CORN

Impact of Defoliation on Corn Forage Yield

J. G. Lauer,* G. W. Roth, and M. G. Bertram

ABSTRACT

Farmers, agronomists, and crop insurance adjusters question whether leaf defoliation damage caused by hail or other factors affects corn (*Zea mays* L.) forage yield the same as grain yield. Our objective was to evaluate the effects of defoliation on corn grown for forage production. In studies conducted during 3 yr at two sites in Wisconsin and one site in Pennsylvania, forage yield decreased as leaf removal increased in severity, and as time of defoliation neared silking. Forage yield response to increasing levels of defoliation was quadratic. Averaged across all environments, forage yield decreased 16% when 100% defoliation occurred at V7. Likewise 100% defoliation decreased forage yield 43, 70, and 40% at V10, R1, and R4 growth stages, respectively. Greater forage yield decreases are measured with early defoliation (V7–V10) than predicted grain yield decreases currently used by hail adjusters. This likely occurred because both increased leaf removal and decreased grain yield combine to reduce forage yield. The response to defoliation from simulated hail damage is different between corn forage and corn grain. Alternative predictive models for estimating forage yield losses should be used by insurance adjusters.

Hail damage occurs each year in many areas where corn is grown for forage production, and accurate assessment of its effects are important for adjusting crop insurance claims. The effects of hail damage on corn grown for grain production are well documented (Hanway, 1969; Hicks et al., 1977; Shapiro et al., 1986), and include effects from stand reductions, plant injury, and defoliation. Procedures for assessing the effects of hail damage on corn grown for grain yield are used by crop insurance adjusters in the USA (National Crop Insurance Services, 1998).

Corn forage yield response to defoliation is not as well documented as the grain yield response. Uncertainty exists among farmers, agronomists, and crop insurance adjusters whether the current charts for assessing grain yield potential are adequate for corn insured for forage use.

Baldridge (1976) studied the effects of simulated hail damage on both forage and grain yield in irrigated environments in Montana. Defoliation at the 7- and 11-leaf stages reduced forage yield more than grain yield. Conversely, defoliation at the 15-leaf, tasseling, and milk stages caused reduced grain yield more than forage yield. Forage yield reductions from 75% defoliation at the 7- and 11-leaf stages averaged 6 and 23%, respectively. The standard industry hail damage corn leaf loss chart (National Crop Insurance Services, 1998) predicts grain yield losses from 75% defoliation at 7- and 11-leaf stage corn to be 5 and 12%, respectively.

It is uncertain whether the loss data from the irrigated study in Montana could be applied to the dairy region in the Northcentral or Northeast USA where corn forage is commonly grown. Shapiro et al. (1986) showed that the effects of defoliation on grain yield varied with the environment, and were likely a function of the hybrid stress tolerance and the level of stress following defoliation.

Defoliation can also affect the maturity of the crop. Hicks et al. (1977) showed that defoliation before tasseling resulted in increased ear moisture at harvest and delayed maturity, while defoliation following tasseling hastened maturity. Johnson (1978) also reported that early defoliation at the five-leaf stage delayed silking and pollination.

A better understanding of the relationship between defoliation and forage yield loss would help to improve our ability to predict corn forage yield losses from hail damage. Our objective was to evaluate the effects of defoliation on corn grown for forage production under a range of conditions in Wisconsin and Pennsylvania. This study evaluated the effects of defoliation at various growth stages and intensities on corn forage yield loss and whole plant moisture.

MATERIALS AND METHODS

Experiments were conducted during 2000, 2001, and 2002 at the University of Wisconsin Agricultural Research Stations near Arlington and Marshfield, WI, and the Russell Larson Agricultural Research Farm near State College, PA. The soil at Arlington was a Plano silt loam (fine-silty, mixed, mesic Typic Argiudoll), at Marshfield a Withee silt loam (fine-loamy, mixed Aquic Glossoboralf), and at State College a Hagerstown silt loam (fine, mixed mesic Typic Hapludalf). Management practices were typical of those utilized commercially in many dryland fields in the USA.

