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Biomass Production, Nitrogen Accumulation and Yield in Wheat under Two Tillage Systems and Nitrogen Supply in the Argentine Rolling Pampa

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Abstract: Biomass production and partition, total nitrogen accumulation, grain yield and yield components in wheat were evaluated along two years. In 2000, two tillage systems were analyzed: mouldboard plough and chisel plough, for two cultivars: Buck Poncho and Buck Charrúa, under three fertilization treatments: I) without N, ii) 90 kg N ha^{-1} in a single dose at sowing and iii) 45 kg N ha^{-1} at sowing + 45 kg N ha^{-1} at the end of tillering. In 2001, the tillage systems and fertilization treatments were the same as in the previous year. Buck Yapeyú and Buck Poncho were tested as cultivars. In 2000, during the first stages, biomass production was higher in the Conventional Tillage (CT) treatment than in Chisel (VT). Nevertheless, at maturity, no significant differences were found in biomass or grain production between the tillage systems. There were significant effects of the fertilization treatments on all growth stages analyzed. In 2001, biomass and grain yield were lower than in the previous year. At anthesis, neither the tillage systems nor the fertilization treatments led to significant differences in biomass production. At maturity, the tillage treatments caused significant effects on biomass production, total N accumulation and yield, while the different fertilization treatments no produced any effects. Biomass production, total N accumulation and yield depended on the NO_3^- availability, which was modified by rainfall amount and distribution and sowing date. Chisel plough was an effective tillage system, when N availability and sowing date were suitable. Nevertheless, when both sowing date and N availability were unfavorable, the conventional tillage produced a better response than that of the non-conventional tillage. When response for fertilization treatments was found, this was independent of the moment and dose applied. Cultivar yields did not show significant differences in each considered year.

Key words: Wheat · biomass · nitrogen · tillage systems

INTRODUCTION

In the humid wheat region of Argentina, mainly in The Rolling Pampas, continuous agriculture has caused soil degradation by excessive and inadequate tillage practices [1]. This, added to cultivated crops such as soybean, with little stubble, has produced an important decrease of soil organic matter and soil losses by erosion [2]. Within non-conventional tillage, zero tillage allows to attenuate soil problems produced by this intensified agriculture. Nevertheless, the lower net mineralization, the higher immobilization or the increased denitrification processes observed in this tillage system can result in a lower crop N availability [3, 4], thus affecting N accumulation, crop N use efficiency and biomass accumulation and partition [5, 6]. The chisel tillage has an intermediate effect between mouldboard ploughing and no-tillage, respect to the soil N dynamics [7].

Wheat presents great difficulties to obtain high yields in zero tillage. This could be due to some soil elements that affect initial crop development [8] and low fertility available throughout the crop cycle [9, 10] compared with other tillage systems. The lower availability and the high potential yield of new cultivars result in higher nitrogen requirement with regard to the conventional tillage [11]. This depends, not only, on the nitrogen amount and the moment in which it is available, but also on the crop N use efficiency [12]. In addition, crop production under zero tillage could lead to excessive

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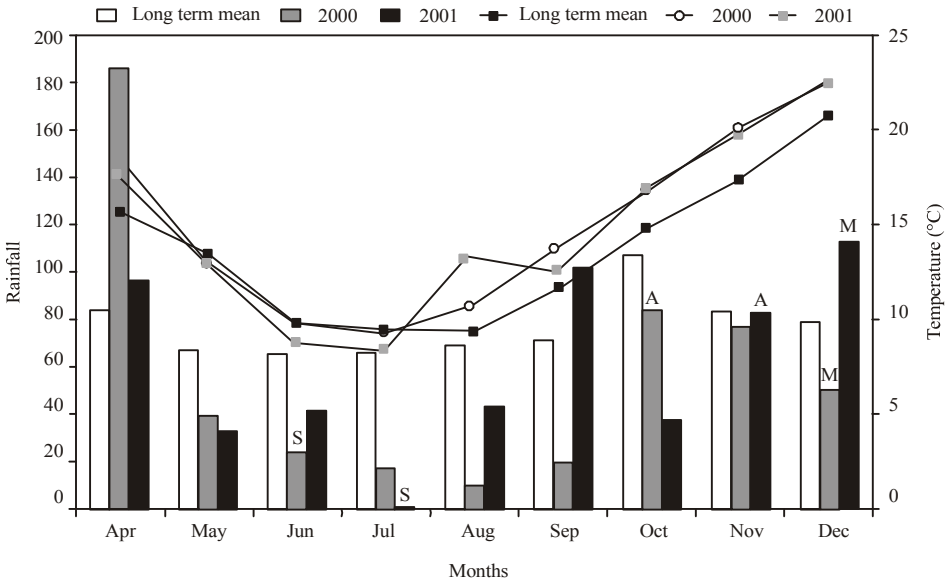

