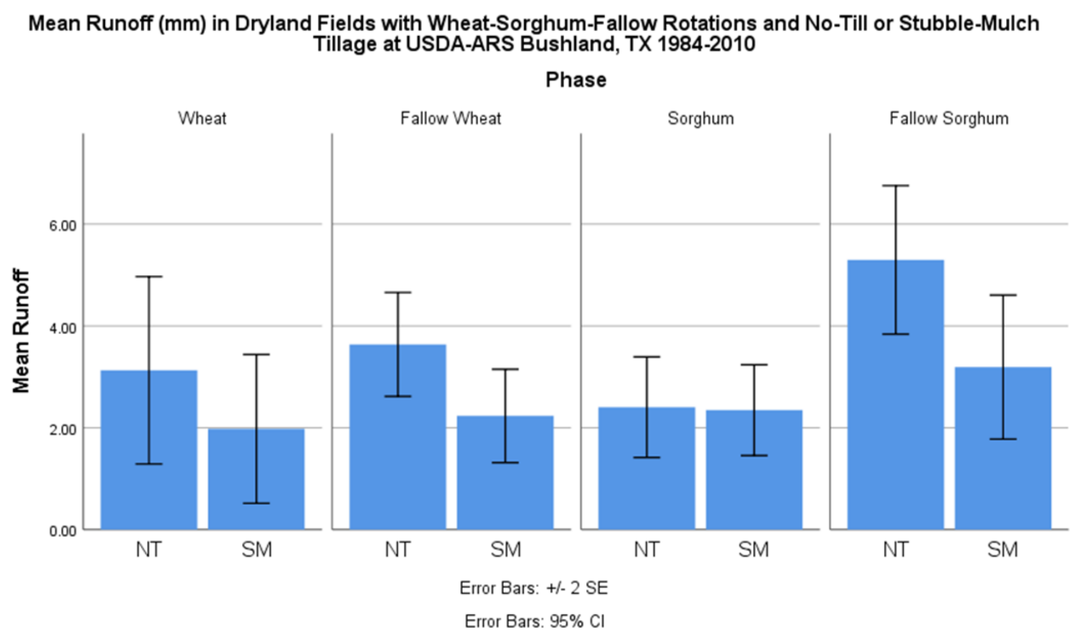

Figure 7. Mean storm runoff in (mm) by tillage and crop phase 1984-2010.

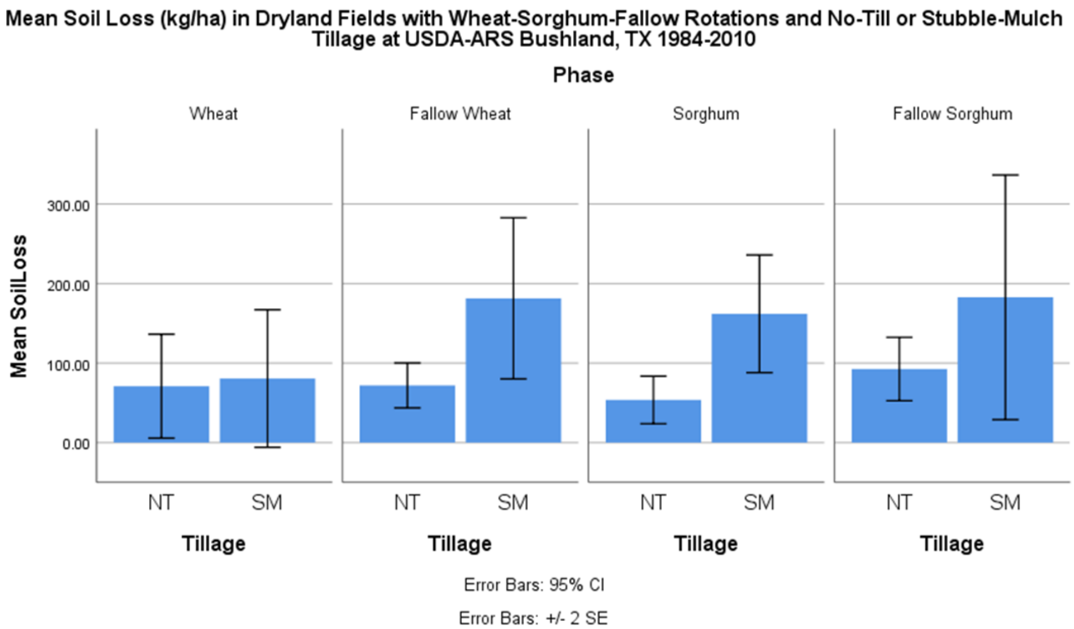

Figure 8. Mean soil loss in kg ha^{-1} by tillage and crop phase 1984-2010.

Baumhardt and Brauer (2018) found some similar characteristics of runoff within storm categories as this study. For example, runoff in the storm category 12.8-25.4 mm resulted in 20.9% of total runoff compared to 25.3% in the Baumhardt and Brauer (2018) study while the 25.5-50.8 mm caused 31.5% of total runoff volume in this study compared to 31.9% from years 1990-2009 in Baumhardt and Brauer (2018).

UNADDRESSED FACTORS

Planting dates vary to allow adequate rainfall for crop establishment. Harvest dates can be delayed by wet conditions that cause problems for machinery and leave the soil susceptible to compaction. Using mean planting and harvest dates described in Hauser and Jones (1991) for data phase organization was unfavorable because precipitation, runoff, and soil loss data could be incorrectly categorized in the wrong crop rotation phase. Actual planting and harvest dates would provide correct categorization of any storm and runoff or soil loss events at the beginning and end of crop and fallow phases when residue cover, tillage operations, and water storage can affect infiltration, runoff, and soil losses. Storm duration records and details of field conditions at the time of runoff and soil loss events could further explain variation in runoff and soil loss volumes.

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APPENDIX A: 27-Year and 9-Year Totals and Means

Precipitation totals only include storm events that resulted in runoff. The following tables in APPENDIX A represent 27-year and 9-year totals and means of precipitation, runoff, and soil loss in all phases of the Wheat-Sorghum-Fallow crop rotation in Bushland, TX from 1984-2010. Wheat (W), Fallow after Wheat (FW), Sorghum (S), Fallow after Sorghum (FS), No-Till (NT), Stubble-Mulch (SM), Precipitation (P), Runoff (RO), and Soil Loss (SL) abbreviations are used in combination to describe totals for each crop phase and tillage management practice.

Precipitation Totals 1984-2010 in (mm)	
27 Year Total	5782
27 Year Average	214
1984-1992 Average	288
1993-2001 Average	182
2002-2010 Average	172
*Only precipitation that resulted in runoff is included in precipitation totals.	

Wheat Phase 6 October to 24 June					
	mm	mm	kg ha^{-1}	mm	kg ha^{-1}
	WP	WNTRO	WNTSL	WSMRO	WSMSL
27 Year Total	2720	310	4116	196	4593
27 Year Average	101	11.5	152	7.3	170
1984-1992 Average	137	11.9	175	8.0	157
1993-2001 Average	87.8	16.1	219	11.5	307
2002-2010 Average	77.4	6.4	62.9	2.2	46.4

Fallow after Wheat Phase 25 June to 15 June					
	mm	mm	kg ha^{-1}	mm	kg ha^{-1}
	FWP	FWNTRO	FWNTSL	FWSMRO	FWSMSL
27 Year Total	5470	702	8702	427	16149
27 Year Average	203	26.0	322	15.8	598
1984-1992 Average	270	40.3	387	26.3	1059
1993-2001 Average	173	23.9	221	13.5	486
2002-2010 Average	165	13.7	359	7.6	249

Sorghum Phase 16 June to 29 October					
	mm	**mm**	**kg ha^{-1}**	**mm**	**kg ha^{-1}**
	SWP	**SNTRO**	**SNTSL**	**SSMRO**	**SSMSL**
27 Year Total	3749	337	5092	329	15541
27 Year Average	139	12.5	189	12.2	576
1984-1992 Average	189	17.6	174	15.5	542
1993-2001 Average	107	8.6	181	12.5	704
2002-2010 Average	121	11.2	211	8.5	482

Fallow after Sorghum Phase 30 October to 7 October					
	mm	**mm**	**kg/ha**	**mm**	**kg/ha**
	FSP	**FSNTRO**	**FSNTSL**	**FSSMRO**	**FSSMSL**
27 Year Total	5370	1017	14159	533	17331
27 Year Average	199	37.7	524	19.7	642
1984-1992 Average	269	52.9	728	30.7	1217
1993-2001 Average	179	35.6	582	18.6	482
2002-2010 Average	148	24.5	264	9.9	227

APPENDIX B: Yearly Totals by Tillage and Crop Phase

Precipitation totals only include storm events that resulted in runoff. The following tables in APPENDIX B represent yearly totals of precipitation, runoff, and soil loss in all phases of the Wheat-Sorghum-Fallow crop rotation in Bushland, TX from 1984-2010. Wheat (W), Fallow after Wheat (FW), Sorghum (S), Fallow after Sorghum (FS), No-Till (NT), Stubble-Mulch (SM), Precipitation (P), Runoff (RO), and Soil Loss (SL) abbreviations are used in combination.

