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Variety Trial Yields: A Look at the Past 65 Years

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RESEARCH SUMMARY

Small-grain variety trials have been conducted at the Dickinson Research Extension Center for decades, but there has been no modern attempt to evaluate yield levels over time. We compared grain yield trends of hard red spring wheat, durum wheat, barley, and oat over almost 70 years. Grain yields increased over time, with a relatively large increase following the switch from clean-till crop-fallow management to intensified, no-till management during the 1990s. Results of this evaluation support the continued adoption of no-till farming methods by crop producers in southwestern North Dakota.

INTRODUCTION

Cereal grains are the oldest domesticated crops in the world. In fact, the cultivation of wheat dates back some 10,000 years. Historical yields are difficult to trace this far into history, but recent reports have suggested that naked wheat grown approximately 9,000 years ago in the Euphrates delta at Tell Halula, one of the oldest agricultural sites known to man, yielded approximately 20 bu/ac (Araus et al., 2003). Wheat yields in the Mediterranean region, about 2,000 – 2,500 years ago, were comparable to those above, but on irrigated land may have been as high as 70 bu/ac (Araus et al., 2003; Amir and Sinclair, 1994). In the middle ages, (ca. 500 A.D.) wheat yields in England, Spain and France tended to be somewhat lower than was earlier observed in the Mediterranean region, with only 10 – 15 bu/ac being the usual estimate, while in Egypt, on the rich moist soils of the Nile, yields averaged 20 bu/ac (Wickham, 2005; Kibler and Zinn, 1996). It should be noted that these are approximate estimates, as yield data over large areas is absent, especially as the dates recede farther into history.

Moving into the modern era, cereal yields have embarked on a continual uphill climb. Over the past 100 years, U.S. wheat yields increased from 14 bu/ac in 1907 to 41 in 2007, while yields in North Dakota increased from 11 bu/ac to 36 over the same period (Fig. 1). This increase becomes most pronounced beginning in the 1940s and 50s, when pesticides, fertilizers, and improved crop varieties became available. Up until the middle part of the 20th century, the method by which food production was increased was mainly through the expansion of cultivated land. Beginning in the 1940s, however, many scientists and policymakers began to worry that this strategy, along with the current agricultural management techniques, could not sustain the growing human population. This directly fueled a concerted effort by researchers to increase the productivity of crops through the creation of higher yielding cultivars. These cultivars were bred to increase potential yields on the increasing controlled agricultural landscape, in concert with pesticides and readily available synthetic fertilizers.

Variety trials at the Dickinson Research Extension have been ongoing since 1908, although only data back to 1942 can be obtained. Yields of all crops, including hard red spring wheat [HRSW], durum wheat, oats and barley, have increased over the 65 year period. The purpose of this paper is to provide information on the patterns of increase, and the variation in historical yields of these crops from 1942 to 2007. Causal factors involved in the yield variation over time, such as climatic conditions and management systems, will be discussed.

MATERIALS AND METHODS

Variety trial yield data for the period 1942 to 2007 was obtained from annual reports and Western Dakota Crops

Day research reports when annual reports were unavailable. Weather data was obtained from Dickinson Research Extension Center records. Data was entered into an excel spreadsheet and transferred to SAS 9.1 for statistical analysis.

One-way ANOVA (a = 0.05) was performed to determine yield differences between decades for each crop and differences in temperature and precipitation values between decades. The relationship between climate and yield over all years was investigated by obtaining Pearson product moment correlations for yield of the four crops (HRSW, durum, oats and barley) and the climate variables April, May, June and July average, maximum and minimum temperatures, along with average, maximum and minimum temperatures for the overall April to July period. Precipitation amounts for these same months were also included, as well as total precipitation for the April to July period and total annual precipitation. Correlations between climate variables and yield significant at p =

0.05 were used in simple linear regression to determine the amount of variability in yield accounted for by the climatic condition. The same method was used when data were analyzed within each decade. When more than one significant correlation existed between climatic variables and crop yield a forward-selection multiple regression was performed in lieu of a simple linear regression.

