TILLER EMISSION AND DRY MASS ACCUMULATION OF WHEAT CULTIVARS UNDER STRESS

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ABSTRACT: Tillers are important structures for wheat (*Triticum aestivum* L.) because they contribute to increase the number of spikes per area, enhancing grain yield. Stresses during plants early growth have a sizable effect on tiller production. Three experiments were conducted to evaluate the effects of stresses induced by unevenness in sowing depth, defoliation and differences in soil pH on tiller emission and dry mass accumulation of wheat cultivars. The experiments were carried out in Lages, Southern Brazil, during the winter growing seasons of 2000 and 2001. They were performed in square boxes, under natural conditions of radiation and irrigation. In the first experiment, five types of sowing depths were tested to simulate different systems of unevenness in plant emergence of cultivar Embrapa 16. In the second experiment, two wheat cultivars (BRS 177 and BRS 179) were submitted to four types of main stem defoliation. The third experiment assessed the effects of three levels of soil acidity correction on the tillering pattern of Fundacep 29. Unevenness in sowing depth, alternating pairs of seeds at 3 cm and 5 cm deep, reduced tiller emission and dry mass accumulation. The removal of the first and second main stem leaves reduced significantly BRS 179 tiller dry mass and number and did not affect the tillering pattern of BRS 177. The lack of liming restricted tiller emission and reduced plant dry mass accumulation.
Key words: *Triticum aestivum* L., tillering, sowing depth, defoliation, aluminum

EMISSÃO E ACUMULAÇÃO DE MASSA SECA DE AFILHOS DE TRIGO SOB DIFERENTES ESTRESSES

RESUMO: Os afilhos são importantes estruturas para as plantas de trigo (*Triticum aestivum* L.), porque podem contribuir para o aumento do número de espigas por área e aumentar o rendimento de grãos. Estresses na fase inicial da cultura podem afetar esse processo. O presente trabalho foi realizado com o objetivo de avaliar a emissão de afilhos e o acúmulo de massa seca, em condições ambientais adversas ao afilhamento, para determinar a sensibilidade desse processo em comunidade de plantas. No primeiro experimento simulou-se a semeadura a diferentes profundidades, no segundo reduziu-se artificialmente a área foliar e no terceiro experimento cultivou-se plantas em diferentes níveis de alumínio no solo. Os experimentos foram realizados em Lages, SC, nos anos de 2000 e 2001, em telado (condições naturais de radiação e com irrigação) e em caixas. A desuniformidade de profundidade de semeadura, os danos causados às plantas pelo corte de folhas do colmo principal e o desequilibro nutricional causado pelos níveis de correção do solo com calcário reduziram a emissão de afilhos e o acúmulo de massa seca.
Palavras-chave: *Triticum aestivum* L., afilhamento, profundidade de semeadura, corte de folhas, alumínio

INTRODUCTION

Tiller emission and survival of Brazilian wheat cultivars is low under field conditions (Alves et al., 2000). Only high input crops produce more than 300 spikes m^{-2} at harvesting. Conversely, it is common to find wheat fields with more than 600 spikes m^{-2} in the United States (Goos et al., 1999). These numbers either emphasize the low tillering ability of Brazilian wheat cultivars or that the prevailing environmental conditions in the South of Brazil are not favorable for tillering expression.

Tiller initiation, emission and survival depend on the intensity of competition among plants in the community. Experiments carried out by Alves et al. (2000) and Almeida et al. (2000) tiller initiation and emission can occur very early in the crop ontogeny, between the emission of the second and the fourth leaves. Evenness in plant emergence may enhance tiller production, survival and contribute to grain yield. The importance of uniformity in plant growth and development is related to the establishment of competition and its consequences on apical dominance (Merotto Jr. et al., 1999). Apical dominance is influenced by the amount of incident solar radiation and by the relationship between red (R) and far-red (FR) light inside the canopy (Ballaré et al., 1987). Both factors may suppress tiller initiation and survival, depending on the cultivar (Rajcan & Swanton, 2001).

The level of competition established in the community between tiller initiation and external emission can also be affected by the plant leaf area. Reductions in the photosyntetically active surface may restrict carbohydrate availability to sustain tiller production. Alves et al. (2000), working with isolated wheat, oat and barley plants, noticed that cutting one of the first four leaves of the main stem did not interfere with tiller emergence. This indicates that leaf area reduction was not limiting to tillering in a low competition environment. The defoliation effect on tiller production will probably be different in a community with 300 pl m^{-2}, where the level of competition is higher.