Wheat Phase 6 October to 24 June					
	mm	mm	kg ha^{-1}	mm	kg ha^{-1}
Year	**WP**	**WNTRO**	**WNTSL**	**WSMRO**	**WSMSL**
1984	167	50.6	1157	32.8	942
1985	88.4	6.5	25.9	11.7	139
1986	230	22.8	177	8.4	99.1
1987	151	5.2	88.7	0.4	8.9
1988	110	0.5	0.0	0.0	0.0
1989	169	6.8	64.8	9.5	135
1990	0.0	0.0	0.0	0.0	0.0
1991	122	0.1	0.0	1.0	20.3
1992	195	14.7	64.5	8.4	69.9
1993	80.5	0.0	0.0	0.0	0.0
1994	14.0	0.0	0.0	0.0	0.0
1995	119	5.6	38.5	0.7	30.0
1996	0.0	0.0	0.0	0.0	0.0
1997	128	18.7	0.0	2.5	0.0
1998	160	90.1	1710	67.5	2383
1999	99.3	9.5	133.0	21.3	190
2000	89.2	8.4	0.3	0.1	0.0
2001	101	12.4	89.2	11.3	157
2002	42.7	0.0	0.0	0.5	0.0
2003	113	0.7	0.0	0.7	19.1
2004	42.9	6.5	0.0	5.5	0.0
2005	24.6	8.8	125	7.7	312
2006	51.8	2.5	0.0	0.0	0.0
2007	77.7	0.6	0.0	0.1	0.0
2008	102	27.6	267	5.2	86.4
2009	99.6	0.4	0.0	0.0	0.0
2010	143	10.5	174	0.5	0.0

Fallow after Wheat Phase 25 June to 15 June					
Year	mm FWP	mm FWNTRO	kg ha^{-1} FWNTSL	mm FWSMRO	kg ha^{-1} FWSMSL
1984	278	36.1	267	43.8	0.0
1985	251	39.6	433	16.4	587
1986	320	37.9	142	23.2	991
1987	369	52.0	645	30.9	969
1988	294	62.1	362	29.0	239
1989	321	82.3	1227	57.9	2602
1990	141	1.0	0.0	0.0	0.0
1991	199	12.7	0.0	1.8	47.4
1992	257	39.2	407	34.1	4098
1993	139	3.7	0.0	0.2	0.0
1994	191	12.9	160	8.7	222
1995	265	30.1	360	20.1	828
1996	232	17.8	173	23.4	1248
1997	141	32.9	290	3.3	523
1998	186	26.6	110	41.2	447
1999	247	60.5	593	22.8	1103
2000	54.9	12.4	180	0.0	0.0
2001	101	18.6	126	1.6	0.0
2002	145	0.2	0.0	0.2	7.7
2003	102	6.1	284	15.3	1167
2004	224	0.6	0.0	0.1	0.0
2005	54.9	3.0	31.2	9.9	393
2006	218	58.9	2669	8.9	418
2007	185	21.9	0.0	20.6	0.0
2008	218	16.5	81.5	9.1	160
2009	111	8.1	104	3.9	100
2010	226	8.4	56.6	0.1	0.0

	Sorghum Phase 16 June to 29 October				
	mm	mm	kg ha^{-1}	mm	kg ha^{-1}
Year	SP	SNTRO	SNTSL	SSMRO	SSMSL
1984	182	3.5	0.0	0.7	17.2
1985	211	45.5	413	43.4	573
1986	208	3.9	40.9	0.7	14.9
1987	247	6.6	47.4	2.5	28.7
1988	184	33.7	381	17.5	287
1989	152	21.8	117	15.0	192
1990	141	14.3	153	38.4	2144
1991	147	1.9	55.8	1.5	130.0
1992	225	27.0	357	19.5	1490
1993	162	33.7	722	44.6	2982
1994	177	4.2	18.0	16.8	512
1995	146	20.1	781	27.2	1971
1996	232	2.4	18.8	10.9	610
1997	13.2	0.0	0.0	0.1	0.0
1998	26.2	0.0	0.0	0.0	0.0
1999	147	16.9	90.3	12.9	256
2000	62.5	0.5	0.0	0.0	0.0
2001	0.0	0.0	0.0	0.0	0.0
2002	102	0.0	0.0	1.1	21.3
2003	103	2.9	112	8.7	807
2004	181	15.1	91.6	14.7	658
2005	30.2	0.0	0.0	0.5	15.1
2006	193	0.3	1.2	4.6	44.0
2007	107	11.2	126	8.1	528
2008	195	11.5	56.8	3.6	0.0
2009	92.2	7.6	332	10.2	490
2010	83.6	52.0	1177	25.3	1770

Fallow after Sorghum 30 October to 7 October					
	mm	mm	kg ha^{-1}	mm	kg ha^{-1}
Year	FSP	FSNTRO	FSNTSL	FSSMRO	FSSMSL
1984	208	105	2690	86.4	5709
1985	204	36.7	564	53.4	1951
1986	343	57.9	700	28.5	718
1987	339	84.9	1095	10.4	254
1988	294	77.8	622	32.2	356
1989	321	61.7	614	31.6	1050
1990	141	18.0	122	0.4	10.8
1991	234	3.4	40.0	1.8	55.5
1992	339	31.0	100	31.2	848
1993	191	33.2	384	17.5	0.0
1994	191	19.0	618	28.6	2337
1995	265	28.7	273	4.2	178
1996	232	51.7	791	15.9	795
1997	141	11.5	44.8	0.0	0.0
1998	186	82.2	1823	62.4	0.0
1999	247	80.8	1243	37.1	1026
2000	61.0	0.0	0.0	0.0	0.0
2001	101	13.7	62.8	1.8	0.0
2002	145	7.9	114	10.8	83.1
2003	99.6	0.0	0.0	0.2	0.0
2004	224	44.6	293	19.9	511
2005	54.9	21.6	333	21.1	845
2006	157	27.7	396	0.2	2.4
2007	185	36.8	5.5	24.8	0.0
2008	138	29.0	507	10.0	521
2009	104	5.7	107	0.0	0.0
2010	226	46.9	618	2.4	80.3

APPENDIX C: Kolmogorov-Smirnov Normality Test for NT and SM Full Datasets

Full Dataset 1984-2010 No-Till Management Plots (10A, 11A, 12A)			
	Precipitation (mm)	Storm Runoff (mm)	Soil Loss (kg ha^{-1})
Mean	26.7	5.24	132
Standard Error of Mean	1.4	0.73	19.3
Standard Deviation	19.4	10.0	266
	Kolmogorov-Smirnov Test		
H_o: α (0.05) < ρ	Data is normally distributed		
H_a: α (0.05) > ρ	Data is not normally distributed		
ρ value (determination)	0.001	0.001	0.001
results	α (0.05) > ρ (0.001)	α (0.05) > ρ (0.001)	α (0.05) > ρ (0.001)
conclusion	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed

Full Dataset 1984-2010 Stubble-Mulch Management Plots (10B, 11B, 12B)			
	Precipitation (mm)	Storm Runoff (mm)	Soil Loss (kg ha^{-1})
Mean	26.7	3.79	282
Standard Error of Mean	1.4	0.67	44.2
Standard Deviation	19.4	9.20	609
	Kolmogorov-Smirnov Test		
H_o: α (0.05) < ρ	Data is normally distributed		
H_a: α (0.05) > ρ	Data is not normally distributed		
ρ value (determination)	0.001	0.001	0.001
results	α (0.05) > ρ (0.001)	α (0.05) > ρ (0.001)	α (0.05) > ρ (0.001)
conclusion	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed

APPENDIX D: Shapiro-Wilk Normality Test for 9 Year Means

Summary Table for Shapiro-Wilk Normality Tests	
9 year means Wheat Phase NT (Precip., Runoff, Soil Loss)	Data is normally distributed.
9 year means Wheat Phase SM (Precip., Runoff, Soil Loss)	Data is normally distributed.
9 year means Fallow after Wheat Phase NT (Precip., Runoff, Soil Loss)	Data is normally distributed.
9 year means Fallow after Wheat Phase SM (Precip., Runoff, Soil Loss)	Data is normally distributed.
9 year means Sorghum Phase NT (Precip., Runoff, Soil Loss)	Data is normally distributed.
9 year means Sorghum Phase SM (Precip., Runoff, Soil Loss)	Data is normally distributed.
9 year means Fallow after Sorghum Phase NT (Precip., Runoff, Soil Loss)	Data is normally distributed.
9 year means Fallow after Sorghum Phase SM (Precip., Runoff, Soil Loss)	Data is normally distributed.