RESULTS AND DISCUSSION

All crops showed substantial yield improvements over the period of record, with barley possessing the greatest average yield increase, from 33 bu/ac in the 1940s to 80 bu/ac in the 2000s (Fig. 2). Hard red spring wheat, durum wheat and oats all had lowest yields in the 1950s and highest yields in the 1990s, with increases in yield averaging 30, 24 and 58 bu/ac respectively (Fig. 3, 4 and 5). Statistically speaking, average barley and spring wheat yields were consistent through the 1940s and 50s, increased in the 60s, and then increased again in the 90s ($p = 0.03$ and 0.02 respectively). Average durum wheat and oat yields, on the other hand, remained consistent from the 40s through the 80s, then increased in the 90s ($p = 0.01$ for both).

When discussing variability in yields, one of the most obvious factors of influence is the weather. Climatic variation affects grain yields from year to year, but the extent to which yield variation is driven by climate over the period of record has not previously been investigated at the DREC. Weather data has been collected at the Dickinson

Research Extension Center since 1898. Given that this period of record corresponds with available yield data, an investigation of the impact of climate on historical variety trial yields was deemed appropriate.

No statistical differences were seen in average growing season temperatures or average maximum or minimum growing season temperatures between decades (Table 1). When observing each month individually, July stood out as having significantly lower maximum temperatures in the 1990s than any other decade ($p = 0.01$). No other differences in monthly average temperatures were observed between decades. Average yearly and monthly precipitation did not differ significantly between decades (Table 2).

The small amount of variation in climate data between decades foreshadowed the low degree of overall influence that temperature and precipitation had on small grain yields over the past 65 years. Still, some impact of climate was observed when weather and yield data was compared year by year. Multiple regression showed that overall July maximum temperature explained 20% of the variation in oat yield and June max temps explained an additional 5% of the variation. Durum yields were also negatively impacted by June maximum temperatures, which explained 15% of the variation in yields over the 65 years. Total precipitation explained 9% of the variation in HRSW, with yields responding positively to increasing precipitation.

It seems from the above analyses that climate had limited influence on historical small grain yields; however, the large variability in climate data over time may obscure real relationships between climate and yield that would be apparent over shorter periods of time. This possibility led to an analysis of the effects of climate on yields within each decade, at which point a different picture then the one suggested above begins to come into view. When analyzed within decade, monthly high temperatures had a strong negative effect on yields of durum, barley and oats in some periods. In fact, during the 1940s, 80s and 90s 57%, 52% and 61% of oat yield variation between years was tied to the negative effect of increasing July temperatures, while in the 1950s 53% of the variation in oat yield between years was tied to the negative effect of increasing June temperatures (Fig. 6). Barley yields were negatively affected by increasing June temperatures in the 1960s and 90s, with 59% and 41% of yield variability tied to this factor respectively (Fig. 7). Durum was also negatively affected by increasing June maximum temperatures in the 1960s and 90s, with 50% and 59% of yield variability explained respectively (Fig. 8).

Precipitation had a less prevalent effect on yields when observed within decade, but still was a factor in some years.

In the 1980s 53% and 63% of HRSW and barley yield variability between years was explained by the positive effect of increasing annual precipitation (Fig. 9 and 7 respectively). Durum yield was positively influenced by increasing May precipitation in the 1990s, which accounted for 60% of yield variation (Fig. 8).

Dividing and analyzing temperature and precipitation data by decade is somewhat arbitrary, but it does elucidate the effect of climate on grain yields. Still, the overall effects of climate on the various crops were inconsistent and variable between decades. This indicates that complex relationships exist between climate factors, but also fundamentally suggests that other factors must be driving the yield increases which were observed over the past six and a half decades. The pattern of yield increase over time differed among crops. HRSW yields increased significantly from the 1960s to the 70s, while barley yields increased more gradually from the 1950s to the 70s. Oat and durum yields, on the other hand, were consistent from the 1940s up to the 80s. A substantial boost in yield of all crops was then observed from the 1990s to the present.

From the 1940s through the 80s variety trials were consistently managed under the crop-fallow system, so this precluded any rotational effect on increasing small grain yields. One explanation for the yield increase from the 50s to the 70s is the introduction of higher yielding varieties, but an equally if not more important factor over this period was the greater availability of pesticides and synthetic fertilizers. Pesticides allowed growers greater control over the agroecosystem by minimizing interspecific competition as well as pest and disease damage. These products were effective to the point that in many cases cultural practices for pest and disease control were neglected. This eventually led to less than ideal conditions in the field in some circumstances and further dependence on synthetic pesticides and fertilizers as curatives.