The synchrony between the main stem and tiller developmental rates is an essential condition for tiller survival (Wobeto, 1994). Main stem and tillers present the same rate of development under favorable conditions (Masle, 1985). Acid soils and aluminum toxicity are two factors that restrict root development and limit nutrient uptake (Ernani et al., 2002). Root constraints imposed by low soil pH may increase the lack of synchronism between main stem and tiller dry mass accumulation rates, leading to tiller supression.

Unevenness in sowing depth, acid soils and leaf area reduction due to insects are stresses commonly found in Brazil during wheat early growth. The importance of each one of these stresses on tiller production is difficult to assess under field conditions because they often interact with other uncontrolled variables. This work aimed at evaluating, under controlled environmental conditions, isolated effects of stresses induced by variations in sowing depth, defoliation and differences in soil pH on tiller emission and dry mass accumulation of wheat cultivars.

MATERIAL AND METHODS

Three experiments were carried out in Lages, SC, Brazil (27º52'30'' S and 50º18'20'' W) during the growing seasons of 2000 and 2001. The trials were performed in square boxes, 1.2 m wide and 30 cm high, under natural conditions of radiation and with irrigation. The boxes were filled with an Haplumbrept soil, limed to pH 6.0, excepting experiment 3, where the soil pH was modified according to each treatment. N, P and K were applied according to the recommendations of Comissão Brasileira de Fertilidade do Solo -RS/SC (1995).

Each box was sown with six rows, oriented from north to south. The two outside rows were considered borders. The four central rows formed a treatment replication (experiments 1 and 2). In experiment 3, the whole box was considered as replication, setting up three replications per treatment. Pre-germinated seeds were sown in the boxes when the primary seminal root was already extruded from the seed. The distance between two adjacent plants inside the row was 1.5 cm in experiment 1. Plants were 1.7 cm apart in experiments 2 and 3. Row spacing was 20 cm for all three experiments.

Experiment 1 seeding made on 5/26/01 used cultivar Embrapa 16, and evaluated five sowing depths. A completely randomized experimental design was used, testing the following treatments: uniform sowing depth of 3 cm; uneven sowing depth, positioning the seeds alternately 3 cm and 4 cm deep; uneven sowing depth, positioning the seeds alternately 3 cm and 5 cm deep; uneven sowing depth, positioning pairs of seeds at the same depth (two seeds positioned at 3 cm, the next two at 4 cm and so forth); uneven sowing depth, positioning pairs of seeds at the same depth (two seeds positioned at 3 cm, the next two at 5 cm and so forth).

Fifteen plants were harvested per replication 33 days after seeding, when they were in the 5.1 stage of the Haun scale. The following measurements were performed:

a) dry mass accumulation: tillers and the main stem were separated during harvesting, placed in different paper bags and dried at 60ºC. After reaching constant weight, tillers, main stem and total dry mass were determined;

b) tiller production: the number of each tiller type and the total number of tiller produced were assessed just before harvesting by counting externally visible tillers on each leaf axyl.

Experiment 2 was conducted with two contrasting wheat cultivars in terms of tillering ability (BRS 177 and BRS 179). Both cultivars were submitted to different types of main stem defoliation. The seeding was done on 5/23/2001 at a constant 3 cm depth and plant emergence occurred four days later. A 2 × 5 factorial scheme, completely randomized design was used. The following treatments were tested: Control (without defoliation); Defoliation 1: cutting the first leaf of the main stem at stage 1.1 of the Haun scale; Defoliation 2: cutting the second leaf of the main stem at stage 2.1; Defoliation 3: cutting of third leaf of the main stem at stage 3.1; Defoliation 4: cutting the first leaf at stage 1.1 and the second at stage 2.1. Twenty five plants were harvested per replication, 53 days after emergence, at stage 5.5 of the Haun scale. Dry mass accumulation and tiller production were evaluated as described previously.