Fig. 1: Monthly rainfall and long term mean rainfall (columns) and monthly temperature and long term mean temperature (line). S: sowing, A: anthesis, M: maturity

soil surface compaction, with consequent adverse effects on crop growth [13, 14]. Chisels could be an effective way to stop soil degradation produced by conventional tillage thus avoiding, at the same time, problems found for zero tillage system. The aim of present research was to analyze aerial biomass production and partition, total N accumulation and wheat yield, under conventional tillage and chisels, with N fertilization in different doses and moments of application along two years.

MATERIALS AND METHODS

Two trials were carried out in 2000 and 2001 in La Plata, at the Estación Experimental JJ Hirschhorn (35° LS) on a typical argiudol soil with a slight deficiency of internal drainage. During the growing season, both monthly rainfall and temperature and long-term mean rainfall and temperature were recorded (Fig. 1). Seeds of wheat were sown on 21 June 2000 and 23 July 2001. During 2000, two tillage systems were evaluated: mouldboard plough (CT) and chisel plough (VT) for two different cultivars: Buck Poncho (early heading cultivar, BP) and Buck Charrúa (late heading cultivar, BCH). Three fertilization treatments were evaluated: I) without N (N0), ii) 90 kg N ha^{-1} applied in a single dose at sowing (N1) and iii) 45 kg N ha^{-1} at sowing + 45 kg N ha^{-1} at the end of tillering (N2). In 2001, the tillage systems and fertilization treatments were the same as in the previous year and the cultivars tested were Buck Yapeyú (BY) and Buck Poncho (BP), both early heading cultivars. Nitrogen was applied as urea and 100 kg ha^{-1} of triple superphosphate (0-20-0) was applied at sowing. Before sowing, analysis of soil samples (top 0.20 m) indicated the following values in 2000 for the mouldboard plough: OM: 4.21%, total N: 0.21%, NO_3^-: 76.6 ppm, assimilable P (Bray Kurtz): 6.7 ppm and for the chisel plough: OM: 4.38%, total N: 0.21%, NO_3^- : 42.6 ppm, assimilable P (Bray Kurtz): 6 ppm. In 2001, values for the mouldboard plough were: OM: 4.40%, total N: 0.23%, NO_3^-: 69 ppm, assimilable P (Bray Kurtz): 9.7 ppm and for the chisel plough were: OM: 4.05%, total N: 0.22%, NO_3^-: 47 ppm, assimilable P (Bray Kurtz): 7.7 ppm. The experimental design was a Randomized Block with 4 replications. Each plot was 3 m wide and 10.25 m long. The NO_3^- soil availability was analyzed for both tillage systems at different growth stages by means of a portable reflectometer Nitrachek 404. In both trials the number of tillers m^{-2} with more than two leaves was counted. At the end of the tillering, in growth stages (GS) 22, according to Zandoks *et al.* [15] scale, three rows of 0.50 m (0.30 m^2) were harvested and dried at 70ºC for 48 h for aerial biomass determination. Similar methodology was used at anthesis, GS 65, scale and biomass partitioned in ear and straw. At maturity, GS 95, scale, total biomass was calculated after separating in grain, chaff and straw (stems + leaves) [15]. Dried plant material was milled and digested for total N determination by micro Kjeldahl method. On the basis of this value and dry matter, total accumulated N was calculated. Grain yield, harvest index (HI), kernel weight (KW) and number of ears m^{-2} and grains m^{-2}, were determined. Nitrogen use

Table 1: Biomass at tillering and anthesis, under two tillage systems: mouldboard plough (CT) and chisel plough (VT), three fertilization treatments: I) without N (N0), ii) 90 kg N ha^{-1} applied in a single dose at sowing (N1) and iii) 45 kg N ha^{-1} at sowing + 45 kg N ha^{-1} at the end of tillering (N2), for two cultivars: Buck Poncho (BP) and Buck Charrúa (BCH). 2000