The boost in yields seen in all crops from the 1980s through the 90s was substantial and not related to climate. It is likely that this phenomenon resulted from several factors. In the mid 1990s, tillage was eliminated following the purchase of no-till planting equipment. Black fallow was replaced with chemical fallow, and shortly thereafter with more intensified cropping system where variety trials were rotated with legumes. This increased cropping intensity was made possible by the enhanced soil water retention occurring under no-till management, as well as the benefits realized by increasing soil organic matter contents and biological nitrogen fixation occurring under the legume phase. Increased organic matter content, which result from legume and cereal residues, lead to a more active and balanced microbial population as well as the enhanced availability of soil nutrients and possible disease suppression (Kennedy et al., 2004; Stone et al., 2004). Biologically fixed N can be available for use by the subsequent crop, as well as providing a reserve pool of potentially mineralizable N (Lupwayi and Kennedy, 2007). An intensified rotational cropping system can also help to break insect pest and disease cycles, while rotations including distinct crops can reduce weed pressure (Teasdale et al., 2004). No-till systems in general have been known to reduce the abundance of annual weeds and to increase the rates of weed seed predation, which can account for the fate of up to 70% or more of weed seeds (Gallandt, 2006; Westerman et al., 2003). These benefits, actualized by an intensified no-till rotational system can account for a substantial portion of the increase in yields seen through the 1990s; however, differences in fertilizer and herbicide programs were integral to these yield increases. By nature, the implementation of no-till cropping systems necessitated a more ambitious herbicide program. This program served to reduce weed competition on a more consistent basis than was affected in the past when timely tillage and less disciplined herbicide use were relied upon.

In conclusion, variety trial yields of all cereal grains increased substantially over the 65 year period of record. The greatest yield increase over a 10 year span for all crops occurred during the 1990s, while more gradual and less substantial increases during the preceding decades. The boost in crop yields seen from the 1980s to the 90s most likely resulted from the change in management from clean-tilled crop-fallow to intensified no-till cropping and the practices intrinsic to that system. On average, climate varied little between decades, but was observed to effect grain yields. The most prominent effects of climate were observed when decades were considered separately, with growing season high temperatures generally having a negative effect on yields, and increasing precipitation having a positive effect on yields of HRSW, durum and barley.

Table 1. Selected growing season (GS) and monthly temperature data for the variety trial period of record. Growing season refers to May through July.

Years	Temperature (°F)					
	Avg GS	Max GS	Min GS	May Max	June Max	July Max
1942-49	60	73	47	65	71	83*a*
1950-59	61	75	47	66	74	83*a*
1960-69	61	74	48	65	74	83*a*
1970-79	61	75	48	66	77	83*a*
1980-89	62	77	47	68	77	85*a*
1990-99	60	73	47	66	75	79*b*
2000-07	[illegible]	75	[illegible]	65	75	[illegible]

Table 2. Selected precipitation data for the variety trial period of record.

Years	Precipitation (in.)				
	April	May	June	July	Annual Total
1942-49	1.38	1.82	4.36	1.99	17.32
1950-59	1.19	1.82	3.49	1.99	16.12
1960-69	1.92	2.77	4.01	2.47	17.52
1970-79	2.50	2.90	3.71	1.63	18.44
1980-89	1.24	2.00	3.00	2.20	17.67
1990-99	1.51	2.20	3.88	2.85	18.10
2000-07	1.36	2.55	3.56	2.20	17.22

