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Forage Pasture Production, Risk Analysis, and the Buffering Capacity of Triticale

William M. Clapham,* James M. Fedders, A. Ozzie Abaye, and Edward B. Rayburn

ABSTRACT

Many livestock producers minimize input costs by relying solely on naturalized, mixed-species pasture, but expose themselves to risks associated with forage yields that fluctuate in response to variable environmental conditions. This study was undertaken to assess winter triticale (×*Triticosecale* spp.) as a potential component of forage systems from the perspective of reducing forage yield risk. Triticale was sown each month from May until October in replicated plots for five consecutive years. Monthly harvests of triticale and mixed-pasture plots were made through October during the year of establishment and in April and May the following spring. Monte Carlo simulation modeled differences between triticale and mixed pasture yields for each planting month and harvest month combination. The models predicted that triticale yields in August (June planted) and October (August planted) should exceed mixed pasture yields by averages of 0.62 ± 0.32 (mean ± standard deviation) and 0.77 ± 0.52 Mg ha^{-1}, respectively. Yields of triticale planted in July or later and harvested in the following spring were also predicted to exceed mixed pasture by 0.50 ± 0.21 Mg ha^{-1} for July planted/April harvest to 1.33 ± 0.32 Mg ha^{-1} for September planted/April harvest. Risk analysis produced probabilities of benefit from incorporating triticale into forage systems, thus generating more meaningful results than conventional ANOVA.

Grazing livestock systems in the Appalachian Region of the United States are largely based on perennial mixed, cool-season pastures. Forage production and quality of mixed cool-season grass pastures varies throughout the growing season and has been extensively reviewed (Nelson and Volenec, 1995; Sheath and Clark, 1996; Vallentine, 2001). Pastures are complex systems due to defoliation by grazing, trampling, temporal growth patterns, and responses to stress and predation (Tainton et al., 1996). Several different strategies have been examined to extend the grazing season and improve seasonal forage distribution and thus buffer the impacts of plant stress due to biotic or abiotic factors. Allen (1992) compared dry matter intake and performance of stocker cattle from several fescue-based (*Festuca arundinacea* Schreb.) forage systems and systems supplemented with conserved forage. They concluded the stockers performed acceptably with several of the forage systems. However, their results are reported solely on the basis of mean animal performance and not on the inherent variation that defines the risk, or probability of success or failure, of achieving a performance goal.

A buffered forage system is a term that we use to describe a combination of a base of mixed perennial pasture and complementary available forage paddocks (one crop or mixed) that function together to reduce variability in forage production due to seasonal dynamics, extreme environmental conditions, and forage distribution patterns, and that meet the nutritional needs of grazing livestock. Small grains are used routinely as forages in many areas to extend the grazing season during spring, fall, and winter and to complement established mixed pastures (McColoy et al., 1971; Brown and Almodares, 1976; Juskiw et al., 1999). Although there are costs associated with planting annual forages, spring-planted winter annuals establish readily, and the yield distribution of spring-planted winter annuals provides forage for grazing in late summer and fall (Jedel and Salmon, 1995). We chose to evaluate winter triticale as an annual component of forage systems in our environment due to triticale's tolerance to cold temperatures that are common during early spring and late fall and to drought, a common summer phenomena.

Livestock and forage production are risky endeavors, and for many decades governments around the world have intervened to reduce financial losses and protect farming enterprises (Hardaker et al., 2004). The environment in which a producer or any business operates is influenced directly and indirectly by environmental and market forces that cannot be controlled and as a result, risk is a function of the vagaries of the natural and market environments (Hardaker et al., 2004).

Pasture and field crops integrate the effects of the environment during a production cycle in the form of yield and quality. Variation in environmental (e.g., weather) conditions from year to year or month to month can result in variable crop productivity. Although uncontrollable, this variation can be integrated into a metric based on probabilities that permit assessment of success and failure and form the basis on which to make decisions. Risk assessment is a formal attempt to identify and quantify risk factors and generate probabilities of success or failure of particular decisions (Vose, 2000). Risk models are built on distributions that describe the probability of a given outcome. Monte Carlo

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simulations repeatedly sample probability distributions randomly within a model to produce a large number of trials. The distribution of the outcomes is true to the distribution of the sampled data (Vose, 2000). Risk analysis is routinely used in decision making to maximize incidence of successful outcomes in many business enterprises. Although risk analysis is employed successfully among many disciplines, its use in agriculture is limited. Lansigan et al. (1997) employed risk analysis to formally relate the effects of weather and management practices on rice (*Oryza sativa* L.) production. Their study demonstrated through an analysis of the standard deviation of rice yield that soil type had a major effect on risk; specifically the standard deviation of heavy clay soil types were one-eighth that of sandy soils because of greater water availability during periods of drought. Fox et al. (2005) used risk analysis to ascertain the economic viability of water harvesting in semiarid Burkina Faso and Kenya. Parsch et al. (1997) modeled steer performance as a function of pasture stocking rate and weather variability. They found that increased stocking rate leads to greater risk as a result of greater variance in weight gain and net return. Perillat et al. (2004) used risk efficiency analysis to show that more intensive systems, including pasture fertilization and energy supplementation, improved production and risk efficiency of backgrounding and finishing steers on pasture in Canada. Anderson (2000) argued that most people have an aversion to risk, and in formal studies seek to optimize the mean value of the objective function or goal such as maximum yield or profit.

