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Conservation compliance credit for winter wheat fall biomass production and implications for grain yield

Gregory S. McMaster and W.W. Wilhelm

*Producers participating in federal farm and conservation programs must reduce potential erodibility below certain thresholds on lands classified as highly erodible. The Natural Resource Conservation Service (NRCS) will credit producers in Colorado for the quantity of green winter wheat (*Triticum aestivum *L.) biomass at the beginning of the winter period towards compliance in reducing erosion. Unfortunately, few data exist on fall winter wheat biomass production, and fall production varies widely based on many site-specific factors at planting and during the fall, and can be expensive to document. To address these problems, a crop simulation model called SHOOTGRO was used to predict the amount of green biomass present. By combining planting dates, sowing rates, and conditions of NO_3, NH_4, total water in the soil profile, and water in the seedbed layer at planting for three sites in eastern Colorado a total of 216 scenarios were simulated, both to assist NRCS in determining compliance and to better understand the dynamics of early winter wheat biomass production.*

Essentially all land in eastern Colorado is classified as highly erodible, mainly due to wind erosion, by the NRCS. Producers participating in federal farm and conservation programs are required by the 1985 National Food Security Act to reduce potential erodibility of their land below certain thresholds. One erosion prevention action allowed by NRCS is to cover soil with green biomass. In winter wheat production systems, establishing either residue or green biomass plant cover before entering winter is an important means of reducing potential erodibility.

The NRCS has had difficulties determining compliance credit for green biomass present on December 1 for winter wheat producers. The December 1 date was chosen by NRCS because this is the period when residue cover and live biomass is relatively low, little growth will occur until spring, and therefore the soil is at greatest risk to erosion. These difficulties include: (1) little existing data for fall biomass production by winter wheat, especially in Colorado, and (2) field verification by NRCS of biomass production is too costly. Extrapolating from scarce databases to different soils, local weather, large variation in conditions at planting, and different planting dates have been almost impossible with any degree of reliability.

We believe that this problem is best ad-

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Interpretive summary

On lands classified as highly erodible, producers participating in federal farm programs must take actions designed to reduce potential erodibility below certain thresholds. The USDA-NRCS will credit winter wheat producers for green biomass present entering winter towards compliance in reducing erosion. A crop simulation model called SHOOTGRO was used to predict fall biomass production. The main factors affecting fall biomass production were planting date and total water in the soil profile at planting. Secondary factors were sowing rate and water in the seedbed layer at planting. Nitrogen had little effect. Fall biomass production was primarily controlled by heat units accumulated during the fall. NRCS is using these results to credit producers for compliance in conservation programs.

Key words: biomass, conservation programs, production, residue cover, soil erosion, wheat, yield.

Table 1. Characteristics of the sites

Site	Lat	Long	Mean annual Precipitation (mm)	Annual Pet (mm)	Years	No. years	Source
Akron	N40°09'	W103°09'	396	1075	1912-1991	80	CPRS*
Cheyenne Wells	N38°49'	W102°21'	394	1400	1918-1992†	67	NOAA
Rocky Ford	N38°02'	W103°42'	296	1800	1918-1990‡	71	NOAA

*Central Great Plains Research Station, Akron, Colorado
†except 1921, 1947-1949, and 1985
‡except 1921

dressed by computer models that simulate growth as influenced by climate, soil type, varying conditions at planting, and planting dates. Simulated results can be summarized, the minimum green biomass expected 90% of the time determined, and credit given producers for this minimum biomass production without on-site verification. If producers feel this minimum estimate is too low, evidence of greater production can be submitted. If severe and unusual weather conditions result in extremely low green biomass production, producers could be granted a variance to the required residue/biomass amount.