	2000	
Biomass (kg ha^{-1})	Tillering	Anthesis
Tillage (T)		
CT	3590a	10140a
VT	2920b	9320b
Fertilization (F)		
N0	3000b	8880b
N1	3500a	10580a
Cultivars ©		
BP	3160a	8790b
BCH	3350a	10660a
Interactions		
T x F	Ns	**
F x C	Ns	Ns
C x T	Ns	**

Within the same column and treatment, values followed by the same letter do not differ statistically according to Tukey test (p > 0.05)
**: Significant at 0.05 and Ns: Not significant

Table 2: Effect of two tillage systems: mouldboard plough (CT) and chisel plough (VT) and two fertilization treatments: I) without N (N0), ii) 90 kg N ha^{-1} applied in a single dose at sowing (N1) on biomass at anthesis, 2000

Biomass (kg ha^{-1})	N0		N1
CT	9810a	Ns	10470a
VT	7780b	*	10860a

Within the same column and treatment, values followed by the same letter do not differ statistically according to tukey test (p > 0.05)
In the same row: **: Significant at 0.05 and Ns: Not significant

efficiency for the production of biomass (NUE biomass) and for the grain production (NUE yield) were calculated as the increase produced by each unit of N applied. Data were processed by ANOVA and means were separated according to the Tukey test (p = 0.05).

RESULTS

Significant differences in biomass production and N accumulation were found between years, tillage systems and fertilization treatments.

In 2000, during the first stages, biomass production was higher in CT treatment than that in VT. Nevertheless, at maturity, no significant differences were found for biomass or grain production between tillage systems. There were significant effects of the fertilization treatments for all growth stages analyzed.

At tillering (Table 1), biomass presented significant differences between tillage systems and fertilization treatments. Greater biomass production was obtained with CT and N1 treatments. Tillers m^{-2} increased in plots with N application (680 and 714 for N0 and N1, respectively). This also caused an increase in biomass production in plots with additional N. No significant differences among cultivars were observed. No interactions for any of the three variables were found.

At anthesis (Table 1), biomass was affected by tillage systems, fertilization treatments and cultivars. Biomass production was lower for VT, N0 and BP. Interaction between tillage systems and fertilization treatments (T x F) was found (Table 1). The fertilization effect was greater in VT treatment (biomass increased 40%) than in CT (biomass increased 6%) (Table 2).

At maturity (Table 3), biomass production was not modified by tillage systems, but there were differences due to the fertilization treatments and cultivars. Biomass production was greater for N1 and N2 treatments, no matter the moment of nitrogen application and for BCH. No interaction was found for biomass production. Total N accumulation had a similar behavior to biomass for all cases analyzed except for cultivars. Generally, grain yield and yield components were increased by nitrogen

Table 3: Biomass, yield, HI, ears m^{-2}, grains m^{-2}, KW and total N accumulation, under two tillage systems: mouldboard plough (CT) and chisel plough (VT), three fertilization treatments: I) without N (N0), ii) 90 kg N ha^{-1} applied in a single dose at sowing (N1) and iii) 45 kg N ha^{-1} at sowing + 45 kg N ha^{-1} at the end of tillering (N2), for two cultivars: Buck Poncho (BP) and Buck Charrúa (BCH) at maturity, 2000

Treatments	Biomass (kg ha^{-1})	Yield (kg ha^{-1})	HI	Ears m^{-2}	Grains m^{-2}	KW (g)	Total N (kg ha^{-1})
Tillage (T)							
CT	14760a	5350a	0.36a	518a	13473a	40.05a	157a
VT	15280a	5550a	0.36a	531a	14021a	39.75a	167a
Fertilization (F)							
N0	13190b	4750b	0.36a	478b	11586b	40.88a	136b
N1	15970a	5700a	0.36a	551a	14619a	39.32b	188a
N2	15900a	5890a	0.37a	545a	15350a	39.48b	187a
Cultivars ©							
BP	14130b	5400a	0.38a	541a	14518a	37.31b	155a
BCH	15900a	5510a	0.34b	508a	12976b	42.48a	169a
Interactions							
T x F	Ns	Ns	Ns	Ns	Ns	Ns	Ns
F x C	Ns	**	Ns	Ns	**	Ns	Ns
C x T	Ns	Ns	Ns	Ns	Ns	Ns	Ns

Within the same column and treatment, values followed by the same letter do not differ statistically according to Tukey test (p > 0.05)
**: significant at 0.05 and Ns:not significant