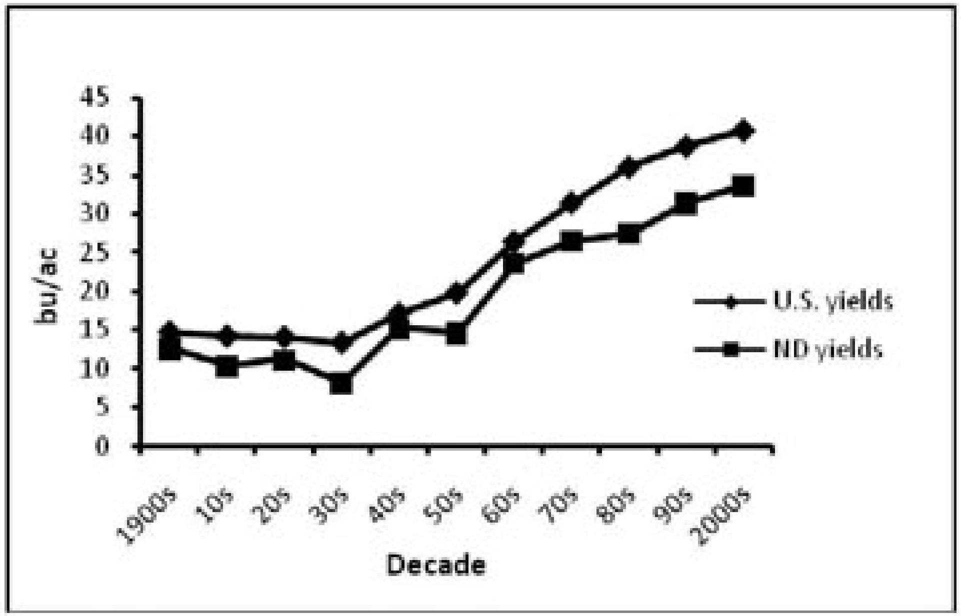

Figure 1. Wheat yields by decade.

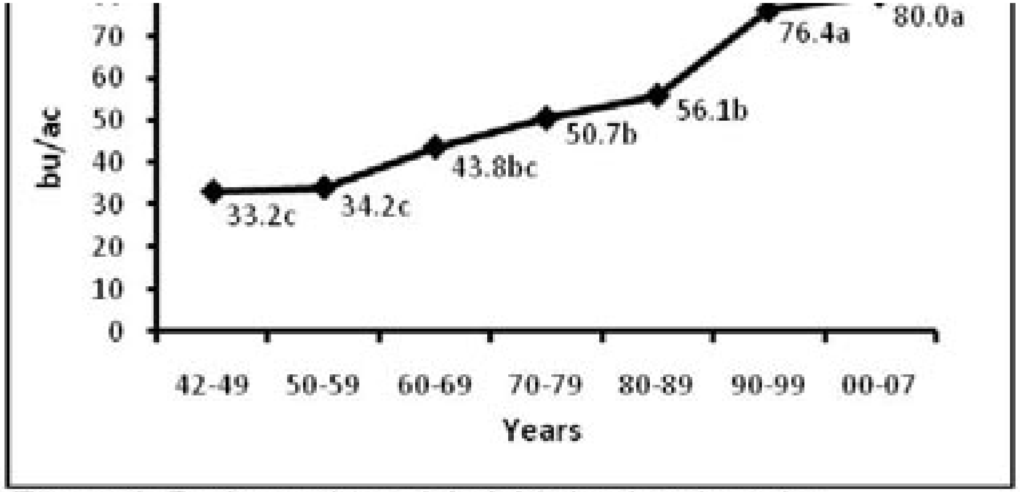

Figure 2. Barley variety trial yields by decade at the Dickinson Research Extension Center.

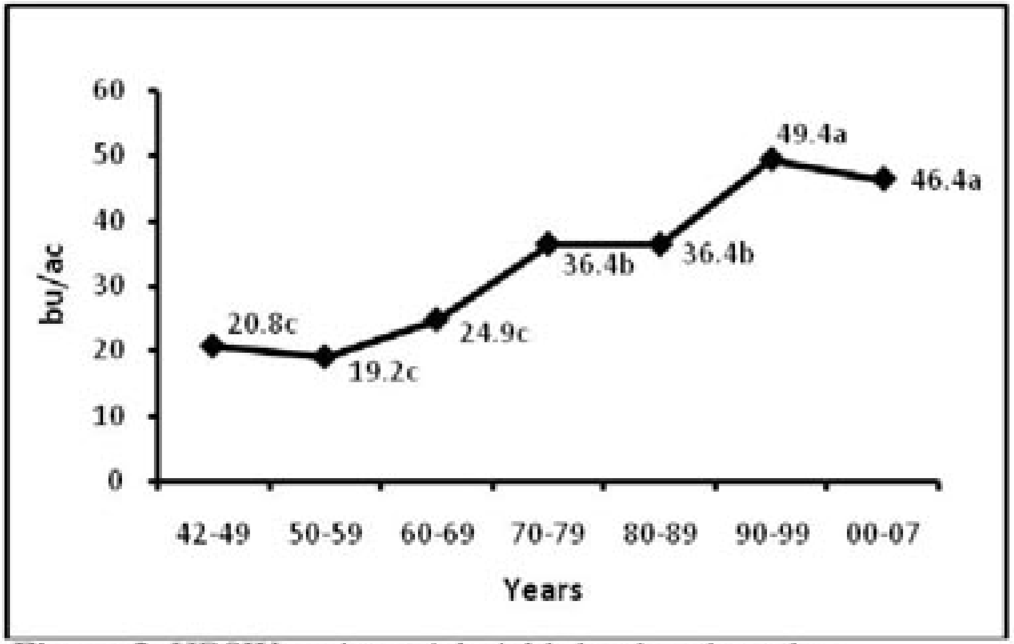

Figure 3. HRSW variety trial yields by decade at the Dickinson Research Extension Center.