Experiment 3 involved cultivar Fundacep 29, sown on July 6, 2000. The soil used in this experiment presented the following characteristics: clay content - 400 g kg^{-1} ; H_2O pH - 4.7 ; P - 2.3 mg kg^{-1}; K - 24 mg kg^{-1}; OM – 2.6 g kg^{-1}; Al – 3.3 cmol$_c$ kg^{-1}; and Ca+Mg –

1.6 cmol$_c$ kg^{-1}. Quantities equivalent to 150 kg ha^{-1} of P_2O_5 and K_2O were applied to the soil on each experimental unit at the planting day.

A completely randomized block design was used, with three treatments. Three levels of soil acidity correction were evaluated: unlimed acid soil; ¼ of the liming rate to elevate the soil water pH to 6.0; and full liming rate to rise the soil water pH to 6.0, according to the recommendations of the Comissão Brasileira de Fertilidade do Solo-RS/SC (1995).

Plants were harvested on September 12, at stage 6.5 of the Haun scale. Twenty plants were harvested per replication. Dry mass accumulation and tiller production were assessed following same procedures described before.

The nomenclature used to identify leaves and tillers in all trials was adapted from Masle (1985). The tillers were denominated with the letter T, followed by the number of the leaf from which they originated. Weeds, diseases and insects were controlled in all experimental units so that they did not interfere with the crop development.

An analysis of variance was performed separately for each experiment; F values were considered significant at the $P < 0.05$ level. Differences among treatments were compared using the Duncan test at $P < 0.05$.

RESULTS AND DISCUSSION

Stresses caused by unevenness in sowing depth, defoliation of the main stem and lack of full correction of soil acidity affected tiller emission and dry mass accumulation (Tables 1, 2 and 3). In Experiment 1, seeds positioned closer to the soil surface usually emerged earlier, producing "dominant" plants. Seeds placed deeper in the soil took longer time to emerge, generating "dominated" plants. The uneven emergence restricted tillering in the treatments with two dominant and two dominated plants per row (Table 1). Treatments 4 and 5 presented lower emission of T1, T2 and T3, and less dry matter allocation to the tillers for both dominant and dominated plants, in comparison to the control (even sowing depth). Conversely, the rotation between a "dominant" and a "dominated" plant inside the row (treatments 2 and 3) had less pronounced effects on the wheat tillering ability, in relation to the uniform seeding.

Table 1 - Dry mass of first tiller (T1), second tiller (T2) and third tiller (T3), tiller dry mass, plant dry mass (main stem + tillers), and number of emitted tillers in 15 wheat plants sown at different sowing depths.

Treatment		Dry mass (g)				
		T1	T2	T3	Tillers	Plants
1	Uniform sowing [1/]	0.22 ab*	0.62 a	0.14 a	0.98 ab	3.71 ab
2	Dominant plants	0.36 a	0.66 a	0.12 a	1.13 a	3.87 a
	Dominated plants	0.37 a	0.58 ab	0.08 bc	1.02 ab	3.66 ab
3	Dominant plants	0.22 ab	0.47 bc	0.07 bc	0.75 bc	3.09 cd
	Dominated plants	0.24 a	0.56 ab	0.10 ab	0.88 ab	3.30 bc
4	Dominant plants	0.07 bc	0.39 c	0.58 c	0.51 cd	2.93 cd
	Dominated plants	0.01 c	0.33 c	0.04 c	0.41 d	2.85 cd
5	Dominant plants	0.08 bc	0.33 c	0.06 bc	0.47 d	2.84 cd
	Dominated plants	0.04 c	0.33 c	0.04 c	0.41 d	2.65 d

Treatment		Emitted tillers (nº)			
		T1	T2	T3	Total
1	Uniform sowing	3.50 b	13.50 a	10.75 a	27.75 a
2	Dominant plants	6.75 a	13.50 a	8.75 ab	29.00 a
	Dominated plants	5.25 ab	12.75 ab	6.75 bc	24.75 a
3	Dominant plants	4.50 b	11.75 abcd	7.50 abc	23.75 a
	Dominated plants	3.25 bc	12.50 abc	9.00 ab	25.25 a
4	Dominant plants	1.25 cd	10.50 bcd	4.75 c	16.50 b
	Dominated plants	0.50 d	10.00 bcd	4.25 c	14.75 b
5	Dominant plants	1.25 cd	9.00 d	7.00 bc	17.50 b
	Dominated plants	0.75 d	9.75 cd	4.75 c	15.25 b

[1/] 1 – Even sowing depth (3 cm), 2 – uneven sowing depth of 1cm with individual seeds (3,4,3,4...) 3 – uneven sowing depth of 2 cm with individual seeds (3,5,3,5...), 4 – uneven sowing depth of 1 cm with pairs of seeds (3,3,4,4,3,3...), 5 – uneven sowing depth of 2 cm with pairs of seeds (3,3,5,5,3,3...)