Nine Year Means of Wheat Phase with No-Till			
	Precipitation (mm)	Storm Runoff (mm)	Soil Loss (kg ha^{-1})
Mean	101	11.5	152
Standard Error of Mean	18.4	2.81	46.5
Standard Deviation	132	4.86	80.5
	Shapiro-Wilk Test Analysis		
H_o: α (0.05) < ρ	Data is normally distributed		
H_a: α (0.05) > ρ	Data is not normally distributed		
N	3	3	3
ρ value (determination)	0.313	0.853	0.525
results	α (0.05) < ρ (0.313)	α (0.05) < ρ (0.853)	α (0.05) < ρ (0.525)
conclusion	Fail to reject H_o; Data is normally distributed	Fail to reject H_o; Data is normally distributed	Fail to reject H_o; Data is normally distributed

Nine Year Means of Wheat Phase with Stubble-Mulch Tillage			
	Precipitation (mm)	Storm Runoff (mm)	Soil Loss (kg ha^{-1})
Mean	101	7.23	170
Standard Error of Mean	18.4	2.71	75.4
Standard Deviation	132	4.70	131
	Shapiro-Wilk Test Analysis		
H_o: α (0.05) < ρ	Data is normally distributed		
H_a: α (0.05) > ρ	Data is not normally distributed		
N	3	3	3
ρ value (determination)	0.313	0.792	0.836
results	α (0.05) < ρ (0.313)	α (0.05) < ρ (0.792)	α (0.05) < ρ (0.836)
conclusion	Fail to reject H_o; Data is normally distributed	Fail to reject H_o; Data is normally distributed	Fail to reject H_o; Data is normally distributed

Nine Year Means of Fallow After Wheat Phase with No-Tillage			
	Precipitation (mm)	Storm Runoff (mm)	Soil Loss (kg ha^{-1})
Mean	203	26.0	322
Standard Error of Mean	33.8	7.45	51.2
Standard Deviation	58.6	13.4	88.7
	Shapiro-Wilk Test Analysis		
H_o: α (0.05) < ρ	Data is normally distributed		
H_a: α (0.05) > ρ	Data is not normally distributed		
N	3	3	3
ρ value (determination)	0.129	0.745	0.310
results	α (0.05) < ρ (0.129)	α (0.05) < ρ (0.745)	α (0.05) < ρ (0.310)
conclusion	Fail to reject H_o; Data is normally distributed	Fail to reject H_o; Data is normally distributed	Fail to reject H_o; Data is normally distributed

Nine Year Means of Fallow After Wheat Phase with Stubble-Mulch Tillage			
	Precipitation (mm)	Storm Runoff (mm)	Soil Loss (kg ha^{-1})
Mean	203	15.8	598
Standard Error of Mean	33.8	5.52	240
Standard Deviation	58.6	9.56	417
	Shapiro-Wilk Test Analysis		
H_o: α (0.05) < ρ	Data is normally distributed		
H_a: α (0.05) > ρ	Data is not normally distributed		
N	3	3	3
ρ value (determination)	0.129	0.599	0.549
results	α (0.05) < ρ (0.129)	α (0.05) < ρ (0.599)	α (0.05) < ρ (0.549)
conclusion	Fail to reject H_o; Data is normally distributed	Fail to reject H_o; Data is normally distributed	Fail to reject H_o; Data is normally distributed

Nine Year Means of Sorghum Phase with No-Tillage			
	Precipitation (mm)	Storm Runoff (mm)	Soil Loss (kg/ha)
Mean	139	12.5	189
Standard Error of Mean	25.1	2.67	11.3
Standard Deviation	43.6	4.63	19.5
	Shapiro-Wilk Test Analysis		
H_o: α (0.05) < ρ	Data is normally distributed		
H_a: α (0.05) > ρ	Data is not normally distributed		
N	3	3	3
ρ value (determination)	0.299	0.543	0.360
results	α (0.05) < ρ (0.299)	α (0.05) < ρ (0.543)	α (0.05) < ρ (0.360)
conclusion	Fail to reject H_o; Data is normally distributed	Fail to reject H_o; Data is normally distributed	Fail to reject H_o; Data is normally distributed

Nine Year Means of Sorghum Phase with Stubble-Mulch Tillage			
	Precipitation (mm)	Storm Runoff (mm)	Soil Loss (kg ha^{-1})
Mean	139	12.2	576
Standard Error of Mean	25.1	2.03	66.3
Standard Deviation	43.6	3.51	115
	Shapiro-Wilk Test Analysis		
H_o: α (0.05) < ρ	Data is normally distributed		
H_a: α (0.05) > ρ	Data is not normally distributed		
N	3	3	3
ρ value (determination)	0.299	0.843	0.508
results	α (0.05) < ρ (0.299)	α (0.05) < ρ (0.843)	α (0.05) < ρ (0.508)
conclusion	Fail to reject H_o; Data is normally distributed	Fail to reject H_o; Data is normally distributed	Fail to reject H_o; Data is normally distributed

Nine Year Means of Fallow After Sorghum Phase with No-Till			
	Precipitation (mm)	Storm Runoff (mm)	Soil Loss (kg ha^{-1})
Mean	199	37.7	524
Standard Error of Mean	36.3	8.26	137
Standard Deviation	62.9	14.3	237
	Shapiro-Wilk Test Analysis		
H_o: α (0.05) < ρ	Data is normally distributed		
H_a: α (0.05) > ρ	Data is not normally distributed		
N	3	3	3
ρ value (determination)	0.475	0.761	0.595
results	α (0.05) < ρ (0.475)	α (0.05) < ρ (0.761)	α (0.05) < ρ (0.595)
conclusion	Fail to reject H_o; Data is normally distributed	Fail to reject H_o; Data is normally distributed	Fail to reject H_o; Data is normally distributed

Nine Year Means of Fallow After Sorghum Phase with Stubble-Mulch Tillage			
	Precipitation (mm)	Storm Runoff (mm)	Soil Loss (kg ha^{-1})
Mean	199	19.7	642
Standard Error of Mean	36.3	6.03	297
Standard Deviation	62.9	10.5	514
	Shapiro-Wilk Test Analysis		
H_o: α (0.05) < ρ	Data is normally distributed		
H_a: α (0.05) > ρ	Data is not normally distributed		
N	3	3	3
ρ value (determination)	0.475	0.820	0.478
results	α (0.05) < ρ (0.457)	α (0.05) < ρ (0.820)	α (0.05) < ρ (0.478)
conclusion	Fail to reject H_o; Data is normally distributed	Fail to reject H_o; Data is normally distributed	Fail to reject H_o; Data is normally distributed

APPENDIX E: Kolmogorov-Smirnov Field Analysis by Phase and Category

Summary Table for Kolmogorov-Smirnov Normality Tests	
Wheat Phase NT Precipitation (10A, 11A, 12A)	Data is not normally distributed.
Wheat Phase NT Runoff (10A, 11A, 12A)	Data is not normally distributed.
Wheat Phase NT Soil Loss (10A, 11A, 12A)	10A, 12A-Data is normally distributed. 11A- Data is not normally distributed.
Wheat Phase SM Precipitation (10B, 11B, 12B)	10B-Data is normally distributed. 11B, 12B- Data is not normally distributed.
Wheat Phase SM Runoff (10B, 11B, 12B)	Data is not normally distributed.
Wheat Phase SM Soil Loss (10B, 11B, 12B)	Data is not normally distributed.
Fallow after Wheat NT Precipitation (10A, 11A, 12A)	Data is not normally distributed.
Fallow after Wheat NT Runoff (10A, 11A, 12A)	Data is not normally distributed.
Fallow after Wheat NT Soil Loss (10A, 11A, 12A)	10A, 11A-Data is normally distributed. 12A- Data is not normally distributed.
Fallow after Wheat SM Precipitation (10B, 11B, 12B)	Data is not normally distributed.
Fallow after Wheat SM Runoff (10B, 11B, 12B)	10B, 11B- Data is normally distributed. 12B- Data is not normally distributed.
Fallow after Wheat SM Soil Loss (10B, 11B, 12B)	10B-Data is normally distributed. 11B, 12B- Data is not normally distributed.
Sorghum NT Precipitation (10A, 11A, 12A)	10A, 11A-Data is normally distributed. 12A- Data is not normally distributed.
Sorghum NT Runoff (10A, 11A, 12A)	Data is not normally distributed.
Sorghum NT Soil Loss (10A, 11A, 12A)	Data is not normally distributed.
Sorghum SM Precipitation (10B, 11B, 12B)	10B, 11B-Data is normally distributed. 12B- Data is not normally distributed.
Sorghum SM Runoff (10B, 11B, 12B)	Data is not normally distributed.
Sorghum SM Soil Loss (10B, 11B, 12B)	Data is not normally distributed.
Fallow after Sorghum NT Precipitation (10A, 11A, 12A)	Data is not normally distributed.
Fallow after Sorghum NT Runoff (10A, 11A, 12A)	Data is not normally distributed.
Fallow after Sorghum NT Soil Loss (10A, 11A, 12A)	Data is not normally distributed.
Fallow after Sorghum SM Precipitation (10B, 11B, 12B)	Data is not normally distributed.

Fallow after Sorghum SM Runoff (10B, 11B, 12B)	Data is not normally distributed.
Fallow after Sorghum SM Soil Loss (10B, 11B, 12B)	11B-Data is normally distributed. 10B, 12B- Data is not normally distributed.