Risk is inherent in every business and agricultural enterprise, however metrics to quantify and compare risk are rarely presented to the agricultural community, particularly to growers, in a useful way. Crop performance is often described in terms of average yield without much consideration of variation in yield from year to year, season to season and/or site to site. The mean and variation together describes the potential usefulness of a crop. However, only the mean among crops, years and sites are most commonly reported as similar or 'significantly different' per ANOVA or regression. Production risk "comes from the unpredictable nature of the weather and uncertainty about the performance of crops or livestock" (Hardaker et al., 2004). Sources of risk are also institutional, financial, and associated with markets. In this study we focus on quantifying production risks associated with forage production from mixed pasture and buffering these risks with winter triticale and its associated production risk. In this study, our objective function is forage yield. The objective function might be very different if we were focusing on disease incidence, soil degradation, market deviation and timing, etc. For every harvest, each crop has a mean yield and associated variance, and even though mixed pasture is a very different crop than triticale, the associated variances are useful in deriving a metric quantifying the associated production risks. We assume that useful data distributions can be generated with Monte Carlo simulation and use of the Central Limit Theorem.

Livestock production in Appalachia is dependent on managing perennial mixed pastures. Incorporation of annual forage grains into existing forage systems could reduce the risks associated with livestock enterprises. The objectives of this study are to: (i) develop yield probability functions for mixed-species pasture and winter triticale (planted in late spring, summer and fall) harvested throughout summer, fall, and early spring; (ii) assess the ability of spring-planted, summer-planted, and fall-planted triticale to complement perennial pasture forage production; and (iii) to assess the buffer capacity (risk lowering) of available paddocks of alternative forages. This report is an initial evaluation of risk modeling as a tool to assess forage system performance and is not intended as a robust model of regional triticale and mixed pasture production.

MATERIALS AND METHODS

Plot Management

The study was conducted in southern West Virginia (38°47′18″ N, 81°58′50″ W) on a gently sloping hilltop field with an elevation of 880 m. The field had been used previously as a hay meadow and pasture but livestock were excluded from the site over the entire course of the present study. Combined, orchardgrass (*Dactylis glomerata* L.), Kentucky bluegrass (*Poa pratensis* L.), and tall fescue contributed 60 to 70% of the vegetation. White clover (*Trifolium repens* L.) and broadleaved weeds such as dandelion (*Taraxacum officinale* G.H. Weber ex Wiggers) and narrow-leaved plantain (*Plantago lanceolata* L.) were common sward constituents. Soils were of the Gilpin series (fine-loamy, mixed, active, mesic Typic Hapludults; pH 6.1).

Plots (3 by 3m) were established each year from 1999 through 2003 using a randomized complete block design with four replications. The plot area was moved to a new location within the same field from year to year to ensure that triticale was established consistently on ground that was freshly converted from perennial vegetation. Pure stands of triticale were seeded on a monthly basis from May through October each year. Glyphosate was used to kill existing vegetation on a set of four plots, 4 to 6 wk before each planting date. Plots were rotary tilled to a depth of 15 cm immediately before drilling triticale (cv. Trical 102) at a rate of 224 kg ha^{-1} with a plot seeder in rows spaced 15 cm apart. Fertility amendments consisted of 33.6 kg N ha^{-1} as 10–20–20 commercial fertilizer incorporated at sowing and broadcast by hand in mid-March of the spring following establishment. Additional N was broadcast at a rate of 33.6 kg N ha^{-1} as 34–0–0 after each plot was harvested with the exception of the October harvests when no amendments were applied.

Dry matter yield was determined from a single strip, 2.1 m long, centered within each plot and cut to leave a 6.5 cm stubble, a height that reduced the possibility of damaging the triticale growing point. Vegetative forage was harvested with a rotary mower that blew the clipped forage directly into cloth bags. After the harvest strips were clipped the remaining forage within the plot was clipped and discarded. Dense reproductive growth in spring was clipped with a sickle-bar mower, hand raked, and bagged. The entire forage sample from each plot was oven-dried and weighed. Initial harvests were taken 6 to 7 wk following seeding with subsequent harvests taken at 4-wk intervals through October. Plots seeded in May, June, July, and August were harvested four, three, two, and one times, respectively, in the year of establish-