At Arlington, in all years the previous crop was soybean [*Glycine max* (L.) Merr.]. Preplant soil samples from the 0- to 0.15-m depth were analyzed for residual nutrient levels in the previous fall. For the study conducted in 2000, soil test results were organic matter: 34 g kg^{-1}, pH: 6.8, P: 43 mg kg^{-1}, and K: 115 mg kg^{-1}; in 2001 results were: organic matter: 26 g kg^{-1}, pH: 6.8, P: 78 mg kg^{-1}, and K: 202 mg kg^{-1}; and in 2002 results were: organic matter: 33 g kg^{-1}, pH: 6.8, P: 79 mg kg^{-1}, and K: 247 mg kg^{-1}. In each year, 180 kg N ha^{-1}, 40 kg P_2O_5 ha^{-1}, and 40 kg K_2O ha^{-1} fertilizer was applied preplant using urea (46–0–0) and sidedress in a 5 by 5 cm band at planting with a starter fertilizer (6–24–24). In each year, the soil in the study area was prepared for seeding by fall chisel plowing and spring

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fertilizer application followed by field cultivating. On 25 Apr. 2000, 28 Apr. 2001, and 25 Apr. 2002, a Kinze (Williamsburg, IA) planter was used to seed Pioneer Brand '34G82' corn at a rate of 8.65 seeds m^{-2} in furrows 5 cm deep in rows 76 cm apart to achieve a target plant density at harvest of 7.91 plants m^{-2}. Plots were four rows wide by 7.62 m long. In 2000 weeds were controlled by applying 1.47 kg a.i. ha^{-1} acetochlor [2-chloro-*N*-(ethoxymethyl)-*N*-(2-ethyl-6-methylphenyl)acet-amide] and 0.50 kg a.e. ha^{-1} clopyralid [3,6-dichloro-2-pyridinecarboxylic acid] + 0.19 kg a.i. ha^{-1} flumetsulam [*N*-(2,6-difluorophenyl)-5-methyl[1,2,4]triazolo[1,5-*a*]pyrimidine-2-sulfonamide] (tank mixture) followed post-emergence with 0.14 kg a.i. ha^{-1} dicamba [3,6-dichloro-2-methoxybenzoic acid]. In 2001 weeds were controlled by applying pre-emergence 2.45 kg a.i. ha^{-1} acetochlor and 0.03 kg a.i. ha^{-1} halosulfuron [3-chloro-5-[[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]-1-methyl-1*H*-pyrazole-4-carboxylic acid] (tank mixture). In 2002 weeds were controlled by applying pre-emergence 2.45 kg a.i. ha^{-1} acetochlor and 0.63 kg a.e. ha^{-1} clopyralid + 0.24 kg a.i. ha^{-1} flumetsulam (tank mixture). Plots measuring 6.7 by 0.76 m were harvested on 19 Sept. 2000, 18 Sept. 2001, and 19 Sept. 2002 using a New Holland Model 707 (New Holland, PA) single row corn chopper.

At Marshfield, the previous crop was alfalfa in 2000 and 2001 and corn in 2002. Preplant soil samples from the 0- to 0.15-m depth were analyzed for residual nutrient levels in the previous fall. In 2000, soil test results were organic matter: 38 g kg^{-1}, pH: 7.1, P: 35 mg kg^{-1}, and K: 100 mg kg^{-1}; in 2001 results were: organic matter: 32 g kg^{-1}, pH: 7.1, P: 24 mg kg^{-1}, and K: 60 mg kg^{-1}; and in 2002 results were: organic matter: 29 g kg^{-1}, pH: 6.5, P: 38 mg kg^{-1}, and K: 103 mg kg^{-1}. Fertilizer was applied sidedress in a 5 by 5 cm band at planting with a starter fertilizer (17–17–17) and sidedress with a cultivator using urea (46–0–0). Rates were 70, 80, and 140 kg N ha^{-1}; 34, 43, and 24 kg P_2O_5 ha^{-1}; and 34, 43, and 24 kg K_2O ha^{-1} in 2000, 2001, and 2002, respectively. In each year, the soil in the study area was prepared for seeding by fall chisel plowing and spring field cultivating. On 27 Apr. 2000, 13 May 2001, and 15 May 2002 a John Deere (Moline, IL) planter was used to seed Pioneer Brand '37J99' corn at a rate of 8.90 seeds m^{-2} in furrows 5 cm deep in rows 76 cm apart to achieve a target plant density at harvest of 7.91 plants m^{-2}. Plots were four rows wide by 7.62 m long. In 2000 and 2001 weeds were controlled by applying pre-emergence 1.96 kg a.i. ha^{-1} acetochlor, 0.50 kg a.e. ha^{-1} clopyralid + 0.19 kg a.i. ha^{-1} flumetsulam, and 1.12 kg a.i. ha^{-1} atrazine [6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine] (tank mixture). In 2002 weeds were controlled by applying pre-emerge 1.96 kg a.i. ha^{-1} acetochlor and 0.50 kg a.e. ha^{-1} clopyralid + 0.19 kg a.i. ha^{-1} flumetsulam (tank mixture). Plots measuring 7.6 by 0.76 m were harvested on 25 Sept. 2000, 28 Sept. 2001, and 24 Sept. 2002 by hand and chopped through a Gehl 860 (West Bend, WI) corn chopper.