Kolmogorov-Smirnov Test for Normality on No-Till Fields by Crop Phase			
	10A Wheat Phase Precipitation	11A Wheat Phase Precipitation	12A Wheat Phase Precipitation
H_o: α (0.05) < ρ	Data is normally distributed	Data is normally distributed	Data is normally distributed
H_a: α (0.05) > ρ	Data is not normally distributed	Data is not normally distributed	Data is not normally distributed
α (significance level)	0.05	0.05	0.05
ρ value (determination)	0.038	0.001	0.003
results	α (0.05) > ρ (0.038)	α (0.05) > ρ (0.001)	α (0.05) > ρ (0.003)
conclusion	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed

Kolmogorov-Smirnov Test for Normality on No-Till Fields by Crop Phase			
	10A Wheat Phase Runoff	11A Wheat Phase Runoff	12A Wheat Phase Runoff
H_o: α (0.05) < ρ	Data is normally distributed	Data is normally distributed	Data is normally distributed
H_a: α (0.05) > ρ	Data is not normally distributed	Data is not normally distributed	Data is not normally distributed
α (significance level)	0.05	0.05	0.05
ρ value (determination)	0.025	0.001	0.001
results	α (0.05) > ρ (0.025)	α (0.05) > ρ (0.001)	α (0.05) > ρ (0.001)
conclusion	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed
*All zero values and reader malfunctions (RM) were removed from datasets before analysis.			

Kolmogorov-Smirnov Test for Normality on No-Till Fields by Crop Phase			
	10A Wheat Phase Soil Loss	11A Wheat Phase Soil Loss	12A Wheat Phase Soil Loss
H_o: α (0.05) < ρ	Data is normally distributed	Data is normally distributed	Data is normally distributed
H_a: α (0.05) > ρ	Data is not normally distributed	Data is not normally distributed	Data is not normally distributed
α (significance level)	0.05	0.05	0.05
ρ value (determination)	0.200	0.009	0.200
results	α (0.05) < ρ (0.200)	α (0.05) > ρ (0.009)	α (0.05) < ρ (0.200)
conclusion	Fail to eject H_o; Data is normally distributed	Reject H_o; Data is not normally distributed	Fail to reject H_o; Data is normally distributed
*All zero values, no sample recordings (NS), not installed recordings (NI), and sampler malfunction recordings (smalf) were removed from datasets before analysis.			

Kolmogorov-Smirnov Test for Normality on No-Till Fields by Crop Phase			
	10A Fallow after Wheat Phase Precipitation	11A Fallow after Wheat Phase Precipitation	12A Fallow after Wheat Phase Precipitation
H_o: α (0.05) < ρ	Data is normally distributed	Data is normally distributed	Data is normally distributed
H_a: α (0.05) > ρ	Data is not normally distributed	Data is not normally distributed	Data is not normally distributed
α (significance level)	0.05	0.05	0.05
ρ value (determination)	0.001	0.001	0.001
results	α (0.05) > ρ (0.001)	α (0.05) > ρ (0.001)	α (0.05) > ρ (0.001)
conclusion	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed

Kolmogorov-Smirnov Test for Normality on No-Till Fields by Crop Phase			
	10A Fallow after Wheat Phase Runoff	11A Fallow after Wheat Phase Runoff	12A Fallow after Wheat Phase Runoff
H_o: α (0.05) < ρ	Data is normally distributed	Data is normally distributed	Data is normally distributed
H_a: α (0.05) > ρ	Data is not normally distributed	Data is not normally distributed	Data is not normally distributed
α (significance level)	0.05	0.05	0.05
ρ value (determination)	0.001	0.001	0.001
results	α (0.05) > ρ (0.001)	α (0.05) > ρ (0.001)	α (0.05) > ρ (0.001)
conclusion	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed
*All zero values and reader malfunctions (RM) were removed from datasets before analysis.			

Kolmogorov-Smirnov Test for Normality on No-Till Fields by Crop Phase			
	10A Fallow after Wheat Phase Soil Loss	11A Fallow after Wheat Phase Soil Loss	12A Fallow after Wheat Phase Soil Loss
H_o: α (0.05) < ρ	Data is normally distributed	Data is normally distributed	Data is normally distributed
H_a: α (0.05) > ρ	Data is not normally distributed	Data is not normally distributed	Data is not normally distributed
α (significance level)	0.05	0.05	0.05
ρ value (determination)	0.200	0.113	0.011
results	α (0.05) < ρ (0.200)	α (0.05) < ρ (0.113)	α (0.05) > ρ (0.011)
conclusion	Fail to eject H_o; Data is normally distributed	Fail to reject H_o; Data is normally distributed	Reject H_o; Data is not normally distributed
*All zero values, no sample recordings (NS), not installed recordings (NI), and sampler malfunction recordings (smalf) were removed from datasets before analysis.			

Kolmogorov-Smirnov Test for Normality on No-Till Fields by Crop Phase			
	10A Sorghum Phase Precipitation	11A Sorghum Phase Precipitation	12A Sorghum Phase Precipitation
H_o: α (0.05) < ρ	Data is normally distributed	Data is normally distributed	Data is normally distributed
H_a: α (0.05) > ρ	Data is not normally distributed	Data is not normally distributed	Data is not normally distributed
α (significance level)	0.05	0.05	0.05
ρ value (determination)	0.005	0.001	0.200
results	α (0.05) > ρ (0.005)	α (0.05) > ρ (0.001)	α (0.05) < ρ (0.200)
conclusion	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed	Fail to reject H_o; Data is normally distributed

Kolmogorov-Smirnov Test for Normality on No-Till Fields by Crop Phase			
	10A Sorghum Phase Runoff	11A Sorghum Phase Runoff	12A Sorghum Phase Runoff
H_o: α (0.05) < ρ	Data is normally distributed	Data is normally distributed	Data is normally distributed
H_a: α (0.05) > ρ	Data is not normally distributed	Data is not normally distributed	Data is not normally distributed
α (significance level)	0.05	0.05	0.05
ρ value (determination)	0.001	0.001	0.001
results	α (0.05) > ρ (0.001)	α (0.05) > ρ (0.001)	α (0.05) > ρ (0.001)
conclusion	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed
*All zero values and reader malfunctions (RM) were removed from datasets before analysis.			

Kolmogorov-Smirnov Test for Normality on No-Till Fields by Crop Phase			
	10A Sorghum Phase Soil Loss	11A Sorghum Phase Soil Loss	12A Sorghum Phase Soil Loss
H_o: α (0.05) < ρ	Data is normally distributed	Data is normally distributed	Data is normally distributed
H_a: α (0.05) > ρ	Data is not normally distributed	Data is not normally distributed	Data is not normally distributed
α (significance level)	0.05	0.05	0.05
ρ value (determination)	0.001	0.019	0.011
results	α (0.05) > ρ (0.001)	α (0.05) > ρ (0.019)	α (0.05) > ρ (0.011)
conclusion	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed
*All zero values, no sample recordings (NS), not installed recordings (NI), and sampler malfunction recordings (smalf) were removed from datasets before analysis.			

Kolmogorov-Smirnov Test for Normality on No-Till Fields by Crop Phase			
	10A Fallow after Sorghum Phase Precipitation	11A Fallow after Sorghum Phase Precipitation	12A Fallow after Sorghum Phase Precipitation
H_o: α (0.05) < ρ	Data is normally distributed	Data is normally distributed	Data is normally distributed
H_a: α (0.05) > ρ	Data is not normally distributed	Data is not normally distributed	Data is not normally distributed
α (significance level)	0.05	0.05	0.05
ρ value (determination)	0.001	0.008	0.001
results	α (0.05) > ρ (0.001)	α (0.05) > ρ (0.008)	α (0.05) > ρ (0.001)
conclusion	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed

Kolmogorov-Smirnov Test for Normality on No-Till Fields by Crop Phase			
	10A Fallow after Sorghum Phase Runoff	11A Fallow after Sorghum Phase Runoff	12A Fallow after Sorghum Phase Runoff
H_o: α (0.05) < ρ	Data is normally distributed	Data is normally distributed	Data is normally distributed
H_a: α (0.05) > ρ	Data is not normally distributed	Data is not normally distributed	Data is not normally distributed
α (significance level)	0.05	0.05	0.05
ρ value (determination)	0.001	0.001	0.001
results	α (0.05) > ρ (0.001)	α (0.05) > ρ (0.001)	α (0.05) > ρ (0.001)
conclusion	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed
*All zero values and reader malfunctions (RM) were removed from datasets before analysis.			

Kolmogorov-Smirnov Test for Normality on No-Till Fields by Crop Phase			
	10A Fallow after Sorghum Phase Soil Loss	11A Fallow after Sorghum Phase Soil Loss	12A Fallow after Sorghum Phase Soil Loss
H_o: α (0.05) < ρ	Data is normally distributed	Data is normally distributed	Data is normally distributed
H_a: α (0.05) > ρ	Data is not normally distributed	Data is not normally distributed	Data is not normally distributed
α (significance level)	0.05	0.05	0.05
ρ value (determination)	0.001	0.015	0.001
results	α (0.05) > ρ (0.001)	α (0.05) > ρ (0.015)	α (0.05) > ρ (0.001)
conclusion	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed
*All zero values, no sample recordings (NS), not installed recordings (NI), and sampler malfunction recordings (smalf) were removed from datasets before analysis.			