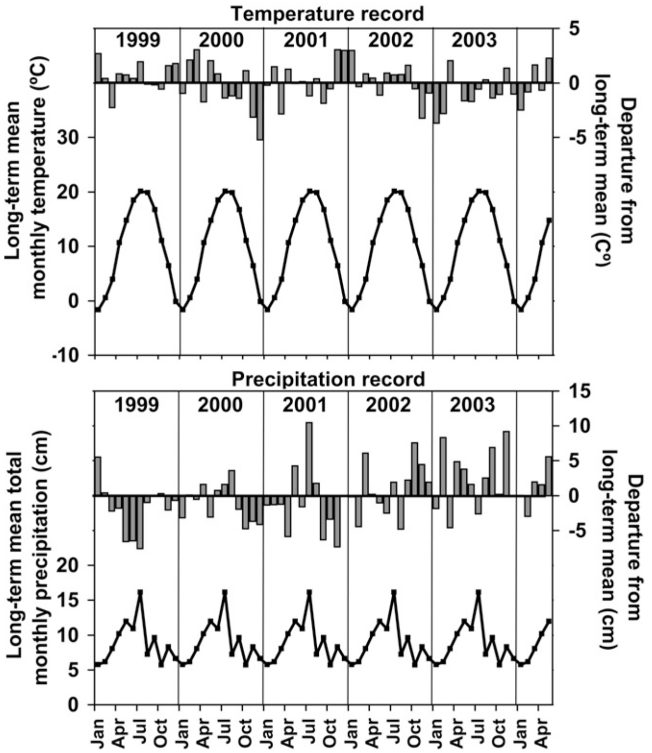


Fig. 1. Monthly temperature and precipitation record from January 1999 through May 2004 as recorded at an automated weather station adjacent to the plot areas. The sinusoidal pattern at the bottom of the figures depict the long-term (8-yr) mean monthly temperatures and total liquid precipitation at the field site. Monthly departures from the long-term values are depicted at the top of each figure. Since precipitation gauge was not heated, the values depicted during periods of freezing weather may be less than actual precipitation.

ment and twice in the spring of the following year. Plots seeded in September and October were harvested only in the spring of the year following establishment. Early vegetative spring growth was harvested in early April. Reproductive regrowth from these plots was harvested in early May. The May harvests were timed to coincide with boot stage of the reproductive tillers. Eight plots of triticale were established in September, the traditional planting season for winter triticale in our area, to allow for harvest of one set of replicates only once in May and harvest of the other set in both April and May. The September-established plots harvested only in May are designated as the 1-cut plots and the September-established plots cut in both April and May are designated as the 2-cut plots.

Triticale yields were compared with yields of perennial mixed-pasture plots that were incorporated into the plot design each year. Vegetation of the mixed-pasture plots consisted only of the existing mixture of species within the plots as no overseeding was attempted. The vegetation on the mixed-pasture plots was initially clipped and discarded during the same week that the May plots were established each year. Regrowth from the mixed-pasture plots was harvested on the same schedule as that used for the May-established plots. Fertility amendments to the mixed-pasture plots also followed the same schedule and amounts as the May-established plots.

The PROC mixed procedure of SAS was used to compare least square means of cumulative yield averaged across the 5 yr of study (Littell et al., 1991). The procedure was run separately for each harvest month. Block and establishment year were considered random effects and plot treatment (mixed pasture and May-, June-, July-, August-, 1-cut September-, 2-cut September- and October-establishment) was a fixed effect. Standard errors of the difference among the least square means were generated to determine significant plot treatment effects on cumulative yield.

Risk Analysis

The mean, standard deviation and shape of a yield distribution are required to assess accurately the probability of achieving a goal or objective function, such as yield or quality. Even with our relatively large data set compiled over five field seasons, we had a limited number of observations to define the monthly yield distribution of a given treatment. A bootstrapping technique was used to model monthly yields to fully populate distribution curves for each harvest month and treatment combination. The nonparametric bootstrap procedure is an iterative process of resampling with replacement from an existing set of experimental observations (Davison and Hinkley, 1997). Our data sets consisted of 20 observations (5 yr by four replications except for occurrences of missing data) for each harvest month and treatment combination. The bootstrap procedure used @Risk software (version 4.5; Palisade Corp., Newfield, NY) running as an add-in within Microsoft Excel 2000 (Microsoft Corp., Redmond, WA). Annual production for a given treatment and harvest month was simulated by selecting four random observations from the appropriate data set. The number of random samples per simulation was set at four since that was the number of replicated observations per year in our data sets. The selection from the data set was done ‘with replacement’ which means that it was possible, although rare, to reselect the same observation up to four times per simulation. The four samples were then averaged to produce a simulated mean yield and then the process was repeated for 5,000 iterations. At the end of the process, the results from the 5,000 simulations were used to define the overall mean, standard deviation, and shape of the data distribution. This procedure was repeated for each harvest month and treatment combination. The overall mean values of the simulated populations were virtually identical to the mean values of the actual data sets from which they were derived. The standard deviations of the simulated yields averaged 0.49 times that of the raw data sets. This reduction was expected since the standard deviation of means derived from n points from a data set is $1/n^{0.5}$ times the standard deviation of the data set (Vose, 2000). The distribution of the simulated yields tended to approximate the normal, bell-shaped curve as predicted by the central limit theorem (Mihram, 1972; Vose, 2000).