At State College, in all years the previous crop was soybean. Preplant soil samples from the 0- to 0.15-m depth were analyzed for residual nutrient levels in the previous fall. For the study conducted in 2000, soil test results were organic matter: 30 g kg^{-1}, pH: 6.6, P: 35 mg kg^{-1}, and K: 78 mg kg^{-1}; in 2001 results were organic matter: 19 g kg^{-1}, pH: 6.4, P: 26 mg kg^{-1}, and K: 88 mg kg^{-1}; and in 2002 results were organic matter: 25 g kg^{-1}, pH: 6.2, P: 24 mg kg^{-1}, and K: 109 mg kg^{-1}. In each year, 187 kg N ha^{-1}, 27 kg P_2O_5 ha^{-1}, and 9 kg K_2O ha^{-1} fertilizer was applied preplant using urea (46–0–0) in a 5 by 5 cm band at planting with a starter fertilizer (7–21–7). In each year, the soil in the study area was prepared for seeding by spring chisel plowing and spring field cultivating. On 1 May 2000, 1 May 2001, and 4 May 2002, a John Deere planter was used to seed Pioneer Brand '34G82' corn at a rate of 7.9 seeds m^{-2} in furrows 5 cm deep in rows 76 cm apart to achieve a target plant density at harvest of 6.9 plants m^{-2}. Plots were four rows wide by 7.62 m long. In 2000 weeds were controlled by applying pre-emergence 2.2 kg a.i. ha^{-1} atrazine and 3.4 kg a.i. ha^{-1} metolochlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide] followed post-emergence with 0.16 kg ha^{-1} dicamba. In 2001 weeds were controlled by applying pre-emergence 1.3 kg ha^{-1} atrazine and 2.0 kg a.i. ha^{-1} acetoclor followed post-emergence with 0.28 kg a.i. ha^{-1} dicamba and 0.034 kg ha^{-1} nicosulfuron [2-[[[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]-*N,N*-dimethyl-3-pyridinecarboxamide] (tank mixture). In 2002 weeds were controlled by applying pre-emergence 1.4 kg a.i. ha^{-1} atrazine and 1.4 kg a.i. ha^{-1} metolochlor. Plots measuring 6.7 by 0.76 m were harvested on 22 Sept. 2000, 10 Sept. 2001, and 10 Sept. 2002 using a single row custom designed corn chopper.

The design of each experiment was a randomized complete block with four replications. Defoliation treatments were applied at V7, V10, R1, and R4 (Ritchie et al., 1993). At V7, 100% of the emerged leaf area was removed using shears. At V10, 50 and 100% of the emerged leaf area was removed. Partial leaf removal treatments were applied by measuring from the leaf tip and cutting the leaf end. At R1 and R4, 25, 50, and 100% of the emerged leaf area was removed. The control was a nondefoliated check treatment.

All plots were harvested in all environments shortly after the 50% kernel milk stage of the untreated control (Afuakwa and Crookston, 1984; Ritchie et al., 1993). *Kernel milk* is defined as the amount of milky starch remaining in the kernel (i.e., 25% kernel milk = 75% kernel milkline/starch line + 25% kernel milk). A 750-g subsample was obtained for dry matter determination. Samples were dried for 72 h in an oven at 45°C and weighed immediately.

The agronomic measures of forage yield and moisture were analyzed using SAS PROC GLM and PROC REG (SAS Inst., 2000) procedures. Mean separations were conducted using Fisher's Protected LSD ($P \leq 0.05$). Forage yield was expressed as relative forage yield, determined by dividing the forage yield of each plot by the average of the highest forage yielding defoliation treatment in each environment. The relative forage yield could then be combined for all sites. For each growth stage, the untreated control was used as the starting point to determine the relationship between relative forage yield and level of defoliation. Regression equations between relative forage yield and defoliation for each stage of growth in each environment were developed using environment treatment means. In addition, model equations for each stage of growth over all environments were developed using environment treatment means.

