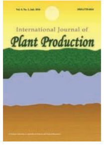

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Strip tillage and sowing: is precision planting indispensable in silage maize?

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Abstract

This work was aimed at assessing whether in silage maize it is possible to replace precision planting with a volumetric seeding in the perspective of developing hybrid machines to strip till and sow both high density crops like winter cereals and low density crops like maize. This in order to reduce the number of machines in the farm, simplify logistics and reduce amortization costs. Two experiments were carried out in 2014 and 2015. In the first year, two tillage-sowing treatments were compared in a randomized block design with 5 replicates: 1) strip-tillage plus volumetric band (0.1 m wide) seeding (ST-VBS) carried out by a Claydon Hybrid 6M at inter axle spacing of 0.6 m and with 35 kg ha^{-1} of seeds; 2) no-tillage plus precision line planting (NT-PLP) carried out by a sod drill Kinze 3100 at row distance of 0.71 m. In the second year, the same two treatments of 2014 were applied, but a third tillage-sowing treatment was also included: strip tillage plus precision line planting (ST-PLP) carried out by a strip tiller Khun Striger at inter axle spacing of 0.71 m plus the Kinze 3100, respectively, in two passages. In 2015, a randomized block design with 3 replicates was adopted. Both in 2014 and 2015 treatments did not differ significantly for actual seeding density and final plant density, individual plant growth indices (plant height, stem diameter, FW, DW) at early stem elongation, flowering and final harvest, neither for total FW and DW yield, nor for biomass composition (starch, protein, lipids, fibre and ash concentrations) at harvest. Results demonstrate that a silage maize crop can perform successfully when established by strip tillage associated with volumetric band seeding. If similar results are demonstrated for high density crops, this will support the strategy of developing hybrid machines to strip till and sow both high density crops and silage maize, which is relevant for many farming systems devoted to forage and biomass production for agro-energy purposes.

Keywords: Conservation tillage; Seedbed; Seeder; Hybrid machine.

Introduction

Strip tillage is widely adopted overseas (Morrison, 2002; Licht and Al-Kaisi, 2005a; Hosking and Bloomer, 2006; Mitchell et al., 2009; Nowatzki et al., 2011) and has been recently introduced and tested in Europe (Morris, 2007; Gemtos et al., 2008; Sessiz et al., 2008), including Italy (Trevini et al., 2013), where it has been proven to allow seedbed tilth and grain maize performance similar to minimum tillage, but with lower soil disturbance and costs. In recent models, strip tillers and seed drills are combined in hybrid machines in order to allow seedbed preparation and sowing and also fertilizer placement, in just one pass (Vance et al., 2014; Yang et al., 2016). This helps sowing at due time, with suitable soil temperature and water availability for a successful crop establishment (Vance et al., 2014).

Nonetheless, hybrid machines are costly and should be amortized by using them over a large acreage. This could be achieved by using the same machine for all crops in a farm. However, wheat and other high density crops are normally sown in narrow-spaced rows (e.g. 0.1-0.2 m) by traditional seeders (Paulsen, 1987), so that tilling all the strips (supposing to equip the strip-tiller with so many tines) would disturb the whole area as it is for the broadcast minimum tillage (Figure 1 A, left). On the other hand, maize and other low density crops are sown in wide-spaced rows (e.g. 0.4-0.8 m) by precision drills (i.e. planters) (Liu et al., 2004; Qi et al., 2015; Yang et al., 2016), which allow to place seeds at a fixed distance along a line (Figure 1 A, right). This stands also for no till planters (Liu et al., 2004). A solution for developing a hybrid machine to strip-till and sow all crops could be to adjust row spacing (i.e. increase row spacing for high density crops and reduce it for low density ones) together with moving from line to banded seed placement (Figure 1 B). This can be supposed not to affect crop performance for high density crops (Hecht et al., 2016). In fact, there is literature on the use of wider row spacing for winter cereals (Hussain et al., 2003; Leithold and Becker, 2011; Bostrom et al., 2012), where the seed density along the row can be increased up to two-fold with no relevant drawbacks on crop yield (Schillinger and Wuest, 2014). This because winter cereal crops have a plastic behaviour thanks to the variation in the number of tillers per plant in response to the space and resources available (Satorre and Slafer, 1999; Johnston and Stevenson, 2001; Hecht et al., 2016). There are also researches on temporary intercrops where the winter cereal is sown at double density along the row and alternated with rows of the companion species such as faba bean, which demonstrate that the winter cereal can yield not markedly less than in the pure crop (Tosti et al., 2016), so that this strategy is likely to be adopted in organic wheat production (Benincasa et al., 2016). In our hypothesis, the winter cereal would be grown alone and the band seeding would guarantee a higher seed spacing, so there is no reason to expect a lower yield.