Because compliance is important, wheat producers must carefully choose procedures that reduce potential erodibility. For instance, efforts to increase residue cover and green biomass during fall may negatively impact final grain yield. Under semi-arid conditions of eastern Colorado, dryland winter wheat yields are strongly related to water availability (McMaster et al. 1994; Norwood 1994; Unger and McCalla 1980; Wilhelm et al. 1989). Too much vegetative growth during the fall may result in excessive use of water and N, leaving insufficient resources in early summer to support grain growth (Winter and Musick 1993). The objectives of this paper are to: (1) use an existing crop model to simulate green biomass production of winter wheat on December 1 for various sites in eastern Colorado with different planting dates and conditions at planting; and (2) report relationships between simulated fall biomass production and grain yield.

Methods

A small-grain cereal growth and development model called SHOOTGRO 3.0 was chosen for simulating winter wheat fall biomass production and final grain yield (McMaster et al. 1991, 1992a, 1992b; Wilhelm et al. 1993). SHOOTGRO is a mechanistic model that simulates the development and growth of morphologically identified individual leaves, internodes, spikelets, and kernels on each culm as affected by temperature, water, N, and light. A variety of conditions at different planting dates were simulated for three main wheat production sites in eastern Colorado located along a potential evapotranspiration gradient but with similar annual precipitation (Table 1). Availability of long-term weather records also determined site selection.

Numerous conditions affect fall biomass production and final grain yield. For each site, 216 combinations of four planting dates, two sowing rates, and three levels each of total water in the soil profile, seedbed soil water, and soil NO_3 and NH_4 were simulated (Table 2). Four planting dates were simulated: September 1, September 15, October 1, and October 15. Typical planting dates in eastern Colorado are 10 to 20 September (Nelson 1993). Two sowing rates of 150 and 250 seeds m^{-2} were simulated. If seed weight of 35 mg (.0012355 oz) is assumed, these equal seeding rates of 52.5 (46.88) and 87.5 kg ha^{-1} (78.14 lb/a^{-1}), respectively. Seeding rates near 50 to 70 kg ha^{-1} (44.65 to 62.51 lb/a^{-1}) are common, with 90 kg ha^{-1} (80.37 lb/a^{-1}) a high rate (Blue et al. 1990; Epplin et al. 1993; McMaster and Smika 1988). Soil water, both total amount in the soil profile and amount in the seedbed zone should be key factors controlling growth and final grain yield in the semi-arid region of eastern Colorado. Availability of N can also be important (Campbell et al. 1977a, 1977b; Wilhelm et al. 1993). Therefore, three levels of each of these factors were simulated representing low, medium, and high levels of availability (Table 2). All simulations had 45 kg N ha^{-1} (.6705 bu/a^{-1})fertilizer applied at planting.

Each combination of initial conditions was simulated for every year of weather records available for the site using a Platner loam soil (fine mixed Aridic Argiustoll). This resulted in over 49,000 wheat production scenarios simulated. Above ground biomass on December 1 and final grain yield for each set of initial conditions within each year was predicted. Predicted values exceeded 90% of the time, or the 10^{th} percentile, for each set of initial conditions at a site was determined. Regression analyses (Jandel Scientific Inc. 1994) were used to determine the relationship between biomass on December 1 and final grain yield.

Calculation of heat units, or growing degree-days, is according to the following equation:

$$GDD = \frac{(T_{max} + T_{min})}{2} - T_{base}$$

$$if \frac{(T_{max} + T_{min})}{2} < T_{base}, then\ GDD = T_{base}$$

Table 2. Planting dates, sowing rates, and initial soil NO_3-N, NH^{+4}-N, and water conditions at planting simulated

All simulations added 45 kg N ha^{-1} at the day of planting

Planting dates: September 1, September 15, October 1, October 15

Sowing rates: Low 150 seeds m^{-2}; High 250 seeds m^{-2}

Depth	Nitrate-N Low	Nitrate-N Medium	Nitrate-N High	Ammonium-N Low	Ammonium-N Medium	Ammonium-N High	Water Low	Water Medium	Water High
(cm)	mg N kg^{-1}			mg N kg^{-1}			kg kg^{-1}		
0-30	2.6	5.1	7.6	0.3	0.7	1.0	*	*	*
30-60	0.7	1.3	2.2	0.2	0.5	0.7	0.17	0.22	0.30
60-90	0.6	1.1	1.5	0.2	0.4	0.5	0.17	0.20	0.27
90-120	0.4	0.8	1.2	0.1	0.2	0.3	0.15	0.17	0.27
120-150	0.3	0.7	1.0	0.1	0.1	0.2	0.12	0.15	0.22
150-180	0.2	0.5	0.7	0.1	0.1	0.1	0.12	0.15	0.22
Total	4.8	9.5	14.2	1.0	2.0	2.8			