RESULTS AND DISCUSSION

The growing seasons at Arlington during 2000, 2001, and 2002 were near the 40-yr average for monthly temperature. Precipitation during 2000 was greater than the 40-yr average with significantly more precipitation in May and June, while precipitation during 2001 was average, and 2002 below average from July to September. The growing seasons at Marshfield during 2000, 2001, and 2002 were near the 40-yr average for monthly temperature. Precipitation during 2000 was near the 40-yr average, during 2001 was greater than average with significantly more precipitation in May and June, and during 2002 was above average for most of the growing

Table 1. Corn forage dry matter yield (Mg ha^{-1}) response to defoliation.

Growth stage	Leaf defoliation	Arlington, WI 2000	Arlington, WI 2001	Arlington, WI 2002	Marshfield, WI 2000	Marshfield, WI 2001	Marshfield, WI 2002	State College, PA 2000	State College, PA 2001	State College, PA 2002	Mean
	%	Mg ha^{-1}									
Control	**0**	**18.4**	**25.2**	**21.1**	**16.7**	**13.4**	**19.4**	**18.9**	**17.0**	**11.4**	**17.9**
V7	**100**	**18.6**	**19.6**	**17.9**	**13.3**	**12.1**	**14.1**	**15.1**	**14.9**	**9.7**	**15.0**
V10	**50**	**18.9**	**22.2**	**18.3**	**11.8**	**9.0**	**15.2**	**16.0**	**16.1**	**8.9**	**15.2**
	100	**15.8**	**14.2**	**12.9**	**6.0**	**6.7**	**9.8**	**13.2**	**9.5**	**4.9**	**10.3**
R1	**25**	**16.4**	**24.0**	**18.1**	**17.1**	**11.7**	**18.8**	**15.1**	**15.3**	**9.0**	**16.2**
	50	**16.6**	**20.8**	**17.0**	**15.5**	**10.1**	**16.1**	**14.7**	**13.7**	**8.6**	**14.8**
	100	**6.3**	**6.6**	**6.9**	**6.5**	**4.1**	**6.4**	**4.0**	**4.8**	**3.1**	**5.4**
R4	**25**	**18.4**	**23.8**	**19.7**	**16.0**	**12.1**	**19.1**	**17.8**	**14.4**	**9.3**	**16.7**
	50	**18.2**	**23.7**	**17.8**	**14.4**	**12.1**	**16.9**	**17.8**	**13.3**	**8.5**	**15.8**
	100	**11.4**	**14.0**	**13.2**	**11.5**	**7.4**	**11.1**	**10.5**	**10.0**	**7.4**	**10.7**
LSD (0.05)		**4.5**	**2.5**	**2.5**	**1.7**	**2.4**	**1.4**	**3.8**	**2.9**	**2.3**	**0.9**

season. The growing seasons at State College for 2000 and 2001 were quite favorable with near normal rainfall and below average temperatures; however, the 2002 growing season was hot and dry with below normal rainfall and above average temperatures in July and August.

Vegetative stages were defined using the collar method, which results in about two fewer leaves being classified than the typical staging system used by hail adjusters (Stevens et al., 1986). Thus, V7 corn would really be nine-leaf corn according to the hail adjuster's growth staging system.

Defoliation did not reduce stand population, so forage yield decrease was due to defoliation. In all environments plant emergence was excellent, resulting in plant populations averaging between 66 800 and 84 900 plants ha^{-1}. Plant density was not significantly different among treatments in any environment, except Marshfield during 2000 where the treatment involving V10–50% defoliation was 7% greater than the average of the other treatments.

Corn forage yield of the untreated control at Arlington, Marshfield, and State College ranged among years from 18.4 to 25.2, 13.4 to 19.4, and 11.4 to 18.9 Mg dry matter ha^{-1}, respectively (Table 1). These forage yields are typical of commercial production fields in the surrounding area, although significant drought occurred at State College during 2002 compared to other years. Averaged over all locations, the untreated control produced the greatest forage yield; however, in specific environments many defoliation treatments were not significantly different from the untreated control forage yield. The defoliation treatment × environment interaction was significant for forage yield, indicating that the response to defoliation varied among environments. For example, 25% defoliation at R4 was not significantly different from the untreated control in nine of nine environments, and 100% defoliation at V7 was not different in four of nine environments. Baldridge (1976) also reported forage yield variations among years in damage from defoliation.