Kolmogorov-Smirnov Test for Normality on Stubble-Mulch Fields by Crop Phase			
	10B Wheat Phase Precipitation	11B Wheat Phase Precipitation	12B Wheat Phase Precipitation
H_o: α (0.05) < ρ	Data is normally distributed	Data is normally distributed	Data is normally distributed
H_a: α (0.05) > ρ	Data is not normally distributed	Data is not normally distributed	Data is not normally distributed
α (significance level)	0.05	0.05	0.05
ρ value (determination)	0.104	0.001	0.003
results	α (0.05) < ρ (0.104)	α (0.05) > ρ (0.001)	α (0.05) > ρ (0.003)
conclusion	Fail to reject H_o; Data is normally distributed	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed

Kolmogorov-Smirnov Test for Normality on Stubble-Mulch Fields by Crop Phase			
	10B Wheat Phase Runoff	11B Wheat Phase Runoff	12B Wheat Phase Runoff
H_o: α (0.05) < ρ	Data is normally distributed	Data is normally distributed	Data is normally distributed
H_a: α (0.05) > ρ	Data is not normally distributed	Data is not normally distributed	Data is not normally distributed
α (significance level)	0.05	0.05	0.05
ρ value (determination)	0.002	0.001	0.001
results	α (0.05) > ρ (0.002)	α (0.05) > ρ (0.001)	α (0.05) > ρ (0.001)
conclusion	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed
*All zero values and reader malfunctions (RM) were removed from datasets before analysis.			

Kolmogorov-Smirnov Test for Normality on Stubble-Mulch Fields by Crop Phase			
	10B Wheat Phase Soil Loss	11B Wheat Phase Soil Loss	12B Wheat Phase Soil Loss
H_o: α (0.05) < ρ	Data is normally distributed	Data is normally distributed	Data is normally distributed
H_a: α (0.05) > ρ	Data is not normally distributed	Data is not normally distributed	Data is not normally distributed
α (significance level)	0.05	0.05	0.05
ρ value (determination)	0.008	0.007	0.007
results	α (0.05) > ρ (0.008)	α (0.05) > ρ (0.007)	α (0.05) > ρ (0.007)
conclusion	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed
*All zero values, no sample recordings (NS), not installed recordings (NI), and sampler malfunction recordings (smalf) were removed from datasets before analysis.			

Kolmogorov-Smirnov Test for Normality on Stubble-Mulch Fields by Crop Phase			
	10B Fallow after Wheat Phase Precipitation	11B Fallow after Wheat Phase Precipitation	12B Fallow after Wheat Phase Precipitation
H_o: α (0.05) < ρ	Data is normally distributed	Data is normally distributed	Data is normally distributed
H_a: α (0.05) > ρ	Data is not normally distributed	Data is not normally distributed	Data is not normally distributed
α (significance level)	0.05	0.05	0.05
ρ value (determination)	0.001	0.001	0.001
results	α (0.05) > ρ (0.001)	α (0.05) > ρ (0.001)	α (0.05) > ρ (0.001)
conclusion	Reject H_o; Data is normally distributed	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed

Kolmogorov-Smirnov Test for Normality on Stubble-Mulch Fields by Crop Phase			
	10B Fallow after Wheat Phase Runoff	11B Fallow after Wheat Phase Runoff	12B Fallow after Wheat Phase Runoff
H_o: α (0.05) < ρ	Data is normally distributed	Data is normally distributed	Data is normally distributed
H_a: α (0.05) > ρ	Data is not normally distributed	Data is not normally distributed	Data is not normally distributed
α (significance level)	0.05	0.05	0.05
ρ value (determination)	0.012	0.005	0.110
results	α (0.05) > ρ (0.012)	α (0.05) > ρ (0.005)	α (0.05) < ρ (0.110)
conclusion	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed	Fail to reject H_o; Data is normally distributed
*All zero values and reader malfunctions (RM) were removed from datasets before analysis.			

Kolmogorov-Smirnov Test for Normality on Stubble-Mulch Fields by Crop Phase			
	10B Fallow after Wheat Phase Soil Loss	11B Fallow after Wheat Phase Soil Loss	12B Fallow after Wheat Phase Soil Loss
H_o: α (0.05) < ρ	Data is normally distributed	Data is normally distributed	Data is normally distributed
H_a: α (0.05) > ρ	Data is not normally distributed	Data is not normally distributed	Data is not normally distributed
α (significance level)	0.05	0.05	0.05
ρ value (determination)	0.134	0.001	0.032
results	α (0.05) < ρ (0.134)	α (0.05) > ρ (0.001)	α (0.05) > ρ (0.032)
conclusion	Fail to reject H_o; Data is normally distributed	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed
*All zero values, no sample recordings (NS), not installed recordings (NI), and sampler malfunction recordings (smalf) were removed from datasets before analysis.			

Kolmogorov-Smirnov Test for Normality on Stubble-Mulch Fields by Crop Phase			
	10B Sorghum Phase Precipitation	11B Sorghum Phase Precipitation	12B Sorghum Phase Precipitation
H_o: α (0.05) < ρ	Data is normally distributed	Data is normally distributed	Data is normally distributed
H_a: α (0.05) > ρ	Data is not normally distributed	Data is not normally distributed	Data is not normally distributed
α (significance level)	0.05	0.05	0.05
ρ value (determination)	0.005	0.001	0.200
results	α (0.05) > ρ (0.005)	α (0.05) > ρ (0.001)	α (0.05) < ρ (0.200)
conclusion	Reject H_o; Data is normally distributed	Reject H_o; Data is not normally distributed	Fail to reject H_o; Data is normally distributed

Kolmogorov-Smirnov Test for Normality on Stubble-Mulch Fields by Crop Phase			
	10B Sorghum Phase Runoff	11B Sorghum Phase Runoff	12B Sorghum Phase Runoff
H_o: α (0.05) < ρ	Data is normally distributed	Data is normally distributed	Data is normally distributed
H_a: α (0.05) > ρ	Data is not normally distributed	Data is not normally distributed	Data is not normally distributed
α (significance level)	0.05	0.05	0.05
ρ value (determination)	0.001	0.002	0.001
results	α (0.05) > ρ (0.001)	α (0.05) > ρ (0.002)	α (0.05) > ρ (0.001)
conclusion	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed
*All zero values and reader malfunctions (RM) were removed from datasets before analysis.			

Kolmogorov-Smirnov Test for Normality on Stubble-Mulch Fields by Crop Phase			
	10B Sorghum Phase Soil Loss	11B Sorghum Phase Soil Loss	12B Sorghum Phase Soil Loss
H_o: α (0.05) < ρ	Data is normally distributed	Data is normally distributed	Data is normally distributed
H_a: α (0.05) > ρ	Data is not normally distributed	Data is not normally distributed	Data is not normally distributed
α (significance level)	0.05	0.05	0.05
ρ value (determination)	0.001	0.005	0.001
results	α (0.05) > ρ (0.001)	α (0.05) > ρ (0.005)	α (0.05) > ρ (0.001)
conclusion	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed
*All zero values, no sample recordings (NS), not installed recordings (NI), and sampler malfunction recordings (smalf) were removed from datasets before analysis.			

Kolmogorov-Smirnov Test for Normality on Stubble-Mulch Fields by Crop Phase			
	10B Fallow after Sorghum Phase Precipitation	11B Fallow after Sorghum Phase Precipitation	12B Fallow after Sorghum Phase Precipitation
H_o: α (0.05) < ρ	Data is normally distributed	Data is normally distributed	Data is normally distributed
H_a: α (0.05) > ρ	Data is not normally distributed	Data is not normally distributed	Data is not normally distributed
α (significance level)	0.05	0.05	0.05
ρ value (determination)	0.001	0.008	0.001
results	α (0.05) > ρ (0.001)	α (0.05) > ρ (0.008)	α (0.05) > ρ (0.001)
conclusion	Reject H_o; Data is normally distributed	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed

Kolmogorov-Smirnov Test for Normality on Stubble-Mulch Fields by Crop Phase			
	10B Fallow after Sorghum Phase Runoff	11B Fallow after Sorghum Phase Runoff	12B Fallow after Sorghum Phase Runoff
H_o: α (0.05) < ρ	Data is normally distributed	Data is normally distributed	Data is normally distributed
H_a: α (0.05) > ρ	Data is not normally distributed	Data is not normally distributed	Data is not normally distributed
α (significance level)	0.05	0.05	0.05
ρ value (determination)	0.001	0.001	0.001
results	α (0.05) > ρ (0.001)	α (0.05) > ρ (0.001)	α (0.05) > ρ (0.001)
conclusion	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed	Reject H_o; Data is not normally distributed
*All zero values and reader malfunctions (RM) were removed from datasets before analysis.			