*Value depends on seedbed soil water conditions: Low = 0.15, Medium = 0.25, and High = 0.35

where T_{max} and T_{min} are daily maximum and minimum air temperature in °C, and T_{base} is the base temperature in °C, and set at 0°C (McMaster 1997).

Results and discussion

Regardless of site, three groups of factors were identified for their effect on winter wheat biomass on December 1 (Figures 1-3). Primary factors influencing fall winter wheat production were planting date and amount of water in the soil profile at planting. Secondary factors were planting density and amount of water in the seedbed zone at planting. Amount of NO_3 and NH_4 in the soil profile at planting had essentially no effect (Figures 1C, 2C, and 3C). The effect of all factors decreased as planting date was delayed. The main reason for these results is that fall biomass production is controlled primarily by time of emergence and growing degree-days (GDD) accumulation. Under normal production practices, planting depth is altered to place seeds into soil with sufficient water to support germination and emergence. This practice, combined with normal precipitation in September and October, results in sufficient soil moisture for seedling emergence within two weeks of planting.

Fall above ground biomass is composed almost entirely of leaves because stem elongation does not begin until spring (McMaster 1997). Potential biomass is a function of leaf and tiller appearance rates and the maximum potential size of blade and sheath tissue. Leaf and tiller appearance is controlled primarily by temperature and secondarily by water and N (Kirby 1995; McMaster and Wilhelm 1995; Wilhelm and McMaster 1995). Blade and sheath growth, however, is strongly affected by water and N in addition to temperature. Timing of tiller appearance is related to the number of leaves on the main stem (Klepper et al. 1984; McMaster et al. 1991), so the rate of leaf appearance affects time of tiller appearance.

Factors such as water and N availability are secondary influences on leaf appearance rates. Most years, sufficient water and N availability for sufficient fall wheat development and fall biomass production depends primarily on GDD. Insufficient GDD accumulate by December 1 with later planting dates (Table 3) to allow much development and fall biomass production is low (Figures 1-3). The difference of about 80 GDD between sites for the last planting date is less than required to produce 1 new leaf on a culm. For the late planting date, less than 400 GDD ac-