As far as low-density crops are concerned, in a few, precision planting seems not questionable, such as in sugarbeet, to obtain taproots with uniform size (Panning et al., 2000; Smith et al., 2003; Findura et al., 2008), whereas in many others, such as silage maize, banded seed placement should not give relevant drawbacks or could even benefit crop performance. The random placement of seeds within bands could be hypothesized to work like a twin-row arrangement which has been proposed since many years ago as an alternative for maize (Karlen and Camp, 1985a; Widdicombe and Thelen, 2002; Robles et al., 2012). In fact, while in wide-spaced rows seeds are narrow-spaced along the row, the random distribution within the band, given the same plant density, would help tend to plant equidistance, thus reducing intra-specific competition. More in general, in some crops plant spacing might result less crucial than supposed. For example, it has been found that changing row spacing (and thus plant spacing along the row) in maize from normal to narrow spacing to twin rows did not affect significantly crop yield (Nelson and Smoot, 2009) or even increased it (Cox et al., 2006).

In addition, an extremely precise seed spacing may be superfluous if the seedbed is not perfectly suitable for crop establishment, as it may occur when the seedbed is prepared with conservative techniques (DeJong-Hughes and Vetsch, 2007; Stagnari et al., 2009; Grisso et al., 2009; Yang et al., 2016). In such cases, in fact, plant emergence may be reduced and thus the geometry of plant arrangement may come out different from planned.

This work was aimed at evaluating the performance of silage maize established by a hybrid strip tiller equipped with volumetric band seeder, as compared to the crop established by either a no-till precision planter or a strip tiller plus a precision planter.

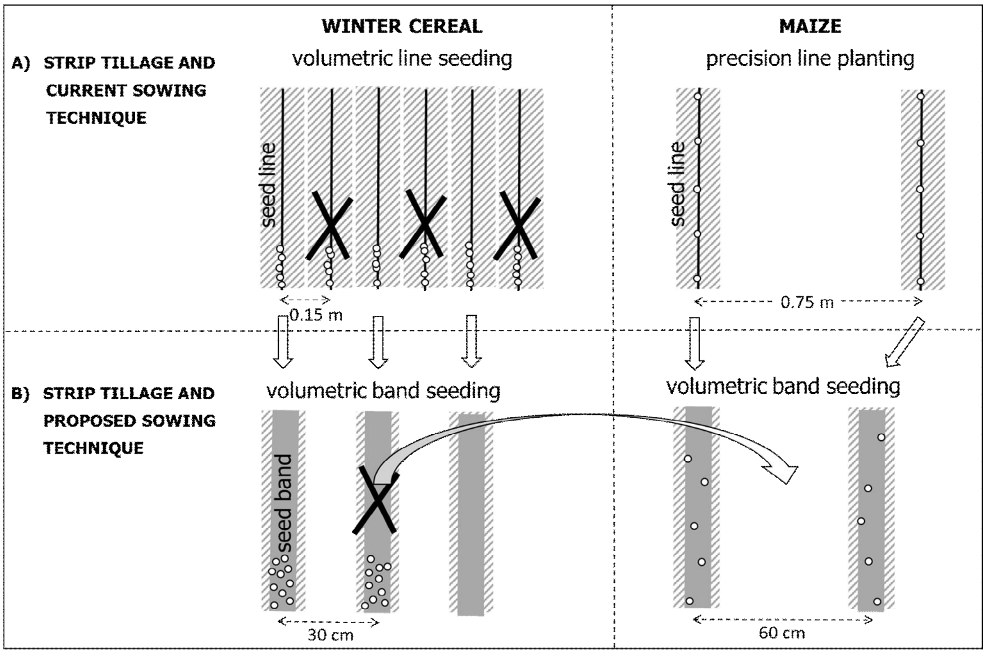

Figure 1. Representation of strip tillage (with 0.15 m wide strips, represented by oblique-weft rectangles) and sowing of a winter cereal (left) and maize (right) as it would be realized according to the current sowing technique (A) and according the proposed solution (B). Small circles represent seeds. In A, the winter cereal is sown by a volumetric seeder in rows about 0.15 m apart and the strip tillage in correspondence of any row would actually result in a broadcast tillage, whereas maize is sown by a precision planter in rows about 0.75 m apart along widely spaced tilled strips. In B, both crops are sown by a same volumetric seeder in about 0.1 m wide bands in correspondence of tilled strips whose centres are about 0.30 m apart in case of winter cereals and about 0.6 m apart in case of maize. In case of hybrid machines, switching from wheat to maize would be easily realized by just removing one tin and closing the correspondent seed line. The band seeding is supposed to guarantee a certain seed spacing thanks to random seed fall.