The mean and standard deviation values generated by the bootstrapping procedure were used as input to the RiskNormal function of the @Risk program to generate a normal frequency distribution and a descending cumulative frequency distribution, sometimes called a cumulative probability curve, of yield for each harvest month and treatment

Table 1. Mean and standard deviation of monthly temperature and precipitation data from the field site compared with a 42-yr record (1963–2005) collected by the U.S. National Weather Service at Beckley, WV, 20 km west of the study site.

	Temperature				Precipitation			
	Period of study		42-yr record		Period of study		42-yr record	
	Mean	SD	Mean	SD	Total	SD	Total	SD
	°C				cm			
January	−2.0	2.7	−1.0	2.9	5.6	3.0	7.8	3.8
February	0.5	1.8	0.7	2.5	6.2	4.5	7.2	3.1
March	4.4	2.4	5.4	2.1	7.9	3.7	9.1	4.5
April	10.7	1.1	11.0	1.4	10.3	3.6	8.8	3.5
May	15.1	1.6	15.4	1.7	12.5	4.8	10.8	4.7
June	18.6	1.1	19.3	1.1	9.3	3.2	9.6	4.1
July	20.0	1.4	21.2	1.1	16.9	6.7	12.2	5.0
August	19.9	0.7	20.6	1.1	7.6	3.4	8.8	3.0
September	16.0	1.4	17.2	1.3	9.8	4.9	8.5	4.9
October	10.7	0.8	11.5	1.7	5.7	4.8	6.5	3.4
November	6.4	2.9	6.4	2.1	8.4	6.6	7.6	3.5
December	−0.7	3.2	1.3	2.7	6.1	2.2	7.9	3.5

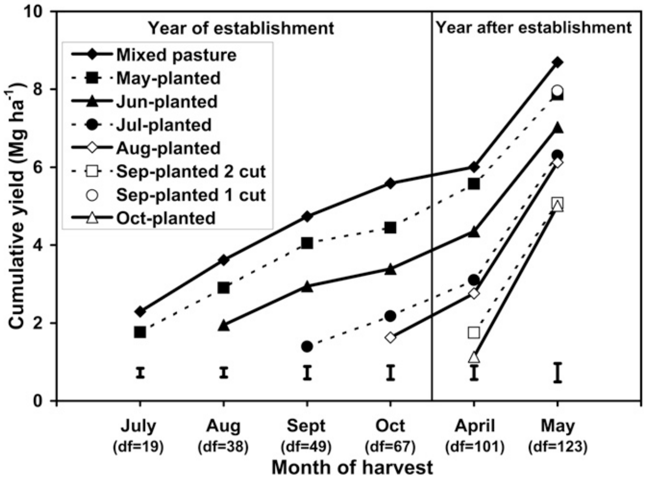


Fig. 2. Least square means of cumulative yield averaged over 5 yr. Although standard errors of difference were calculated for each possible pair comparison within a harvest month, only the largest errors calculated for each month are presented in the bars for clarity of presentation. Degrees of freedom (df) are provided for each harvest month.

combination. Descending cumulative probability curves describe the probability of attaining yields greater than or equal to a given value. Isograms were then created to depict probability of achieving given yields in each harvest month.

Yield comparisons between the mixed pasture and triticale plots were performed using Monte Carlo simulation. A separate simulation model was developed for each planting month and harvest month combination. Each model used two normal probability distributions, one for mixed pasture and one for triticale yield described by the mean and standard deviation generated by the bootstrapping procedure. The 'Correlate Distributions' command of @Risk was used to correlate output from the two probability distributions based on the Pearson product-moment correlations calculated from the field data. Each iteration of the model simulated a single yield for triticale and a single yield for mixed pasture and then calculated the yield difference. Each model was iterated 5,000 times and then the mean and standard deviation of the yield difference were calculated. Although our field data include variation from both within and among years, our simulations do not attempt to separate the spatial, temporal, or other components of variation. Instead we use the total variation within each set to define risk as the probability of success or failure. In this way, risk is a composite of both spatial and temporal variability describing the probability of attaining an objective function.