Kolmogorov-Smirnov Test for Normality on Stubble-Mulch Fields by Crop Phase			
	10B Fallow after Sorghum Phase Soil Loss	11B Fallow after Sorghum Phase Soil Loss	12B Fallow after Sorghum Phase Soil Loss
H_o: α (0.05) < ρ	Data is normally distributed	Data is normally distributed	Data is normally distributed
H_a: α (0.05) > ρ	Data is not normally distributed	Data is not normally distributed	Data is not normally distributed
α (significance level)	0.05	0.05	0.05
ρ value (determination)	0.001	0.095	0.001
results	α (0.05) > ρ (0.001)	α (0.05) < ρ (0.095)	α (0.05) > ρ (0.001)
conclusion	Reject H_o; Data is not normally distributed	Fail to reject H_o; Data is normally distributed	Reject H_o; Data is not normally distributed
*All zero values, no sample recordings (NS), not installed recordings (NI), and sampler malfunction recordings (smalf) were removed from datasets before analysis.			

APPENDIX F: Kruskal-Wallis Field Analysis by Phase and Category

Summary of Wheat and Fallow after Wheat Kruskal-Wallis Tests	
Wheat Phase NT Precipitation (10A, 11A, 12A)	Probability distributions are the same.
Wheat Phase NT Runoff (10A, 11A, 12A)	Probability distributions are the same.
Wheat Phase NT Soil Loss * (10A, 11A, 12A)	The three probability distributions are not the same.
Wheat Phase SM Precipitation (10B, 11B, 12B)	Probability distributions are the same.
Wheat Phase SM Runoff * (10B, 11B, 12B)	The three probability distributions are not the same.
Wheat Phase SM Soil Loss (10B, 11B, 12B)	Probability distributions are the same.
Fallow after Wheat NT Precipitation (10A, 11A, 12A)	Probability distributions are the same.
Fallow after Wheat NT Runoff (10A, 11A, 12A)	Probability distributions are the same.
Fallow after Wheat NT Soil Loss (10A, 11A, 12A)	Probability distributions are the same.
Fallow after Wheat SM Precipitation (10B, 11B, 12B)	Probability distributions are the same.
Fallow after Wheat SM Runoff (10B, 11B, 12B)	Probability distributions are the same.
Fallow after Wheat SM Soil Loss (10B, 11B, 12B)	Probability distributions are the same.
Sorghum NT Precipitation (10A, 11A, 12A)	Probability distributions are the same.
*Indicates the probability distributions of the three fields with the same tillage and crop phase are significantly different at α (0.05). If fields were significantly different, Post-Hoc analysis was conducted as explained in Chapter III-Tables 11, 13, and 15.	

Summary of Sorghum and Fallow after Sorghum Kruskal-Wallis Tests	
Sorghum NT Runoff (10A, 11A, 12A)	Probability distributions are the same.
Sorghum NT Soil Loss (10A, 11A, 12A)	Probability distributions are the same.
Sorghum SM Precipitation (10B, 11B, 12B)	Probability distributions are the same.
Sorghum SM Runoff (10B, 11B, 12B)	Probability distributions are the same.
Sorghum SM Soil Loss (10B, 11B, 12B)	Probability distributions are the same.
Fallow after Sorghum NT Precipitation (10A, 11A, 12A)	Probability distributions are the same.
Fallow after Sorghum NT Runoff * (10A, 11A, 12A)	The three probability distributions are not the same.
Fallow after Sorghum NT Soil Loss (10A, 11A, 12A)	Probability distributions are the same.
Fallow after Sorghum SM Precipitation (10B, 11B, 12B)	Probability distributions are the same.
Fallow after Sorghum SM Runoff (10B, 11B, 12B)	Probability distributions are the same.
Fallow after Sorghum SM Soil Loss (10B, 11B, 12B)	Probability distributions are the same.
*Indicates the probability distributions of the three fields with the same tillage and crop phase are significantly different at α (0.05). If fields were significantly different, Post-Hoc analysis was conducted as explained in Chapter III-Tables 11, 13, and 15.	

Kruskal-Wallis H Test for No-Till Wheat Phase Precipitation (Fields 10A, 11A, 12A)	
H_o: α (0.05) < ρ	The three probability distributions are the same.
H_a: α (0.05) > ρ	The three probability distributions are not the same.
α (significance level)	0.05
H_{stat} (2)	5.35
ρ value (determination)	0.069
results	α (0.05) < ρ (0.069)
conclusion	Fail to reject H_o; The three probability distributions are the same.

Kruskal-Wallis H Test for No-Till Wheat Phase Runoff (Fields 10A, 11A, 12A)	
H_o: α (0.05) < ρ	The three probability distributions are the same.
H_a: α (0.05) > ρ	The three probability distributions are not the same.
α (significance level)	0.05
H_{stat} (2)	3.76
ρ value (determination)	0.153
results	α (0.05) < ρ (0.153)
conclusion	Fail to reject H_o; The three probability distributions are the same.

Kruskal-Wallis H Test for No-Till Wheat Phase Soil Loss (Fields 10A, 11A, 12A)	
H_o: α (0.05) < ρ	The three probability distributions are the same.
H_a: α (0.05) > ρ	The three probability distributions are not the same.
α (significance level)	0.05
H_{stat} (2)	10.2
ρ value (determination)	0.006
results	α (0.05) > ρ (0.006)
conclusion	Reject H_o; The three probability distributions are not the same.

Kruskal-Wallis H Test for No-Till Fallow after Wheat Phase Precipitation (Fields 10A, 11A, 12A)	
H_o: α (0.05) < ρ	The three probability distributions are the same.
H_a: α (0.05) > ρ	The three probability distributions are not the same.
α (significance level)	0.05
H_{stat} (2)	1.83
ρ value (determination)	0.400
results	α (0.05) < ρ (0.400)
conclusion	Fail to reject H_o; The three probability distributions are the same.

Kruskal-Wallis H Test for No-Till Fallow after Wheat Phase Runoff (Fields 10A, 11A, 12A)	
H_o: α (0.05) < ρ	The three probability distributions are the same.
H_a: α (0.05) > ρ	The three probability distributions are not the same.
α (significance level)	0.05
H_{stat} (2)	3,37
ρ value (determination)	0.185
results	α (0.05) < ρ (0.185)
conclusion	Fail to reject H_o; The three probability distributions are the same.

Kruskal-Wallis H Test for No-Till Fallow after Wheat Phase Soil Loss (Fields 10A, 11A, 12A)	
H_o: α (0.05) < ρ	The three probability distributions are the same.
H_a: α (0.05) > ρ	The three probability distributions are not the same.
α (significance level)	0.05
H_{stat} (2)	2.78
ρ value (determination)	0.250
results	α (0.05) < ρ (0.250)
conclusion	Fail to reject H_o; The three probability distributions are the same.

Kruskal-Wallis H Test for No-Till Sorghum Phase Precipitation (Fields 10A, 11A, 12A)	
H_o: α (0.05) < ρ	The three probability distributions are the same.
H_a: α (0.05) > ρ	The three probability distributions are not the same.
α (significance level)	0.05
H_{stat} (2)	3.59
ρ value (determination)	0.166
results	α (0.05) < ρ (0.166)
conclusion	Fail to reject H_o; The three probability distributions are the same.

Kruskal-Wallis H Test for No-Till Sorghum Phase Runoff (Fields 10A, 11A, 12A)	
H_o: α (0.05) < ρ	The three probability distributions are the same.
H_a: α (0.05) > ρ	The three probability distributions are not the same.
α (significance level)	0.05
H_{stat} (2)	2.03
ρ value (determination)	0.363
results	α (0.05) < ρ (0.363)
conclusion	Fail to reject H_o; The three probability distributions are the same.

Kruskal-Wallis H Test for No-Till Sorghum Phase Soil Loss (Fields 10A, 11A, 12A)	
H_o: α (0.05) < ρ	The three probability distributions are the same.
H_a: α (0.05) > ρ	The three probability distributions are not the same.
α (significance level)	0.05
H_{stat} (2)	0.016
ρ value (determination)	0.992
results	α (0.05) < ρ (0.992)
conclusion	Fail to reject H_o; The three probability distributions are the same.

Kruskal-Wallis H Test for No-Till Fallow after Sorghum Phase Precipitation (Fields 10A, 11A, 12A)	
H_o: α (0.05) < ρ	The three probability distributions are the same.
H_a: α (0.05) > ρ	The three probability distributions are not the same.
α (significance level)	0.05
H_{stat} (2)	2.34
ρ value (determination)	0.311
results	α (0.05) < ρ (0.311)
conclusion	Fail to reject H_o; The three probability distributions are the same.

Kruskal-Wallis H Test for No-Till Fallow after Sorghum Phase Runoff (Fields 10A, 11A, 12A)	
H_o: α (0.05) < ρ	The three probability distributions are the same.
H_a: α (0.05) > ρ	The three probability distributions are not the same.
α (significance level)	0.05
H_{stat} (2)	17.6
ρ value (determination)	0.001
results	α (0.05) > ρ (0.001)
conclusion	Reject H_o; The three probability distributions are not the same.

Kruskal-Wallis H Test for No-Till Fallow after Sorghum Phase Soil Loss (Fields 10A, 11A, 12A)	
H_o: α (0.05) < ρ	The three probability distributions are the same.
H_a: α (0.05) > ρ	The three probability distributions are not the same.
α (significance level)	0.05
H_{stat} (2)	4.00
ρ value (determination)	0.135
results	α (0.05) < ρ (0.135)
conclusion	Fail to reject H_o; The three probability distributions are the same.