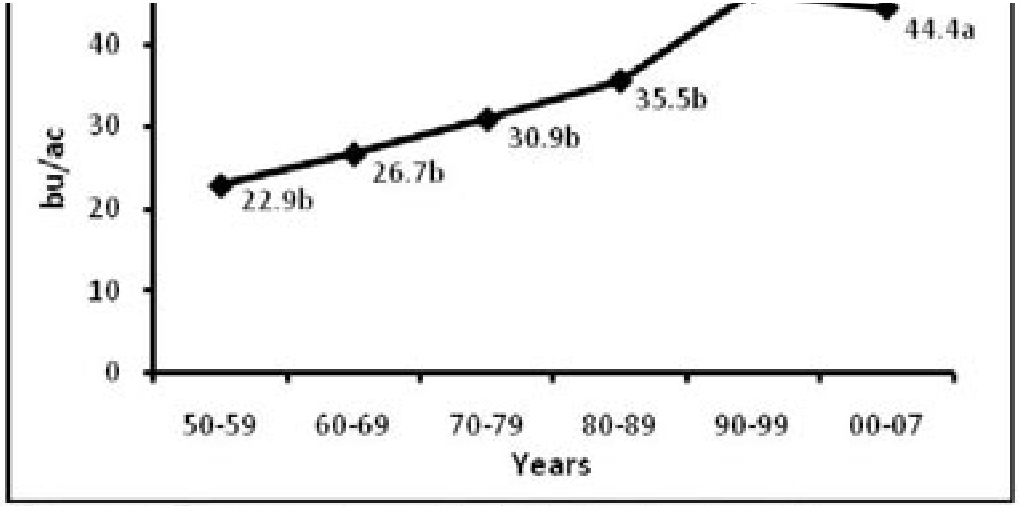

Figure 4. Durum variety trial yields by decade at the Dickinson Research Extension Center.

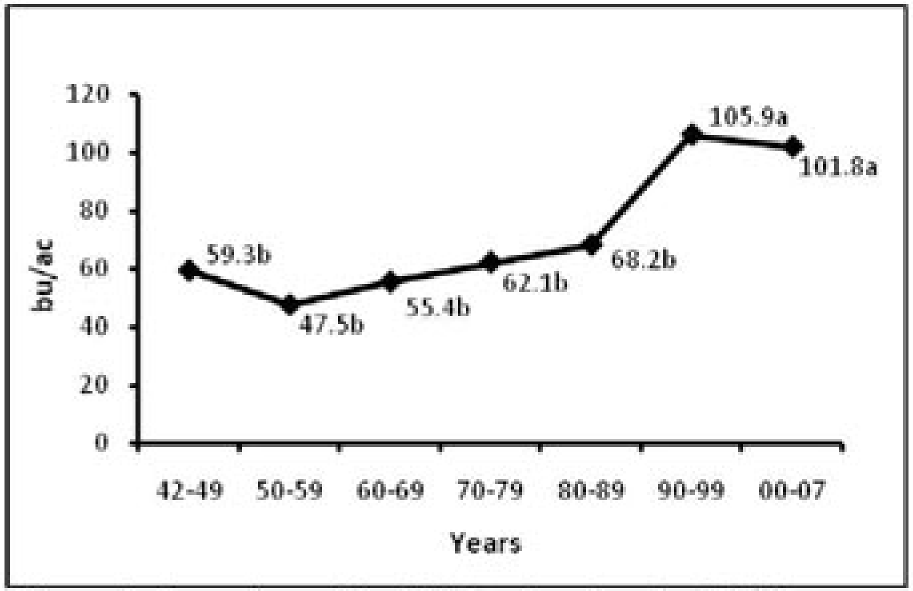

Figure 5. Oat variety trial yields by decade at the Dickinson Research Extension Center.