RESULTS AND DISCUSSION

Variation in forage production is driven in part by climatic factors. The seasonal and year-to-year fluctuations in temperature and precipitation at the study site reflected the temperate climate of the region (Fig. 1). June, July, and August were the warmest months with mean monthly temperatures averaging between 16.8°C in June 2000 and 22.0°C, in July 1999. December, January, and February temperatures were the coldest with monthly means ranging from −5.4°C, in December 2000 and January 2003 to 2.8°C in December 2001. The months of May, June, and July tended to have the greatest amount of precipitation although monthly totals varied widely from year to year and month to month. For instance, the greatest monthly precipitation total, 26.6 cm, was recorded in July 2001 but the precipitation in July 1999 totaled only 8.6 cm. Total precipitation for the May through September growing season ranged from 34.2 cm in 1999 to 68.1 cm in 2003. Monthly mean temperature and total precipitation over the 5-yr study were similar to those for a 42-yr period recorded locally by the U.S. National Weather Service (Table 1). Year-to-year variation in monthly values among the 5 yr of study was also similar to the long-term variation as indicated by standard deviations in Table 1. Comparable variability indicated that the study period effectively spanned a range of weather conditions that was representative of long-term patterns.

Figure 2 illustrates the 5-yr, average, cumulative yield from the mixed-pasture plots and all triticale-planting treatments from the initial harvest of a treatment to the final harvest of all treatments in May of the year following triticale establishment. The mixed-pasture plots had greater cumulative yield ($P < 0.05$) than May-, June-, July-, and August-planted triticale across all harvests taken in the year of establishment. Mean cumulative yields of triticale up through the October harvest in the year of establishment differed by planting month and ranged from an average of 1.63 Mg ha^{-1} for August-planted plots cut only one time in October to 5.57 Mg ha^{-1} for May-planted plots harvested four times. Early planting resulted in a longer period of growth, more harvests, and greater cumulative yield than later planting. Triticale tended to be more productive in early spring than mixed-pasture. As a result, the total average cumulative yields of the mixed-pasture, May-planted triticale and 1-cut, September-planted triticale were near 8.0 Mg ha^{-1} and were not significantly different by the final spring harvest.

Data in Table 2 show the mean monthly forage yields and standard deviations for the mixed pasture and monthly triticale plantings. The yields varied by planting date and harvest month resulting in potential opportunity to reduce risk

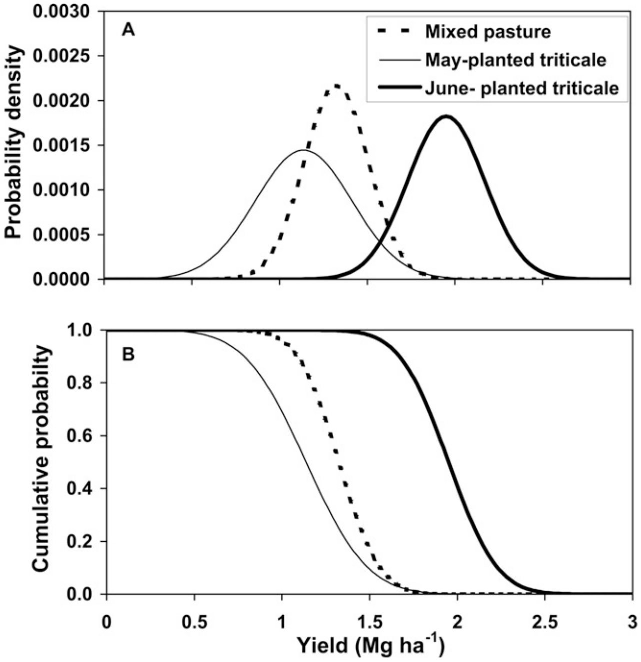
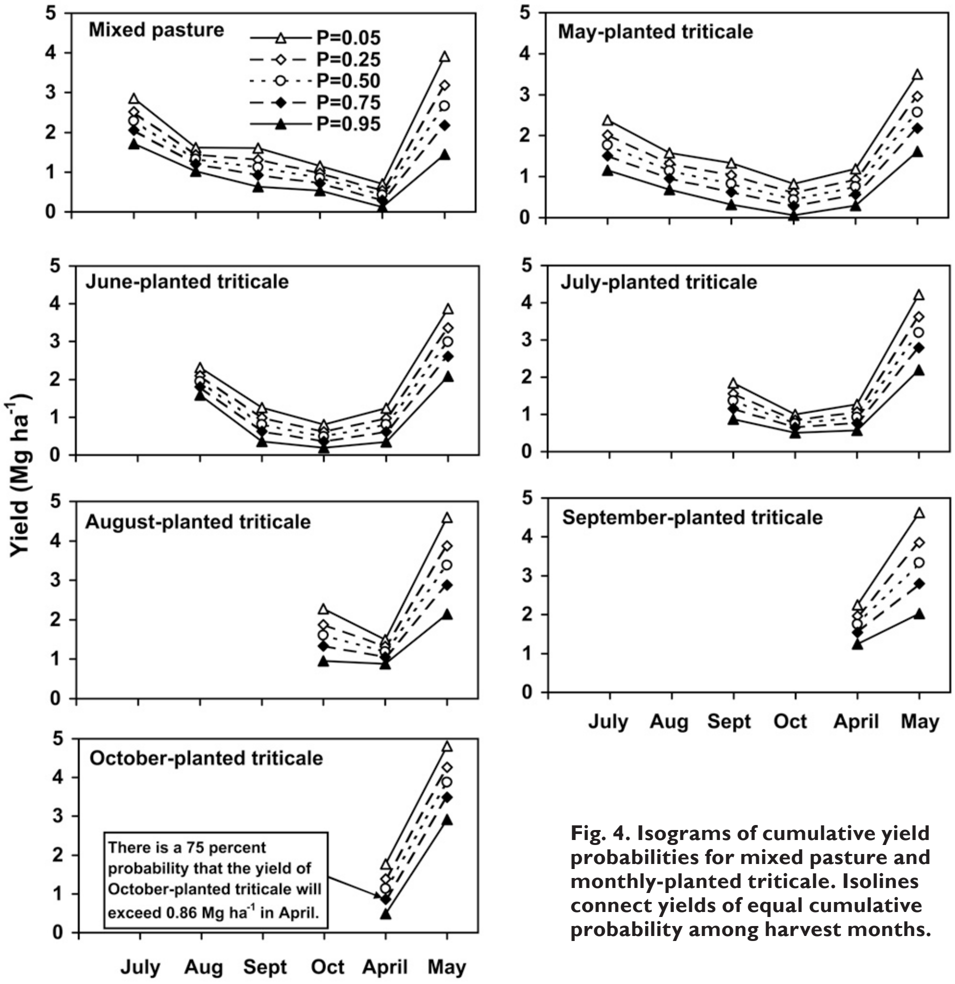