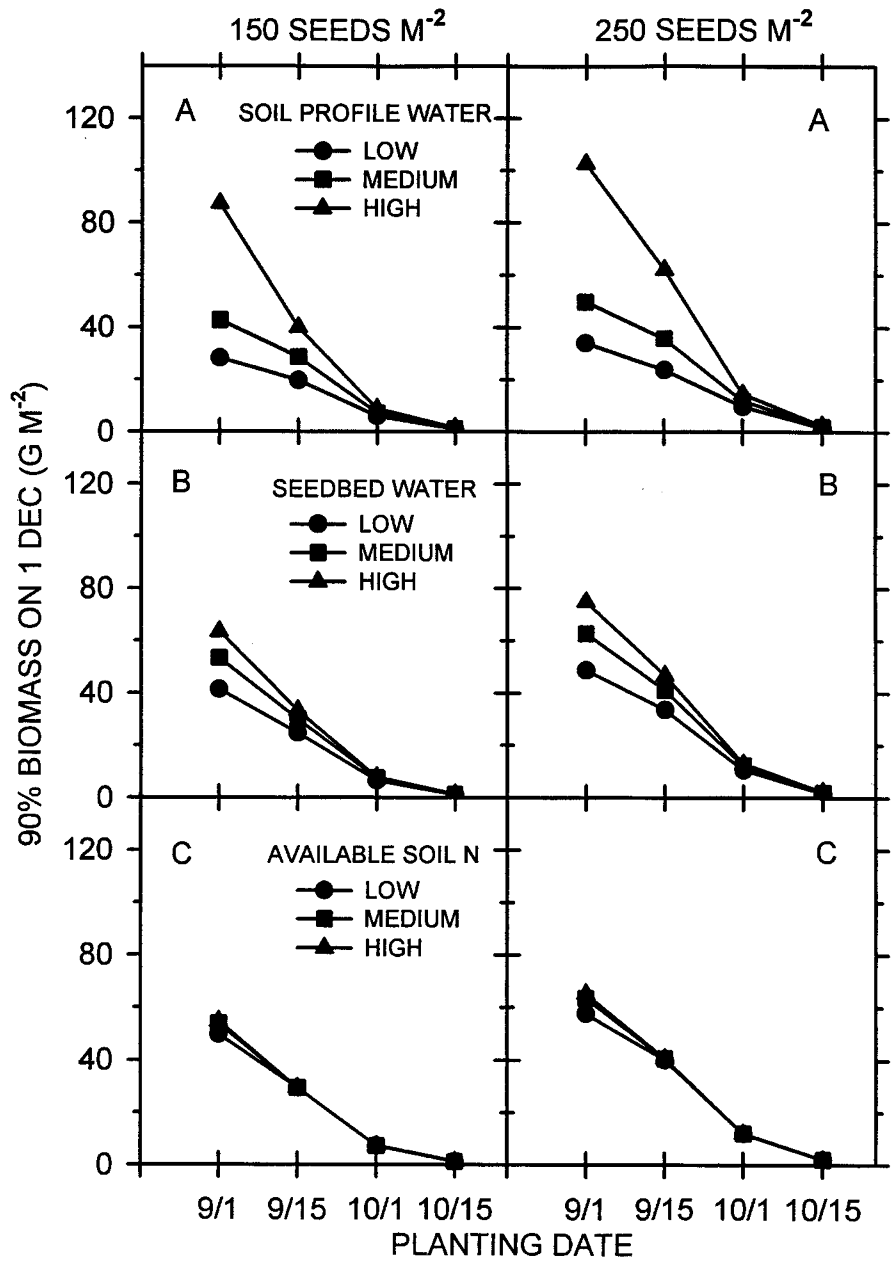

Figure 1. Amount of above ground winter wheat production predicted on December 1 90% of the time at Akron, Colorado for several conditions at planting

Note: For each planting date and sowing rate, responses to total soil water content (A), seedbed water content (B), and available soil N (C) are plotted with all other factors pooled. High, medium, and low levels of total soil water, seedbed water, and available N are listed in Table 2

Table 3. Mean accumulated heat units from different planting dates to December 1 for three sites in eastern Colorado

Site	Mean heat units from planting date to December 1 Sep 1	Sep 15	Oct 1	Oct 15
	C•day			
Akron	991	727	487	313
Cheyenne Wells	1136	853	584	385
Rocky Ford	1164	873	594	391