Kruskal-Wallis H Test for Stubble-Mulch Wheat Phase Precipitation (Fields 10B, 11B, 12B)	
H_o: α (0.05) < ρ	The three probability distributions are the same.
H_a: α (0.05) > ρ	The three probability distributions are not the same.
α (significance level)	0.05
H_{stat} (2)	2.60
ρ value (determination)	0.273
results	α (0.05) < ρ (0.273)
conclusion	Fail to reject H_o; The three probability distributions are the same.

Kruskal-Wallis H Test for Stubble-Mulch Wheat Phase Runoff (Fields 10B, 11B, 12B)	
H_o: α (0.05) < ρ	The three probability distributions are the same.
H_a: α (0.05) > ρ	The three probability distributions are not the same.
α (significance level)	0.05
H_{stat} (2)	8.22
ρ value (determination)	0.016
results	α (0.05) > ρ (0.016)
conclusion	Reject H_o; The three probability distributions are not the same.

Kruskal-Wallis H Test for Stubble-Mulch Wheat Phase Soil Loss (Fields 10B, 11B, 12B)	
H_o: α (0.05) < ρ	The three probability distributions are the same.
H_a: α (0.05) > ρ	The three probability distributions are not the same.
α (significance level)	0.05
H_{stat} (2)	2.04
ρ value (determination)	0.361
results	α (0.05) < ρ (0.361)
conclusion	Fail to reject H_o; The three probability distributions are the same.

Kruskal-Wallis H Test for Stubble-Mulch Fallow after Wheat Phase Precipitation (Fields 10B, 11B, 12B)	
H_o: α (0.05) < ρ	The three probability distributions are the same.
H_a: α (0.05) > ρ	The three probability distributions are not the same.
α (significance level)	0.05
H_{stat} (2)	1.83
ρ value (determination)	0.400
results	α (0.05) < ρ (0.400)
conclusion	Fail to reject H_o; The three probability distributions are the same.

Kruskal-Wallis H Test for Stubble-Mulch Fallow after Wheat Phase Runoff (Fields 10B, 11B, 12B)	
H_o: α (0.05) < ρ	The three probability distributions are the same.
H_a: α (0.05) > ρ	The three probability distributions are not the same.
α (significance level)	0.05
H_{stat} (2)	2.12
ρ value (determination)	0.346
results	α (0.05) < ρ (0.346)
conclusion	Fail to reject H_o; The three probability distributions are the same.

Kruskal-Wallis H Test for Stubble-Mulch Fallow after Wheat Phase Soil Loss (Fields 10B, 11B, 12B)	
H_o: α (0.05) < ρ	The three probability distributions are the same.
H_a: α (0.05) > ρ	The three probability distributions are not the same.
α (significance level)	0.05
H_{stat} (2)	1.98
ρ value (determination)	0.371
results	α (0.05) < ρ (0.371)
conclusion	Fail to reject H_o; The three probability distributions are the same.

Kruskal-Wallis H Test for Stubble-Mulch Sorghum Phase Precipitation (Fields 10B, 11B, 12B)	
H_o: α (0.05) < ρ	The three probability distributions are the same.
H_a: α (0.05) > ρ	The three probability distributions are not the same.
α (significance level)	0.05
H_{stat} (2)	3.59
ρ value (determination)	0.166
results	α (0.05) < ρ (0.166)
conclusion	Fail to reject H_o; The three probability distributions are the same.

Kruskal-Wallis H Test for Stubble-Mulch Sorghum Phase Runoff (Fields 10B, 11B, 12B)	
H_o: α (0.05) < ρ	The three probability distributions are the same.
H_a: α (0.05) > ρ	The three probability distributions are not the same.
α (significance level)	0.05
H_{stat} (2)	1.63
ρ value (determination)	0.442
results	α (0.05) < ρ (0.442)
conclusion	Fail to reject H_o; The three probability distributions are the same.

Kruskal-Wallis H Test for Stubble-Mulch Sorghum Phase Soil Loss (Fields 10B, 11B, 12B)	
H_o: α (0.05) < ρ	The three probability distributions are the same.
H_a: α (0.05) > ρ	The three probability distributions are not the same.
α (significance level)	0.05
H_{stat} (2)	0.467
ρ value (determination)	0.792
results	α (0.05) < ρ (0.792)
conclusion	Fail to reject H_o; The three probability distributions are the same.

Kruskal-Wallis H Test for Stubble-Mulch Fallow after Sorghum Phase Precipitation (Fields 10B, 11B, 12B)	
H_o: α (0.05) < ρ	The three probability distributions are the same.
H_a: α (0.05) > ρ	The three probability distributions are not the same.
α (significance level)	0.05
H_{stat} (2)	2.34
ρ value (determination)	0.311
results	α (0.05) < ρ (0.311)
conclusion	Fail to reject H_o; The three probability distributions are the same.

Kruskal-Wallis H Test for Stubble-Mulch Fallow after Sorghum Phase Runoff (Fields 10B, 11B, 12B)	
H_o: α (0.05) < ρ	The three probability distributions are the same.
H_a: α (0.05) > ρ	The three probability distributions are not the same.
α (significance level)	0.05
H_{stat} (2)	3.24
ρ value (determination)	0.198
results	α (0.05) < ρ (0.198)
conclusion	Fail to reject H_o; The three probability distributions are the same.

Kruskal-Wallis H Test for Stubble-Mulch Fallow after Sorghum Phase Soil Loss (Fields 10B, 11B, 12B)	
H_o: α (0.05) < ρ	The three probability distributions are the same.
H_a: α (0.05) > ρ	The three probability distributions are not the same.
α (significance level)	0.05
H_{stat} (2)	2.19
ρ value (determination)	0.335
results	α (0.05) < ρ (0.335)
conclusion	Fail to reject H_o; The three probability distributions are the same.

APPENDIX G: Precipitation, Runoff, and Soil Loss Measured from Large Storms (>51mm) at Bushland, TX 1984-2010

Precipitation, Runoff, and Soil Loss Measured from Large Storms (>51mm) Bushland, TX 1984-2010 Wheat Phase					
	mm	**mm**	**kg ha^{-1}**	**mm**	**kg ha^{-1}**
Date	**Precipitation**	**WNTRO**	**WNTSL**	**WSMRO**	**WSMSL**
30-Sep-90	52.3	-	-	-	-
11-Jun-92	54.1	3.0	9.3	0.5	35.5
6-May-89	56.9	1.2	18.7	1.2	30.4
26-Aug-96	59.9	-	-	-	-
31-May-88	60.7	0.5	0.0	0.0	0.0
2-Jul-95	61.0	-	-	-	-
8-Jul-10	65.0	-	-	-	-
31-May-86	66.8	0.6	6.5	0.1	21.8
10-Jul-99	80.0	-	-	-	-
11-Sep-85	84.3	-	-	-	-
12-Jun-84	96.5	37.7	814	28.1	636
15-Sep-88	98.0	-	-	-	-
30-Oct-98	131	76.7	1710	64.3	2383
Storm Event Total	967	120	2558	94.3	3106
27 Year Totals	5782	310	4116	196	4593
Percent of 27-year total	16.7	38.7	62.2	48.1	67.6
Blank entries (-) indicate an absence of the crop phase for the storm event.					

Precipitation, Runoff, and Soil Loss Measured from Large Storms (>51mm) Bushland, TX 1984-2010 Fallow After Wheat Phase					
	mm	**mm**	**kg ha^{-1}**	**mm**	**kg ha^{-1}**
Date	**Precipitation**	**FWNTRO**	**FWNTSL**	**FWSMRO**	**FWSMSL**
30-Sep-90	52.3	0.8	0.0	0.0	0.0
11-Jun-92	54.1	22.4	329	28.1	3852
6-May-89	56.9	26.9	712	24.4	1340
26-Aug-96	59.9	9.5	112	8.9	434
31-May-88	60.7	17.6	179	0.7	0.0
2-Jul-95	61.0	9.8	50.1	9.5	101
8-Jul-10	65.0	0.0	0.0	0.0	0.0
31-May-86	66.8	22.5	59.9	20.5	934
10-Jul-99	80.0	16.7	118	0.0	0.0
11-Sep-85	84.3	18.9	192	3.5	38.0
12-Jun-84	96.5	32.5	218	43.7	0.0
15-Sep-88	98.0	43.9	183	28.3	239
30-Oct-98	131	20.1	110	41.2	447
Storm Event Total	967	242	2264	209	7385
27 Year Totals	5782	702	8702	427	16149
Percent of 27-year total	16.7	34.4	26.0	49.0	45.7

Precipitation, Runoff, and Soil Loss Measured from Large Storms (>51mm) Bushland, TX 1984-2010 Sorghum Phase					
	mm	**mm**	**kg ha^{-1}**	**mm**	**kg ha^{-1}**
Date	**Precipitation**	**SNTRO**	**SNTSL**	**SSMRO**	**SSMSL**
30-Sep-90	52.3	0.0	0.0	0.1	0.0
11-Jun-92	54.1	-	-	-	-
6-May-89	56.9	-	-	-	-
26-Aug-96	59.9	0.4	0.0	0.0	0.0
31-May-88	60.7	-	-	-	-
2-Jul-95	61.0	20.0	781	27.2	1971
8-Jul-10	65.0	44.1	765	18.4	1005
31-May-86	66.8	-	-	-	-
10-Jul-99	80.0	16.8	90.3	12.6	256
11-Sep-85	84.3	9.9	145	6.6	108
12-Jun-84	96.5	-	-	-	-
15-Sep-88	98.0	23.6	381	11.7	99.0
30-Oct-98	131	-	-	-	-
Storm Event Total	967	115	2162	76.6	3439
27 Year Totals	5782	337	5092	329	15541
Percent of 27-year total	16.7	34.1	42.5	23.3	22.1
Blank entries (-) indicate an absence of the crop phase for the storm event.					