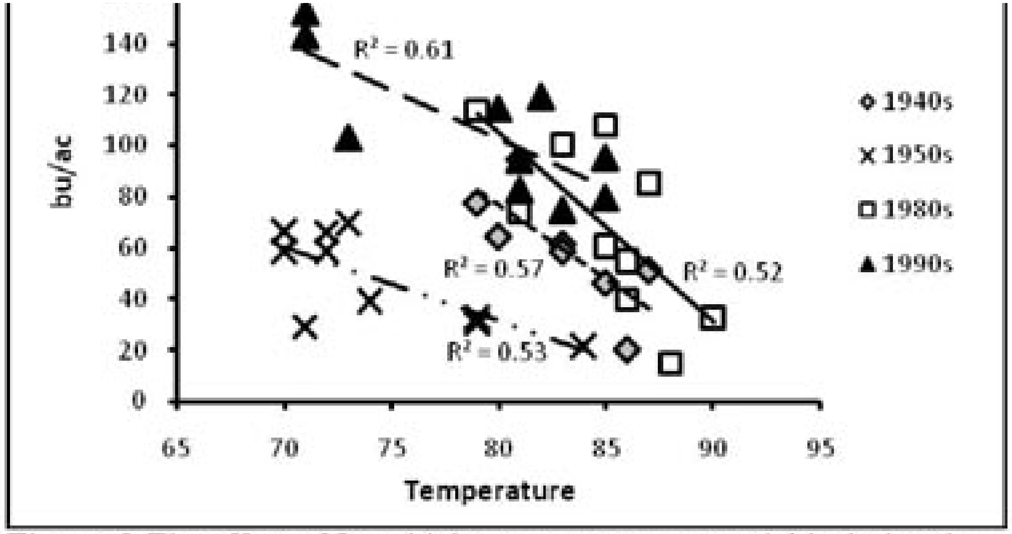

Figure 6. The effect of June high temperature on oat yields during the 1950s and July high temperatures on oat yields during the 1940s, 80s and 90s at the Dickinson Research Extension Center.

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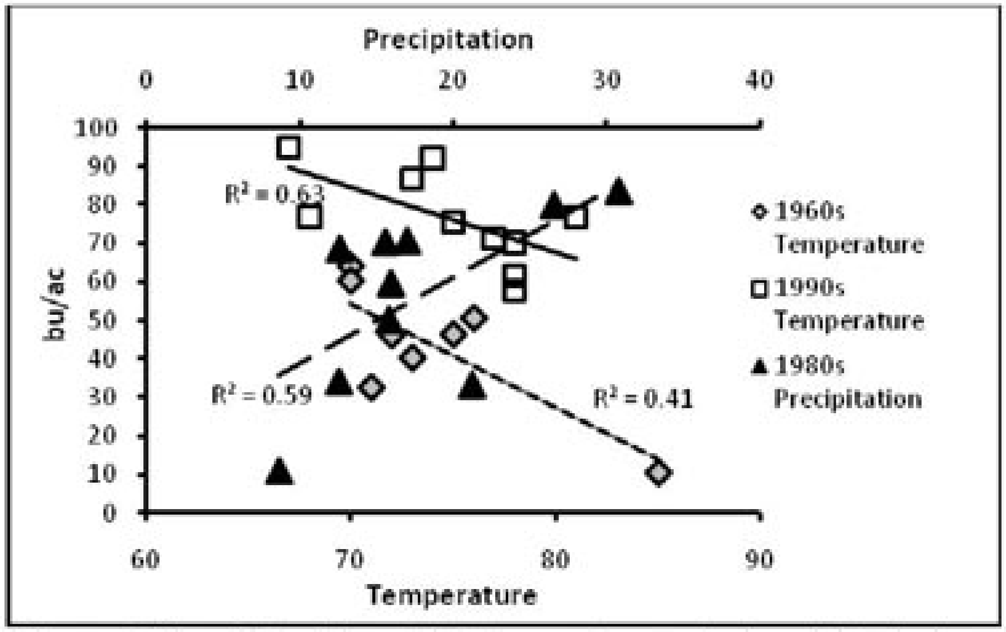


Figure 7. The effect of June high temperature on barley yields during the 1960s and 90s and the effect of annual precipitation on barley yields during the 1980s at the Dickinson Research Extension Center.