Materials and Methods

Two experiments were carried out in 2014 and 2015, in a plain land of the farm Fattorie Novella Sentieri, located in Cappella Cantone, Northern Italy, middle Po valley (45° 13’ N, 9° 51' E, 55 m s.l.m.), a farm of over 700 ha specialized in silage crops (mainly maize and triticale) to support in-farm pig and biogas production. The soil of 2014 was sandy-silty (58% sand, 29% silt, 13% clay), with 1.7% organic matter and high contents of extractable P (460 mg kg^{-1}) and exchangeable K (313 m kg^{-1}). The soil of 2015 was not analyzed, however the field was close to that used in 2014 and fields are quite homogeneous there. About the recent history of the fields that hosted the experiments, maize in 2014 followed a triticale crop, the seedbed preparation of which had been carried out by minimum tillage, whereas maize in 2015 followed a maize crop, the seedbed preparation of which had been carried out by strip tillage. Silage maize, hybrid DKC 4795 (FAO 400) was sown on 15 May 2014 and 22 April 2015. In 2014, two tillage-sowing treatments were compared: 1) strip-tillage plus volumetric band (about 0.1 m wide) seeding (ST-VBS) carried out with a Claydon Hybrid 6M, at inter axle spacing of 0.6 m and with 35 kg ha^{-1} of seeds (i.e. about 11.5 seeds m^{-2}); 2) no-tillage plus precision line planting (NT-PLP) carried out with a sod drill Kinze 3100, at row distance of 0.71 m and nominal seed density of about 11 seeds m^{-2}. In 2015, a third tillage-sowing treatment was included: strip tillage carried out with a strip tiller Khun Striger at inter axle spacing of 0.71 m plus precision line planting with the Kinze 3100 (ST-PLP) (set for the same seed density as in NT-PLP), in two passages. A randomized block design was adopted in both years, with 5 replicates in 2014 and 3 replicates in 2015.

The Claydon Hybrid M6 is a three-point-hitch hybrid machine that prepares the seedbed along strips and sows in one pass. It consists of 19 units 0.30 m apart (inter axle), each having a front tine that creates a strip up to 0.20 m deep and a seeding coulter integrated by a pneumatic pipe line that drives the seed into the soil along a 0.10-0.15 m wide band. A 0.60 m spacing (inter axle) can be obtained by removing one tine and closing one seeding unit every two. The seeding depth is adjusted by three wheels with an extensible rod. Batter boards and springs in the back side level the soil after seeding. Seed distribution is carried out by a volumetric system (Jorgenson, 1988).

The Kinze 3100 is a three-point-hitch sod drill with 8 seeding units 0.70 m apart. Every unit consists of two hoppers, one for the seeds and one for fertilizers or chemicals, a row cleaner (i.e. a couple of wheels integrated with a cutting disc both linked to an oscillating frame compensated by a spring) to clean the seeding line from clods and residues, a double disc opener to sow and a rubber wheel to adjust seeding depth and, at the back side, two adjustable press wheels to close the seeding furrow. The seed distribution is carried out by a mechanic system.

The Kuhn Striger is a three-point-hitch strip tiller. Each working unit consists of a sequence of a cutting disc, a row cleaner and a shank with tine plus a couple of side closing discs (to contain the clods within the strip). A final roller breaks clods, levels and firms the seedbed. Loading springs and a setting system for each tool allow to adjust load and tool arrangement according to soil conditions. The tiller was set for a nominal tine working depth of 20 cm.

In all treatments, the planned seed density was around 11 seeds m^{-2}. In both years each plot was 11.2 or 12 m wide (i.e., 2 passages of 5.6 m or 6.0 m each for the Kinze 3100 and the Claydon Hybrid M6, respectively) and 100 m long. A total of around 200 kg N ha^{-1} was applied, part as digestate (40 m^3 ha^{-1}) derived from the in-farm biogas system and part as mixed organic manure (300 kg ha^{-1} with 21% of N). Crop water requirements were completely met by irrigation with a pivot system.