*Averages followed by the same lower case letter on each column are not different by the Duncan's Test at the $P < 0.05$ level.

Merotto Jr. et al. (1999), varying sowing dates inside the row, also noticed that late-emerging seedlings are dominated by early-emerging plants, having lower capacity to accumulate dry mass and to contribute to grain yield. Since yield definition per area depends on the contribution of the whole plant community and a patchy plant emergence is common in Brazilian wheat fields, irregularity in plant emergence can partially account for the low values of grain yield observed in wheat fields.

The removal of the first and second main stem leaves did not affect BRS 177 tiller dry mass and number in Experiment 2 (Table 2). On the other hand, it reduced those parameters for BRS 179. The cutting of the third leaf did not change the tillering pattern of both cultivars in comparison to the control. There were no differences between cultivars' tiller number and dry mass when the main stem leaf area was preserved. On the other hand, BRS 177 presented higher tiller dry mass and number than BRS 179 when the first or the second leaf was cut. Total plant dry mass accumulation was reduced by defoliation, regardless of cultivar and leaf removed.

The contrasting effects of defoliation on the cultivar's ability to emit and allocate dry mass to the tillers was probably related to strategic differences in ontogeny presented by each genotype to define tiller emission. The small impact of cutting the third leaf on tiller number demonstrates that T1 and T2 definition and emission precedes the expansion of the third leaf, as it has also been shown by Alves et al. (2000) and Almeida et al. (2000).

Sometimes, the same defoliation treatment had different effects on the cultivar tillering pattern, depending on the parameter that is being evaluated. In this sense, cutting the third leaf did not reduce T2 tiller number for both cultivars but decreased their T2 tiller dry mass (Table 2). Care should be taken when analyzing individually and collectively tiller emission and dry mass accumulation. Although related, their behavior can differ depending on the environment the plant is facing. Therefore, if in the moment of tiller emission the environmental conditions are favorable, the plant will produce larger number of tillers. However, more tillers will not necessarily result in greater dry mass accumulation, because this will be determined later in the crop ontogeny, depending on the plant capacity to partition photoassimilates to tillers.

The absence of liming reduced the emission and dry matter accumulation of T1 and T2 tillers (Table 3). The application of ¼ of the required liming rate, increasing soil water pH to 6.0, provided a tillering pattern similar to that obtained with the full rate, for all the analyzed parameters. Considering that the process of tiller emission is sensitive to the presence of exchangeable Al^{+3} in the soil (Mundstock, 1999), it is not necessary the proceed to full correction of soil acidity to maximize Embrapa16 tiller emission and dry mass accumulation. The elimination of aluminum toxic effects to maize roots with partial liming was also reported by Ernani et al. (2002).

The strongest the stress the smallest the emission of tillers (Tables 1, 2 and 3). Besides of favoring tiller

Table 2 - Dry mass of first tiller (T1) and second tiller (T2), tiller dry mass, plant dry mass (main stem + tillers), and number of emitted tillers in 25 plants of the wheat cultivars BRS 177 and BRS 179, submitted to different defoliation levels.

Defoliation level	Dry mass (g)								
	T1			T2		Tillers		Plants	
	BRS 177	BRS 179	Mean	BRS 177	BRS 179	BRS 177	BRS 179	BRS 177	BRS 179
Control[1/]	0.57	0.53	B 0.55	A 1.23 a*	A 1.00 b	A 1.8 a	A 1.9 a	A 7.2 a	A 6.9 a
Defoliation 1	0.75	0.32	B 0.54	A 0.99 a	C 0.26 b	A 1.9 a	B 0.6 b	B 5.9 a	C 2.8 b
Defoliation 2	0.59	0.08	BC 0.34	AB 0.82 a	C 0.30 b	A 1.5 a	B 0.4 b	C 4.8 a	C 2.8 b
Defoliation 3	1.04	0.67	A 0.85	B 0.80 a	B 0.69 a	A 1.8 a	A 1.7 a	C 4.9 a	B 5.1 a
Defoliation 4	0.38	0.19	C 0.28	C 0.31 a	C 0.15 a	B 0.7 a	B 0.4 a	D 2.6 a	D 1.8 a
Mean	0.67 a	0.36 b							