Note: A base temperature of 0°C is used in calculating heat units

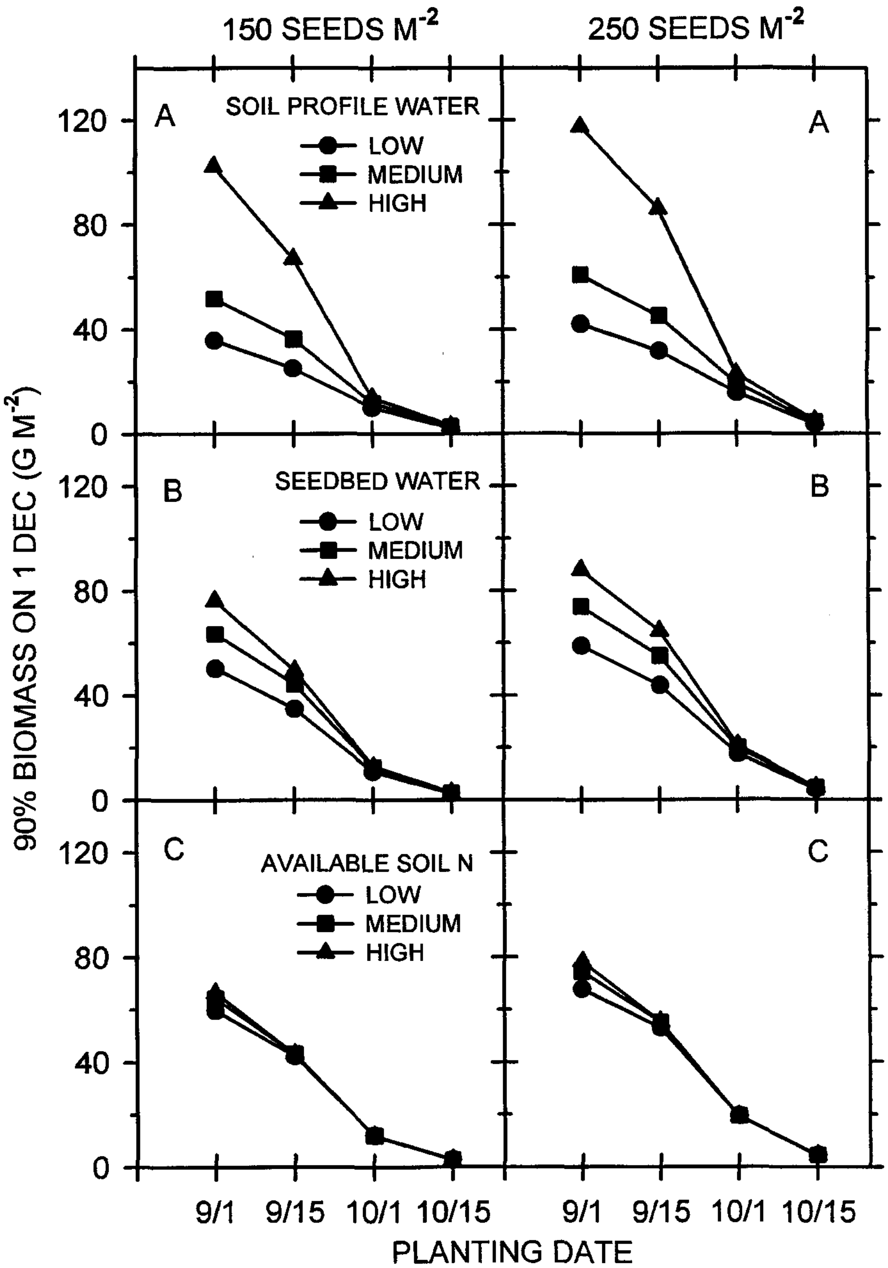

Figure 2. Amount of above ground winter wheat production predicted on December 1 90% of the time at Cheyenne Wells, Colorado for several conditions at planting.

Note: For each planting date and sowing rate, responses to total soil water content (A), seedbed water content (B), and available soil N (C) are plotted with all other factors pooled. High, medium, and low levels of total soil water, seedbed water, and available N are listed in Table 2

cumulated (Table 3), few tillers appeared, and all leaves were very small. At earlier planting dates, sufficient GDD accumulated and leaf and tiller development resulted in greater biomass production compared to the late planting date. Water is an important factor influencing biomass production through its secondary affect on leaf and tiller appearance rates and growth. Soil N seemed to have little impact on fall production in this study because sufficient levels existed for development.

Rarely does simulated biomass on December 1 reach the potential, especially for earlier planting dates. The reason for not achieving potential biomass production levels is primarily because potential growth is not being realized rather than the effects on leaf and tiller development. As planting dates are delayed, differences between potential and realized biomass decrease. This is partly because potential biomass production for late plantings is low and the absolute difference between observed and simulated production is negligible. Also, growth of the first 2-3 leaves is based on seed reserves (Peterson et al. 1989), and therefore water and N levels will have minimal impact on growth at this stage.