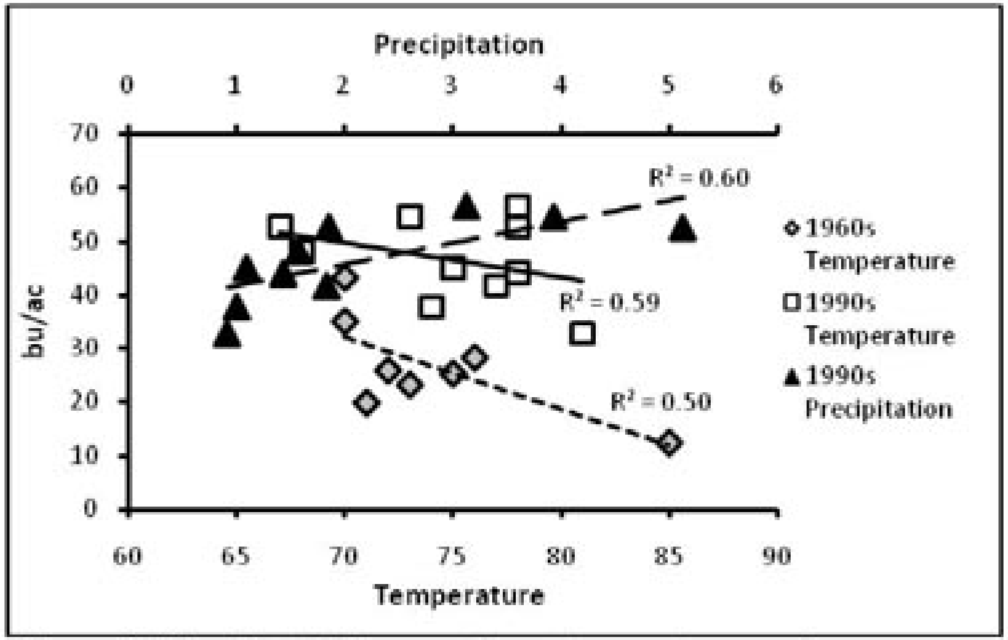
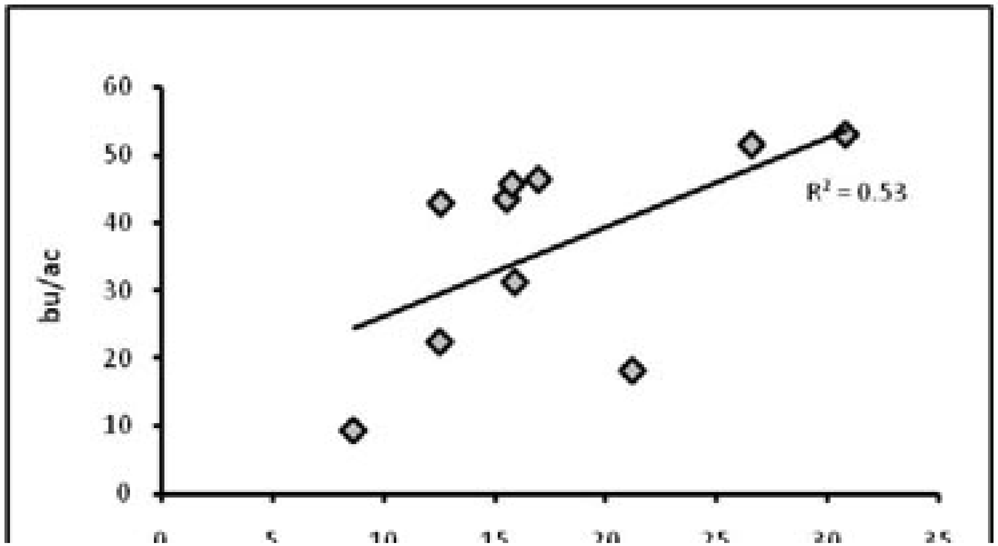


Figure 8. The effect of June maximum temperatures on durum yields during the 1960s and 90s and the effect of May precipitation on durum yield during the 1990s at the Dickinson Research Extension Center.



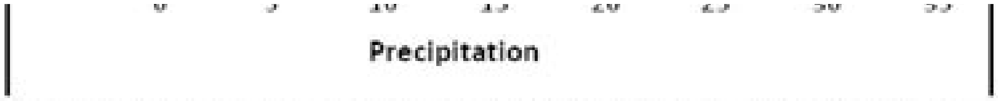


Figure 9. The effect of annual precipitation on HRSW yields during the 1980s at the Dickinson Research Extension Center.

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