Fig. 3. (A) Probability density plot depicting the normal distribution for August harvests of May-planted triticale, June-planted triticale, and mixed-pasture swards. (B) Cumulative descending probability plot for the same swards shown above. Curves define the probability of equaling or exceeding a given yield.

through forage system diversification. The average yield of mixed pasture exceeded that of May-planted triticale in the July harvest (1.77 vs. 1.32 Mg ha^{-1}). However, for each subsequent harvest month in the year of establishment, the yield of previously uncut triticale plots, for example, June-planted triticale harvested in August, exceeded the yield of mixed pasture by 48 to 90% and exceeded the yield of previously harvested triticale by 64 to 268% Triticale vernalized during winter months and grew vigorously during spring. Average yield of triticale from every planting date surpassed that of mixed pasture at the April harvests by 80 to 316% April triticale yields were lowest from plots planted the previous May and increased with each succeeding planting date with the exception of the October planting date.

All triticale-planting treatments started to head during May and were harvested at boot stage. At this harvest, the yields of all triticale treatments, except that planted the previous May, exceeded the yield of mixed pasture. The September-planted triticale cut only once in May produced more than the mixed pasture by 7.96 vs. 2.68 Mg ha^{-1}, nearly a three to one difference. Early spring forage can represent an important economic asset, if grazing can replace feeding hay or other supplements. Forage yields during middle and late spring months are often high and create management challenges for graziers.

Figure 3A illustrates the normal probability distributions, based on mean and standard deviations in Table 2, for the May- and June-planted triticale and mixed-pasture swards harvested in August. Normal distributions are symmetrical, with the peaks of the curves occurring at the mean. The degree of spread and the height of the distributions are both functions of the standard deviation. Smaller standard deviations for yield of mixed pasture harvested in August (0.18 Mg ha^{-1}) resulted in narrower and taller probability density curves than the larger standard deviations of the May- (0.28 Mg ha^{-1}) and June- (0.22 Mg ha^{-1}) planted triticale. Similar probability distributions were generated for each planting date and harvest of interest. For simplicity, we illustrate the concept using May and June plantings and August harvests. In our environment, August is the month in which forage yields are often limited by drought. Cumulative probability curves of the August harvest are depicted in Fig. 3B. These curves describe the probability of equaling or exceeding a given yield. The slopes of the cumulative probabilities are proportional with the standard deviations, for example,



There is a 75 percent probability that the yield of October-planted triticale will exceed 0.86 Mg ha^{-1} in April.

Fig. 4. Isograms of cumulative yield probabilities for mixed pasture and monthly-planted triticale. Isolines connect yields of equal cumulative probability among harvest months.

the smaller the standard deviation, the steeper the slope. As in Fig. 3A, the cumulative probabilities segregate with treatment yields.

Cumulative probability curves generated for each treatment and harvest month combination were used to define isograms of yield probabilities (Fig. 4). The isograms show that monthly harvests decreased, from summer through fall and rebounded in spring. However, the isograms reveal a robust view of the risks associated with a given forage and provide a measure of success and failure to meet forage performance expectations. Mixed pasture and each triticale planting date have a unique family of curves that define yield probability. These differences provide opportunity to choose a forage regime at an acceptable probability of success to meet the nutritional needs of grazing livestock during any period. For example, the curves indicate that triticale would not provide any yield advantage relative to mixed pasture in July. In August, however, yield of mixed pasture decreased and the curves show that June-planted triticale can 'buffer' the mixed pasture because triticale forage yields were higher and risks or variability were lower. For example in August, there is 0.75 probability of June-planted triticale to yield 1.8 Mg ha^{-1} or more but mixed pasture yield at this same 0.75 probability is only 1.2 Mg ha^{-1}. This approach allows direct comparisons of yields and associated risks for different forage systems.