Comparison of fall biomass production at the three sites (Figures 1-3) demonstrates the importance of the relationship between heat unit accumulation and production. Regardless of initial conditions, the small difference in heat unit accumulation among sites for the later planting date results in very similar, low production (Table 3). However, for earlier planting dates, sites having a greater accumulation of heat units in the fall produced more biomass (Akron < Cheyenne Wells < Rocky Ford). This pattern holds regardless of the initial conditions, but was particularly acute for sub-optimal initial conditions. To produce a certain minimum biomass for compliance with federal programs, farmers located in cooler areas must plant earlier than those in warmer locations. If that is not possible, increasing the seeding rate would also increase fall biomass levels, with the positive effect enhanced more by greater soil water at the time of planting.

Given the great range of green biomass values among planting dates and conditions at planting, it might be asked if any of the predicted 90% values will be helpful to the producer in reaching compliance. The NRCS is currently converting biomass values to small-grain equivalents and inserting them into the Wind Erosion Equation for determining compliance. Green biomass is considered about 2.5 times more effective in reducing erosion than crop residue, especially if the residue is flat. As a general rule, on silty clay loam and loam soils, green biomass levels of 25 g m^{-2} is the lower limit of being helpful to producers in meeting compliance (personal comm. T. James, Colorado NRCS). Courser textured soils such as sandy loams and sands would require greater levels of biomass to contribute significantly to compliance. For normal planting dates (September 10 to 15) at even the lowest seeding rate and for low levels of soil water at planting, sufficient fall biomass production is expected, 90% of the time, to significantly contribute to the producers compliance plan.

In semi-arid climates such as eastern Colorado, it is sometimes thought that too much fall biomass production may reduce grain yield. One explanation for reduced yield is increased incidence of diseases. Alternatively, greater fall biomass production could use a greater amount of scarce resources such as water and nutri-

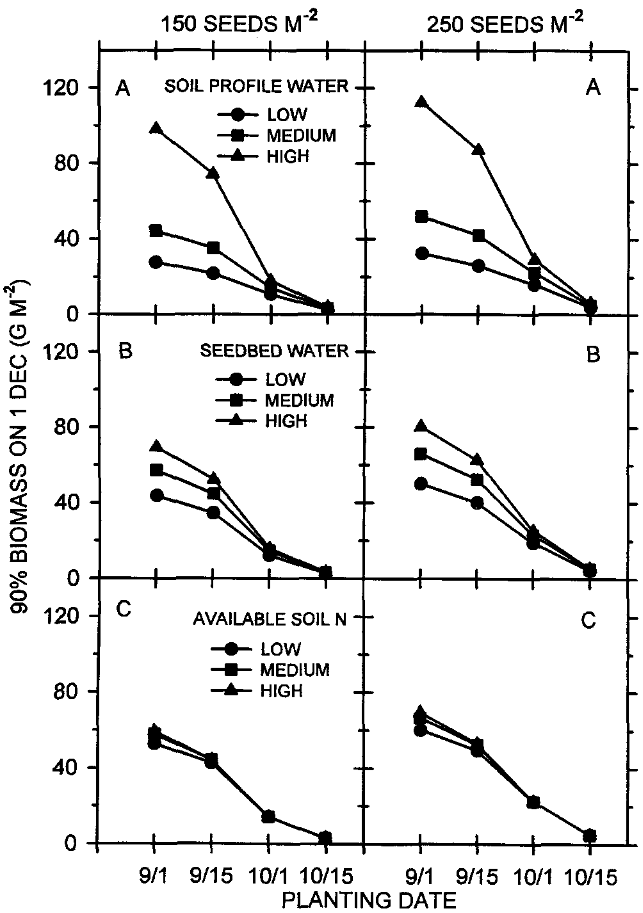

Figure 3. Amount of above ground winter wheat production predicted on December 1 90% of the time at Rocky Ford, Colorado for several conditions at planting

Note: For each planting date and sowing rate, responses to total soil water content (A), seedbed water content (B), and available soil N (C) are plotted with all other factors pooled. High, medium, and low levels of total soil water, seedbed water, and available N are listed in Table 2