Defoliation level	Emitted tillers (nº)					
	T1		T2		Total	
	BRS 177	BRS 179	BRS 177	BRS 179	BRS 177	BRS 179
Control	AB 15.8 a	A 12.5 a	A 23.0 a	A 23.8 a	AB 47.8 a	A 54.5 a
Defoliation 1	B 11.5 a	A 15.5 a	A 20.8 a	C 15.3 b	AB 45.0 a	BC 35.3 a
Defoliation 2	AB 13.8 a	B 4.0 b	A 23.3 a	BC 17.8 b	AB 43.3 a	C 27.8 b
Defoliation 3	A 19.0 a	A 13.0 a	A 23.0 a	A 24.3 a	A 49.3 b	A 60.3
Defoliation 4	AB 15.3 a	A 18.0 a	A 19.5 a	AB 20.8 a	B 37.3 a	B 40.5 a

[1/] Control – all leaves preserved, Defoliation 1: cutting the first leaf of the main stem at stage 1.1 of the Haun scale, Defoliation 2: cutting the second leaf of the main stem at stage 2.1, Defoliation 3: cutting of third leaf of the main stem at stage 3.1, Defoliation 4: cutting the first leaf at stage 1.1 and the second at stage 2.1.

* Averages followed by the same upper case letter on each column and the same lower case letter on each row are not different by the Duncan's Test at the $P < 0.05$ level.

Table 3 - Dry mass of first tiller (T1), second tiller (T2) and third tiller (T3), tiller dry mass, plant dry mass (main stem + tillers), and number of emitted tillers in 20 plants of the wheat cultivar Embrapa 16 grown at three levels of soil acidity correction.

Treatment	Dry mass (g)				
	T1	T2	T3	Tillers	Plants
Control [1/]	0.17 b	0.97 b	0.49 a	1.64 b	5.9 c
¼ of the full rate	1.08 a	2.00 a	0.75 a	3.84 a	10.04 b
Full rate	1.37 a	2.57 a	0.89 a	4.89 a	12.33 a

Treatment	Emitted tillers (nº)			
	T1	T2	T3	Total
Control [1/]	1.7 b	8.8 b	8.3 ns	19.3 b
¼ of the full rate	5.4 a	11.7 a	7.8	24.9 ab
Full rate	6.0 a	13.5 a	8.9	29.0 a

[1/] Unlimed acid soil, ¼ of the liming rate to elevate the soil water pH to 6.0, full liming rate to rise the soil water pH to 6.0,
*Averages followed by the same lower case letter on each column are not different by the Duncan's Test at the $P < 0.05$ level.

omission, the applied stresses also determined a modification in the plant dry mass partition, decreasing tiller dry mass proportionally to the increase in the stress magnitude. For a tiller to become productive, it must present growth rates similar to the main stem (Wobeto, 1994). Unfavorable environmental conditions usually slow down tiller development in relation to the main stem, favoring apical dominance (Almeida et al., 2000; Almeida & Mundstock, 2001). Results of this research reinforce the idea that the chances of tillers to contribute to grain yield are reduced under stressful conditions.

Considering that there must be a synchronism between tillers and main stem development, so that tillers can substantially contribute to grain yield (Wobeto, 1994, Merotto Jr., 1995), Almeida et al. (2002; 2003) raised the question about the real importance of tillering to improve wheat performance under the environmental conditions prevailing in the growing regions of Southern Brazil. In this work, treatments were chosen aiming to simulate stresses commonly found in wheat fields, and to evaluate their influence on the tillering process. This kind of assessment is fundamental to subsidize breeding programs, because there is a lack of information about plant traits that can contribute to enhance grain yield of future wheat cultivars.

Understanding the physiological basis of yield formation is a fundamental step to provide a more holistic view to plant breeders and to increase the potential productivity of cereals. The suppressive effects promoted on tiller emission, by the different kinds of stresses, in addition to the unfavorable environmental conditions for tiller survival commonly verified in Southern Brazil, show there may be a need to change the genetic base of current genotypes, so that the potential wheat productivity can be increased, by enhancy tillering.

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