Figure 5 illustrates results from Monte Carlo simulations of yield comparisons among the mixed pasture and triticale plantings indicating the relative superiority or inferiority of various systems for a given harvest month. Yield differences are shown on a scale of −2 to 2 Mg ha^{-1}. Points falling above the 0-line denote cases where triticale yields exceeded mixed pasture yields. Points falling on the 0-line denote cases where forage yields were similar. Points falling below the 0-line denote cases where mixed pasture out-yielded triticale. The bars represent the range encompassed by the mean plus and minus the standard deviation and therefore indicate the range where 68% of the outcomes occurred. Since most of the modeled May-planted triticale average yields were less than mixed pasture yields by at least a standard deviation, there is no compelling reason to justify incorporating May-planted triticale into our mixed pasture forage systems. In contrast, the first harvests yields of June-, August-, September-, and October-planted triticale had average yield advantages over mixed pasture of 0.66 to 1.33 Mg ha^{-1} with relatively small standard deviations ranging from 0.32 to 0.52 Mg ha^{-1}. These results suggest that there is a high probability that triticale yield could exceed mixed pasture yields at specific times during the year and that triticale may be useful in buffering mixed pasture production in our environment. The consistent yield advantage of triticale in the April harvests reflect the ability of triticale to grow under cooler temperatures than the species in our mixed pastures. The greater standard deviations in May harvest comparisons were proportional with forage yield increases common during spring months.

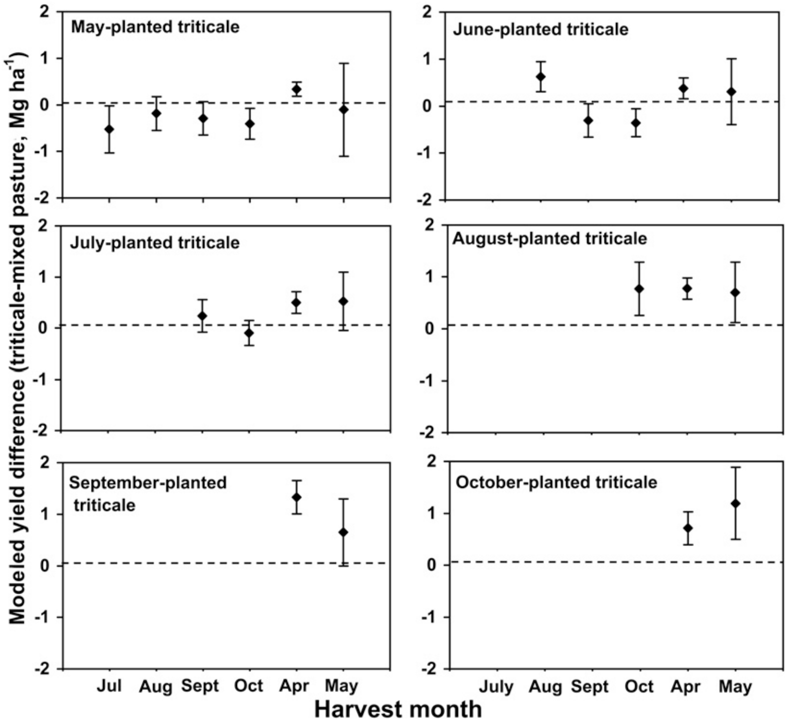


Fig. 5. Mean differences between triticale and mixed-pasture yields from Monte Carlo simulations. Bars are plus and minus the standard deviation. Positive values occur when triticale yields exceed the mixed pasture.

Table 2. Mean and standard deviation of dry matter harvest yields from mixed-pasture and triticale plots. Values are derived from the bootstrapping procedure described in the text.