Table 4: Biomass, yield, HI, ears m^{-2}, grains m^{-2}, KW and total N accumulation, under two tillage systems: mouldboard plough (CT) and chisel plough (VT), three treatments of fertilization: I) without N (N0), ii) 90 kg N ha^{-1} applied in a single dose at sowing (N1) and iii) 45 kg N ha^{-1} at sowing + 45 kg N ha^{-1} at the end of tillering (N2), for two cultivars: Buck Poncho (BP) and Buck Yapeyú (BY) at maturity, 2001

Treatments	Biomass (kg ha^{-1})	Yield (kg ha^{-1})	HI	Ears m^{-2}	Grains m^{-2}	KW (g)	Total N (kg ha^{-1})
Tillage(T)							
CT	12940a	4278a	0.33a	520a	16379a	26.34a	161.6a
VT	10786b	3669b	0.34a	453b	13630b	26.94a	115.3b
Fertilization(F)							
N0	11136a	3770a	0.33a	465a	13309b	28.25a	125.1a
N1	11172a	4180a	0.34a	502a	16172a	26.07ab	148.2a
N2	12997a	3980a	0.33a	492a	15533a	25.62b	145.5a
Cultivars(C)							
BP	12270a	4160a	0.34a	528a	15946a	26.19a	126.0b
BY	11455b	3780a	0.33a	439b	14063a	26.56a	150.9a
Interactions							
T x F	Ns	Ns	Ns	Ns	Ns	Ns	Ns
F x C	Ns	Ns	Ns	Ns	Ns	Ns	Ns
C x T	Ns	Ns	Ns	Ns	Ns	Ns	Ns

Within the same column and treatment, values followed by the same letter do not differ statistically according to Tukey test ($p > 0.05$), Ns: not significant

Table 5: Nitrogen use efficiency for yield and biomass, 2000 and 2001

	2000		2001	
Treatments	NUE yield	NUE biomass	NUE yield	NUE biomass
Fertilization (F)				
N0				
N1	10.55a	30.88a	6.81a	12.59a
N2	12.66a	30.11a	3.49a	12.00a

Within the same column and treatment, values followed by the same letter do not differ statistically according to Tukey test ($p > 0.05$)

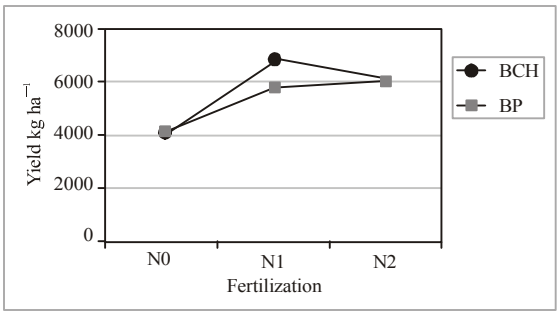

Fig. 2: Effect of two cultivars: BP and BCH and three treatments of fertilization: I) without N (N0), ii) 90 kg N ha^{-1} applied in a single dose at sowing (N1) and iii) 45 kg N ha^{-1} at sowing + 45 kg N ha^{-1} at the end of tillering (N2) on yield, 2000

fertilization and modified by cultivars. Nevertheless, they were not affected by tillage systems. HI was not modified by additional N. Therefore, there were both greater biomass production and increase in grain yield in the fertilized treatments. This increase was obtained through ears m^{-2} and grains m^{-2}. KW decrease caused by fertilization treatments was logical, due to the increase of the other components. BP presented higher HI and grains m^{-2} but lower KW than BCH. There was an interaction F x C for yield (Fig. 2).

In 2001, both biomass and yield were lower than in 2000 and they were significantly higher in CT than in VT. The effect of N fertilization was not significant, no matter the moment and dose applied.

At tillering there were no significant differences in tillers m^{-2} between N fertilization treatments for either of the tillage systems. However, the higher tiller number was registered when fertilizer was applied, mainly, in a single dose at sowing (940, 996 and 952 for N0, N1 and N2 in CT and 817, 950 and 898 for N0, N1 and N2 in VT, respectively).

At anthesis, there were no significant differences in biomass for tillage systems, fertilization treatments or cultivars.

At maturity (Table 4), biomass production was affected for tillage systems and cultivars and no response for the nitrogen fertilization was found. The highest values were obtained in CT for BP cultivar. The ears m^{-2} and yield showed a similar behavior to that of biomass. A higher increase under CT was obtained and no response was found for the N applied. HI did not show differences for any case. The increase in yield under CT was obtained through ears m^{-2} and grains m^{-2}. The grains m^{-2} was modified by fertilization treatments, no matter the time and dose applied. KW was smaller under N fertilization.