An important guideline for timing corn forage harvest is the kernel milkline. Optimum yield and quality of corn forage has been reported shortly after 50% kernel milkline (Wiersma et al., 1993). For the untreated control at Arlington, kernel milk was 48, 21, and 31% during 2000, 2001, and 2002, respectively. Within any particular year, good agreement between kernel milk and forage moisture measurements was observed regardless of defoliation treatment. As kernel milk decreased, forage moisture decreased. For example, during 2000, kernel milk of the untreated control was 48% and forage moisture was 634 g kg^{-1}, whereas for the 100% defoliation at R4 treatment kernel milk was 4% and forage moisture was 533 g kg^{-1}.

The target whole-plant moisture range for timing corn forage harvest depends on the storage method, and varies between 500 and 700 g kg^{-1} (Roth et al., 1995). Corn forage moisture of the untreated control at harvest was generally within this range (Table 2). Averaged across all environments, forage moisture was greatest for 100% defoliation at R1 and lowest for 100% defoliation at R4. With the exception of the 100% defoliation at R4, defoliation tended to delay maturity, in contrast

Table 2. Corn forage moisture (g kg^{-1}) response to defoliation.

Growth stage	Leaf defoliation	Arlington, WI 2000	Arlington, WI 2001	Arlington, WI 2002	Marshfield, WI 2000	Marshfield, WI 2001	Marshfield, WI 2002	State College, PA 2000	State College, PA 2001	State College, PA 2002	Mean
	%	g kg^{-1}									
Control	**0**	**634**	**637**	**588**	**696**	**708**	**668**	**556**	**685**	**596**	**641**
V7	**100**	**640**	**640**	**598**	**693**	**701**	**698**	**581**	**645**	**597**	**644**
V10	**50**	**639**	**645**	**603**	**719**	**728**	**690**	**582**	**661**	**616**	**654**
	100	**632**	**681**	**619**	**710**	**709**	**715**	**590**	**692**	**696**	**671**
R1	**25**	**688**	**647**	**640**	**685**	**723**	**682**	**588**	**699**	**625**	**664**
	50	**657**	**668**	**648**	**680**	**736**	**694**	**592**	**700**	**642**	**669**
	100	**699**	**596**	**693**	**788**	**792**	**779**	**734**	**795**	**765**	**738**
R4	**25**	**654**	**650**	**604**	**698**	**706**	**678**	**594**	**714**	**616**	**657**
	50	**653**	**621**	**643**	**715**	**690**	**690**	**574**	**708**	**608**	**656**
	100	**533**	**437**	**521**	**673**	**682**	**660**	**460**	**684**	**628**	**587**
LSD (0.05)		**56**	**38**	**48**	**27**	**40**	**24**	**25**	**55**	**23**	**12**

to the findings of Hicks et al. (1977), who reported that defoliation following tasseling tended to hasten maturity. Assuming a drydown rate of 5 g kg^{-1} day (Wiersma et al., 1993) for corn forage, many of the defoliation treatments would result in a 1- to 5-d delay in harvest. The 100% defoliation at R1 treatment would result in a 19-d delay assuming a normal drydown rate.

Significant regression coefficients of determination were found at 21 of 27 site-years (Table 3), with the relationship typically fitting a quadratic vs. a linear response. At V10, four of nine environments had significant coefficients describing the relationship between forage yield and defoliation. At R1 and R4, 17 of 18 environments resulted in significant coefficients describing the relationship between forage yield and defoliation.

Increasing leaf defoliation decreases grain yield (National Crop Insurance Services, 1998). Thus, both leaf loss and decreases in grain yield would combine to reduce forage yield (Table 1, Fig. 1). When adjusting for forage yield response to defoliation the response is best described using a quadratic relationship (Fig. 1).

Forage yield response to defoliation varied according to the growth stage at which it occurred. Likewise, grain yield response to defoliation varies according to growth stage (National Crop Insurance Services, 1998). The most sensitive growth stage of forage yield for defoliation treatment was near tasseling and silking (Fig. 1).