Treatment	Harvest month	Yield Mean	Yield SD
		———Mg ha^{-1}——	
Mixed pasture	July	2.29	0.35
May triticale	July	1.77	0.37
Mixed pasture	August	1.32	0.18
May triticale	August	1.14	0.28
June triticale	August	1.95	0.22
Mixed pasture	September	1.12	0.29
May triticale	September	0.83	0.31
June triticale	September	0.81	0.27
July triticale	September	1.36	0.30
Mixed pasture	October	0.85	0.18
May triticale	October	0.44	0.23
June triticale	October	0.49	0.19
July triticale	October	0.75	0.15
August triticale	October	1.62	0.40
Mixed pasture	April	0.42	0.18
May triticale	April	0.76	0.27
June triticale	April	0.79	0.27
July triticale	April	0.92	0.22
August triticale	April	1.19	0.19
September 2-cut triticale	April	1.75	0.31
October triticale	April	1.13	0.39
Mixed pasture	May	2.68	0.75
May triticale	May	2.58	0.57
June triticale	May	2.99	0.55
July triticale	May	3.20	0.62
August triticale	May	3.38	0.74
September 1-cut triticale	May	7.96	0.55
September 2-cut triticale	May	3.33	0.79
October triticale	May	3.88	0.57

Producers influence forage production in a variety of ways including choice of plant materials, fertility amendments, and defoliation management. However, forage growth, quality, and yield are also influenced by the vagaries of weather, pests, foliar diseases, etc. Graziers typically rely on their accumulated knowledge of their own livestock, forage resources, and livestock markets to define annual production goals, develop their grazing system and make adjustments throughout the grazing season. Their decisions also incorporate a subjective level of acceptable risk, however risk attitudes cannot be measured accurately (Anderson et al., 1977). Risk analysis uses stochastic efficiency criteria and permits objective definition of risk that can be incorporated into the decision-making process. Risk analysis relies on distribution curves and Monte Carlo simulation to define yield distributions and the probabilities of events.

Valid mean, forage production values, and estimates of variability can be generated by long-term studies that encompass a range of environmental conditions. However, producers do not typically manage forage resources on a long-term, multi-year basis, but on a year-to-year basis dependent on financial resources, market conditions, animal performance goals, and other factors. Producers relying solely on mean production values may experience problems with over-or under-stocking since the probability of attaining a yield close to the mean value is relatively low in any given year. For example, a single yield from a treatment with a mean monthly production of 1000 kg ha^{-1} and standard deviation of 250 kg would only be expected to yield between 900 and 1,100 kg ha^{-1} (±10% of the mean) in 3 out of 10 yr. Therefore producers should evaluate forage production in relation to expected yield variation, and not just on mean production values. Risk analysis models are based on measurements of mean and variance. Since, in most cases, we cannot know the true population value of these parameters, we rely on estimates derived from samples. There is no one answer to the question of how much data is necessary to generate suitable values of mean and variance for reliable risk analysis. As in conventional statistical analyses, robust data sets can yield accurate and precise estimates of mean and variance. Small data sets are prone to have platykurtic distributions, flatter distribution with wider tails, that reduce model resolution

Historically, data presented in refereed journal articles consist of treatment means and statistics to determine differences among means. Analyzing the means, standard deviations, and the cumulative probabilities associated with the means permit assigning probability functions to meeting yield performance expectations. The analysis permits compiling data over years or locations and transcends the problems associated with site-specific numbers. Likewise the analysis permits comparison and development of probability functions comparing different forage systems at the same site at the same or different times. The data demonstrate that June-planted triticale provided consistent forage yields during August, and August-planted triticale provided consistent forage yields during October when mixed-pasture forage yields were reduced. However, triticale planted during the other months may or may not provide any utility to the producer during the year of establishment. For example May-planted triticale underperformed in comparison to mixed pasture in all months except April the following year. Triticale planted later than May exhibited consistent and superior production relative to mixed pasture in the subsequent spring. Agricultural production is risky and is dependent on outlays of considerable financial resources. These data demonstrate that perennial pasture systems can be buffered, and that the partial and cumulative risks associated with a forage system can be measured. Once risk is estimated, land and resources can be allocated such that a producer's objective function(s) are optimized while risk is minimized.

CONCLUSIONS

Traditional analysis of forage production usually focuses on yield per unit area, seasonal forage yield distribution and estimates of forage quality. These studies are abundant in journal literature and extension bulletins and focus on maximization of yield and quality. Historically the statistical analyses defaulted to the standard and expected ANOVA and regression techniques. Although serial defoliations can be analyzed using ANOVA and Time Series Analysis, these approaches fail to provide estimates of risks associated with treatment adoption. As a result, failure to analyze treatments from the point of view of risk may be associated with failure to transfer technology.

Risk analysis is important because it provides a practical evaluation of the probability of failure or success of a treatment or management system and therefore provides different insights than traditional statistical methods. As the analysis relies on historical data, local data can be used to assess probability on the basis of site specificity or, as data is available, over a region. A more robust assessment would entail data sets from numerous sites depending on scale. We believe that reasonable distributions can be developed with limited sets of data, the Central Limit Theorem and Monte Carlo simulation. This approach does not attempt to partition variance into fixed and random effects or formally test differences among means. However, we believe that risk analysis is important, serves as a heuristic tool to scientists, and provides meaningful information in terms of the probabilities of success or failure to producers. The analysis can be applied to forage yields and quality, and provide estimates of sensitivity for system components. Farmers are in business to make a profit. Providing them with technology that has intrinsic estimates of success or failure will facilitate adoption of cost effective methods.

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