On average, N application increased yield in 10 kg and biomass in 30 kg by kg of N applied for 2000 and 4.5 kg and 10 kg for 2001, respectively (Table 5).

Table 6: Availability of NO_3^- under two tillage systems: mouldboard plough (CT) and chisel plough (VT), for different phenological stages, 2000 and 2001

		2000 (ppm)		2001 (ppm)	
Phenological stages	Fertilization	CT	VT	CT	VT
Before sowing:		76	47	69.5	42.75
End of tillering:	N0	49	26	42.5	17.50
	N1	56	34	48.0	19.50
End of stem elongation:	N0	19	18	10.0	7.50
	N1	21	20	10.0	8.00
Anthesis:	N0	14	15	7.0	7.50
	N1	19	18	11.5	9.50

DISCUSSION

In spite of the early sowing date, tiller number was lower in 2000 than in 2001. This could be due to a higher tiller rate day^{-1} in 2001 caused by higher temperatures and radiation than in the previous year. This situation was not reflected, at maturity, in biomass production or yield. In 2000, at maturity, no significant differences in biomass or grain production between tillage systems were found. This could be due to a decrease in the differences in nutrients availability between CT and VT at late growing stages (Table 6) as it was suggested by [16]. This was also corroborated by total N accumulation, which at maturity did not differ between tillage systems and was positively associated with biomass (r = 0.86). Both tillage systems responded to N fertilization, no matter the moment of application. This effect was greater for VT than for CT, suggesting a greater N deficit in the first case, characteristic of non-conventional tillage [17]. Biomass was positively associated with yield (r = 0.85). The N uptake pattern in wheat indicates that at the end of tillering, the cover reached by the crops determines a high growth rate that is translated in a marked increase in N absorption [18]. On the basis of this pattern, a higher effect of nitrogen fertilization can be expected at split dose versus single dose at sowing. However, effect of N fertilization was independent of the moment of application. This behavior could be associated with environmental conditions during the growing or with intrinsic characteristics of cultivars. The grain yield was positively associated with grains m^{-2} and ears m^{-2} (r = 0.96 and r = 0.78, respectively). The higher grain performances and higher biomass production in 2000 compared to 2001 can be associated with a suitable water availability, in spite of being smaller than the long-term mean for the region. Also, rainfall presented an appropriate distribution, concentrated previous to crop initiation and from stem elongation to maturity. Such situation allowed to satisfy crop water requirements, being in addition propitious for the mineralization processes and N use efficiency. This was observed in total N accumulation of the crop, that was higher when fertilizer was added. Cultivar yield did not show significant differences as a result of certain compensation between their components. Although BCH produced greater biomass, its HI was smaller and, consequently, yield did not increase. BP was more efficient in biomass partition. Interaction F x C was significant as a result of differences in plant structure and heading dates of the cultivars. BCH had greater increase for N1 treatment than BP. This could be associated to BP smaller requirements than BCH due to its intrinsic characteristics and, on the other hand, to the greater BCH canopy, which was manifested from the first growing stages.

In 2001, biomass and yield were lower in LV treatment. The lack of response to N fertilization could be caused by the leaching of N applied due to the high rainfall after fertilizer application and especially at the end of tillering and stem elongation. Although NO_3^- availability at sowing was good, especially for CT, there was an ulterior decrease in nutrients availability due to unfavorable rainfall distribution. For that reason, N fertilization did not increase either the survival of tillers (ears m^{-2}) or the biomass production. This limited availability of nitrogen was accentuated in VT treatment. In this system, the soil humidity increased and temperature decreased due to the presence of stubble in surface during the crop cycle. Thus, although tiller number increased initially, the biomass production and yield at maturity were lower than in CT.

The lack of response to N fertilization was shown through the NUE for both biomass and yield, which were lower than in 2000. Also, N accumulated in the plant was lower than in the previous year and not affected by additional N.

Even though grains m^{-2} is the variable that better explains grain yield, changes in grain weight can affect crop yield. Grain weight is determined by biomass accumulation and grain filling period duration, that also depends on the genotype and environmental conditions. Late sowing date could have caused a shortening of the crop ontogenic stages, being the grain filling period harmed, not only by its shorter duration but also by the higher temperatures, which together with the lower NO_3^- availability, with respect to the previous year, was decisive for crop productivity.

In 2001, although BP was sowed outside its optimum date, it showed sufficient plasticity and demonstrated a greater yield (although not statistically significant) than BY.

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