Grain yield losses of 10% are predicted when complete defoliation occurs at V7. In this study, averaged across all environments, forage yield decreased 16% when 100% defoliation occurred at V7 (Fig. 1 and Table 1). Likewise, 100% defoliation decreased forage yield 43, 70, and 40% at V10, R1, and R4 growth stages, respectively. These results are similar to those reported by Baldridge (1976) in Montana, who concluded forage yield losses from 100% defoliation would average 28% at the 9-leaf (V7), 43% at the 12-leaf (V10), 65% at silking (R1), and 35% at soft dough (R4). Corresponding grain yield losses would be 28, 100, and 40% at V10, R1, and R4, respectively (National Crop Insurance Services, 1998). Simulated hail treatments do not account for bruising, crippling, and other secondary effects; thus, defoliation treatments tend to underestimate forage and grain yield impacts.

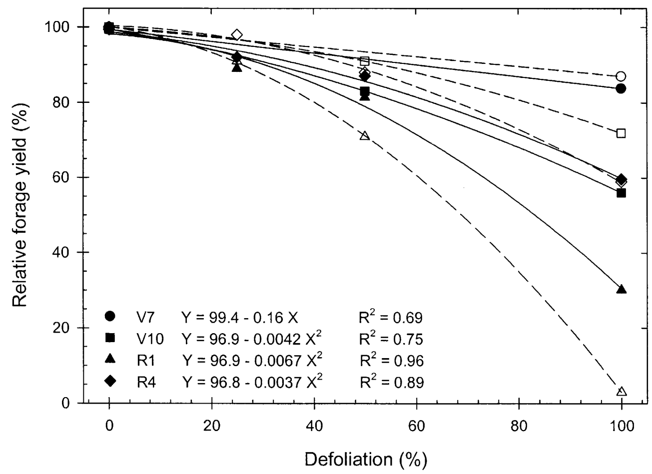

Fig. 1. Relative corn forage yield after defoliation at V7, V10, R1, and R4 (Ritchie et al., 1993). Relative forage yield was determined by dividing the forage yield of each plot by the average of the highest forage yield defoliation treatment for each environment. Model equations used treatment means for each environment. Graph values are treatment means averaged across environments. Dashed lines and open symbols are corresponding predictive relationships between relative grain yield and defoliation derived from (National Crop Insurance Services, 1998) leaf loss charts.

Based on this study, the forage yield and maturity responses to defoliation appear to differ from those observed in other studies measuring grain yield and maturity response. The forage yield responses are relatively consistent among regions. Using the equations listed in Fig. 1, agronomists can estimate the impact of defoliation on corn forage yield.

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Table 3. Relationship between relative corn forage yield (y) and percent defoliation (x) at V7, V10, R1, and R4 (Ritchie et al., 1993). Relative forage yield was determined by dividing the forage yield of each plot by the average of the highest forage yield defoliation treatment for each environment. Values used to develop models were treatment means.

	V10		R1		R4	
Year	**Model**	**R^2**	**Model**	**R^2**	**Model**	**R^2**
			Arlington			
2000	NS	–	$y = 96 - 0.0062x^2$	0.97	$y = 101 - 0.0039x^2$	0.96
2001	$y = 100 - 0.0043x^2$	1.00	$y = 100 - 0.0074x^2$	1.00	$y = 101 - 0.0044x^2$	0.97
2002	NS	–	$y = 95 - 0.006x^2$	0.98	$y = 102 - 0.38x$	0.99
			Marshfield			
2000	$y = 98 - 0.63x$	1.00	$y = 98 + 0.32x - 0.0092x^2$	1.00	$y = 99 - 0.32x$	0.98
2001	NS	–	$y = 95 - 0.0065x^2$	0.98	$y = 95 - 0.0042x^2$	0.96
2002	$y = 101 - 0.49x$	0.99	$y = 100 - 0.0068x^2$	1.00	$y = 100 - 0.0043x^2$	0.99
			State College			
2000	$y = 100 - 0.31x$	1.00	$y = 93 - 0.0072x^2$	0.96	$y = 100 - 0.0044x^2$	0.97
2001	NS	–	$y = 97 - 0.0069x^2$	0.99	$y = 98 - 0.40x$	0.98
2002	NS	–	$y = 101 - 0.70x$	0.95	NS	–

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