Precipitation, Runoff, and Soil Loss Measured from Large Storms (>51mm) Bushland, TX 1984-2010 Fallow after Sorghum Phase					
	mm	**mm**	**kg ha^{-1}**	**mm**	**kg ha^{-1}**
Date	**Precipitation**	**FSNTRO**	**FSNTSL**	**FSSMRO**	**FSSMSL**
30-Sep-90	52.3	10.2	82.3	0.0	0.0
11-Jun-92	54.1	14.5	100	10.7	356
6-May-89	56.9	9.0	0.0	5.7	189
26-Aug-96	59.9	21.0	222	0.0	0.0
31-May-88	60.7	20.1	134	2.4	41.4
2-Jul-95	61.0	14.1	116	3.8	166
8-Jul-10	65.0	24.2	456	0.9	79.0
31-May-86	66.8	35.6	408	24.7	630
10-Jul-99	80.0	25.6	153	6.7	107
11-Sep-85	84.3	23.6	459	28.9	1138
12-Jun-84	96.5	80.7	2159	85.7	5700
15-Sep-88	98.0	49.5	408	29.4	315
30-Oct-98	131	64.5	1823	49.4	Smalf
Storm Event Total	967	393	6520	248	8722
27 Year Totals	5782	1017	14159	533	17331
Percent of 27-year total	16.7	38.6	46.0	46.6	50.3
Blank entries (-) indicate an absence of the crop phase for the storm event. Smalf-sediment sampler malfunction					

APPENDIX H: Characteristics of Storm Runoff and Soil Loss by Storm Category

Characteristics of Storm Runoff by Storm Category (mm)							
Runoff Characteristics	2.6-6.4	6.5-12.7	12.8-25.4	25.5-50.8	50.9-76.2	76.3-101.6	> 127.0
Number of Events	2	70	353	322	55	29	6
NT Mean (mm) (% RO events)	0.01 (50.0)	0.84 (52.9)	2.58 (52.4)	4.4 (57.1)	15.5 (52.7)	29.2 (51.7)	53.8 (50.0)
SM Mean (mm) (% RO events)	0.01 (50.0)	0.61 (47.1)	1.95 (47.6)	2.93 (42.9)	9.48 (47.3)	23.6 (48.3)	51.6 (50.0)
Wheat Phase NT Mean (mm) (% RO events)	0 (0)	0.27 (8.6)	3.07 (7.6)	3.32 (8.1)	4.81 (9.1)	19.2 (6.9)	76.8 (16.7)
Wheat Phase SM Mean (mm) (% RO events)	0 (0)	0.18 (8.6)	2.28 (7.6)	1.51 (7.5)	1.10 (7.3)	14.1 (6.9)	64.3 (16.7)
Fallow Wheat Phase NT Mean (mm) (% RO events)	0 (0)	0.51 (10.0)	2.51 (14.4)	4.94 (17.4)	15.5 (16.4)	26.8 (17.2)	20.1 (16.7)
Fallow Wheat Phase SM Mean (mm) (% RO events)	0 (0)	1.04 (8.6)	2.08 (11.6)	3.09 (10.2)	9.54 (18.2)	24.0 (13.8)	41.2 (16.7)
Sorghum Phase NT Mean (mm) (% RO events)	0 (0)	1.22 (11.4)	2.19 (11.3)	2.29 (12.7)	19.0 (9.1)	16.8 (10.3)	0 (0)
Sorghum Phase SM Mean (mm) (% RO events)	0 (0)	0.75 (10.0)	2.11 (12.7)	3.13 (11.5)	20.4 (7.3)	10.3 (10.3)	0 (0)
Fallow Sorghum Phase NT Mean (mm) (% RO events)	0.01 (50.0)	1.0 (22.9)	2.67 (19.0)	5.79 (18.9)	19.0 (18.2)	43.0 (17.2)	64.5 (16.7)
Fallow Sorghum Phase SM Mean (mm) (% RO events)	0.01 (50.0)	0.53 (20.0)	1.55 (15.6)	3.41 (13.7)	8.15 (14.5)	35.1 (17.2)	49.4 (16.7)
Min. Runoff (mm) Amount NT	0.01	0.01	0.01	0.01	0.04	0.61	20.1
Max. Runoff (mm) Amount NT	0.01	6.32	20	28.8	41.1	80.7	76.8
Min. Runoff (mm) Amount SM	0.01	0.01	0.01	0.01	0.01	0.14	41.2
Max. Runoff (mm) Amount SM	0.01	6.04	21.1	23.3	35.9	85.7	64.3
Total Runoff (mm)	0.02	50.9	804	1214	695	768	316
Average Runoff (mm)	0.01	0.73	2.28	3.77	12.6	26.5	52.7
Percentage of total events	0	8.4	42.2	38.5	6.6	3.5	0.7
Percentage of total Runoff	0	1.3	20.9	31.5	18.1	20	8.2

Characteristics of Soil Loss by Storm Category (mm)							
Storm Categories (mm)	2.6-6.4	6.5-12.7	12.8-25.4	25.5-50.8	50.9-76.2	76.3-101.6	> 127.0*
Number of Events	0	16	169	169	40	22	5
NT Mean (kg ha^{-1}) (% SL events)	0 (0)	60.8 (43.8)	72.1 (53.3)	106 (57.4)	270 (55.0)	443 (54.5)	1214 (60.0)
SM Mean (kg ha^{-1}) (% SL events)	0 (0)	37.3 (56.3)	171 (46.8)	206 (42.6)	749 (45.0)	864 (45.5)	1415 (40.0)
Wheat Phase NT Mean (kg ha^{-1}) (% SL events)	0 (0)	0 (0)	67.87 (7.7)	60.5 (5.9)	11.5 (7.5)	814 (4.5)	1710 (20.0)
Wheat Phase SM Mean (kg ha^{-1}) (% SL events)	0 (0)	0 (0)	87.2 (7.7)	44.1 (4.7)	29.2 (7.5)	636 (4.5)	2383 (20.0)
Fallow Wheat Phase NT Mean (kg ha^{-1}) (% SL events)	0 (0)	0 (0)	77.8 (13.6)	150 (17.2)	247 (17.5)	178 (18.2)	110 (20.0)
Fallow Wheat Phase SM Mean (kg ha^{-1}) (% SL events)	0 (0)	33.6 (12.5)	234 (11.8)	184 (11.2)	1197 (15.0)	139 (9.2)	447 (20.0)
Sorghum Phase NT Mean (kg ha^{-1}) (% SL events)	0 (0)	35.4 (12.5)	75.0 (10.7)	56.2 (8.3)	756 (7.5)	205 (13.6)	0 (0)
Sorghum Phase SM Mean (kg ha^{-1}) (% SL events)	0 (0)	43.3 (31.3)	225 (13.0)	246 (12.4)	1580 (7.5)	154 (13.6)	0 (0)
Fallow Sorghum Phase NT Mean (kg ha^{-1}) (% SL events)	0 (0)	71.0 (31.3)	68.5 (21.3)	101 (26.0)	211 (22.5)	797 (18.2)	1823 (20.0)
Fallow Sorghum Phase SM Mean (kg ha^{-1}) (% SL events)	0 (0)	26.2 (12.5)	116 (14.2)	241 (14.2)	244 (15.0)	1815 (18.2)	0 (0)
Min. SL (kg ha^{-1}) Amount NT	0	8.81	0.09	0.28	6.5	90.3	110
Max. SL (kg ha^{-1}) Amount NT	0	310	423	1111	781	2159	1823
Min. SL (kg ha^{-1}) Amount SM	0	6.29	0.19	1.56	21.9	38.0	447
Max. SL (kg ha^{-1}) Amount SM	0	46.0	1159	1891	3852	5700	2383
Total Soil Loss (Mg ha^{-1})	0	0.762	20.0	25.1	19.4	14.0	6.47
Average Soil Loss (kg ha^{-1})	0	47.6	119	148	485	634	1294
Percentage of total events	0	3.8	40.1	40.2	9.5	5.2	1.2
Percentage of total Soil Loss	0	0.8	23.4	29.2	22.7	16.3	7.6

* Storm category > 127.0 had one storm event with one sediment sampler malfunction on field 12B. Runoff amount for 12B was 49.41 mm.