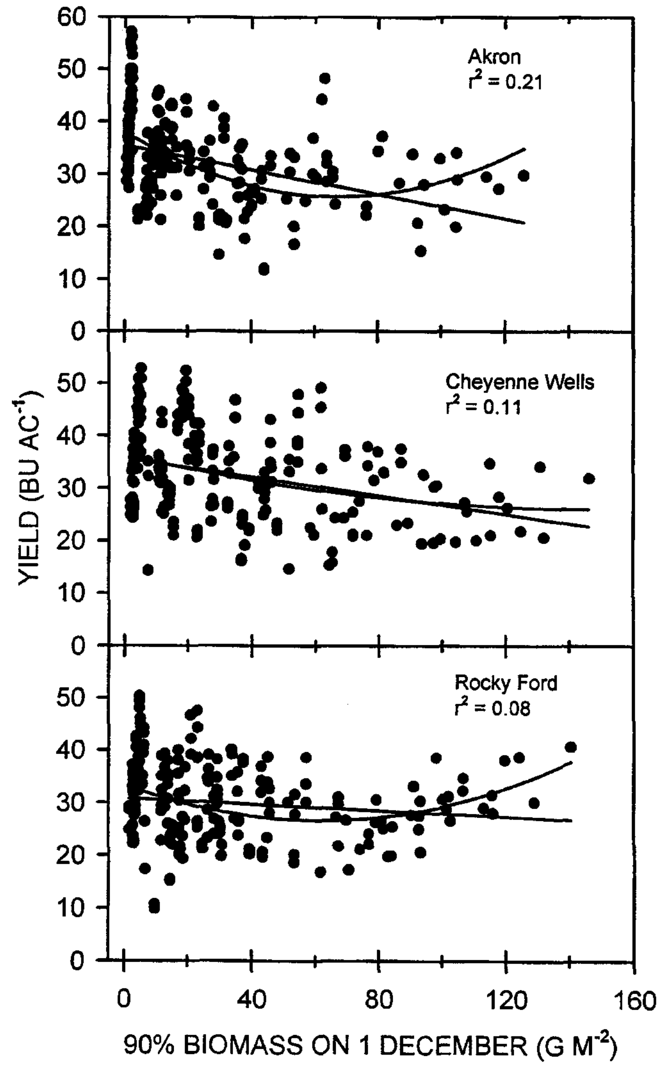

Figure 4. First and second order polynomial regression results for three sites comparing 90% biomass on December 1 and associated final grain yield

Note: Second order polynomial regression results (r^2) are presented in each graph

ents necessary for grain filling and other major yield components determined in the spring. For instance, a major yield determining component is usually the number of spikes per unit area (Blue et al. 1990; McMaster et al. 1994; Rocheford et al. 1988). Spike number is primarily determined in spring by tiller abortion rates. Water stress in spring, as a result of greater water use in the previous fall, may reduce tiller survival. Likewise, low levels of soil water during grain filling will limit yield (McMaster et al. 1994).

Biomass levels on December 1 expected 90% of the time were regressed with the associated final grain yield for each of the 216 initial conditions at each site (Figure 4). Linear regression results were similar for all sites, showing negative relationships between fall biomass and grain yield. However, the slope was significant (negative) for the Akron site only. Second order polynomial regressions fit the data better for all three sites, although the r^2 values were very low (Akron, r^2 = 0.21; Cheyenne Wells, r^2 = 0.11; and Rocky Ford, r^2 = 0.08). Although some results show a slight relationship between 1 December 90% biomass levels and final grain yields, the general pattern is toward no relationship between the two variables. For all sites, regardless of spring growing conditions, low fall biomass levels are not deleterious for final grain yields.

It appears, for most situations, sufficient fall biomass production is expected, 90% of the time, to assist producers in reducing potential erosion and therefore be in compliance with federal programs. The NRCS is now implementing these results in eastern Colorado field offices, and is interested in applying this approach to determine 90% biomass levels for other areas of Colorado (Travis James, personal communication), Kansas (Bud Davis, personal communication), Nebraska (Roger Kanable, personal communication) , and New Mexico (Jan Jinings, personal communication).

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