In both years, actual sowing density was measured in two non-contiguous rows per plot, by carefully digging one-meter long trench to unveil seeds in their own position. Total above-ground fresh biomass yield was determined at final harvest (27 August 2014, 13 August 2015) by harvesting the whole plots. Just before final harvest, crop density (plants m^{-2}) was determined by counting plants along a 4-meter length in two non-contiguous rows per plot, whereas individual plant fresh and dry weight was determined by sampling 10 of those plants per plot (five per row) and oven drying subsamples. Quality parameters (i.e. starch, lipids, proteins, ADF, NDF, ashes) of biomass subsamples were measured by a NIR system at the Nutristar lab (Nutristar Spa, Italy) in 2014 and by a portable device (Agri NIR, DEKALB, Italy) in 2015, after calibration. In 2015, additional measurements to focus on plant growth evolution were carried out by destructive samplings of 10 plants per plot (five per row in two non-contiguous rows per plot) at early stem elongation and flowering, with plant fresh and dry weight determined as above for the sampling at final harvest.

Rainfall and temperature data throughout the two growing seasons were recorded by an automatic weather station located in Trigolo (Province of Cremona), less than 10 km far from the experimental site.

Data within each year we subjected to a fixed model ANOVA and means were subjected to multiple comparison testing by using Fisher's LSD. The R statistical environment (R Core Team, 2014) was used to perform the analysis.

Results and Discussion

Season weather in the two years was much different, colder and wetter in 2014 than in 2015, (Figure 2). This allowed to test the tillage-sowing technique in different conditions, although irrigation allowed to compensate for the different rainfall.

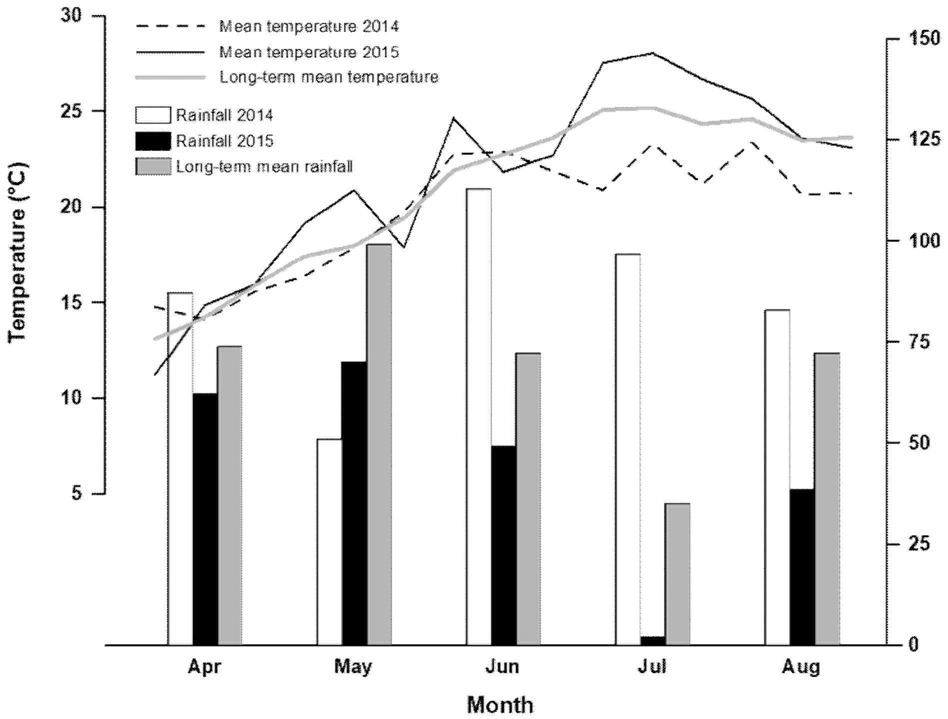

Figure 2. Monthly cumulated rainfall and 10-days mean temperature trend during the maize growing season in 2014 and 2015 and in the long-term (2010-2015) as recorded by an automatic weather station located at Trigolo (Province of Cremona), less than 10 km far from the experimental site. The weather station was installed during the season 2009.

As far as the maize crop performance is concerned, both in 2014 and 2015 most of differences between treatments were not significant. The seed density resulted slightly higher than planned in 2014, especially for NT-PLP, whereas it was slightly lower for ST-VBS in 2015 (Table 1). The lack of precision can be explained for NT-PLP with the mechanical seed distribution used by Kinze 3100, for ST-VBS with the volumetric distribution used by the Claydon Hybrid M6 (Jorgenson, 1988). Within each year, however, differences between treatments in seed density were not significant, due to the variability recorded between plots, especially in ST-VBS (from 8.9 to 16.1 seeds m^{-2} in 2014 and from 8.6 to 10.7 in 2015). This variability is intrinsic of the volumetric seeding (i.e., it was not due to a bad seeder setting and would occur anyway), so it has to be taken as an evidence of the experiment. It actually indicates that the volumetric seeding in a low density crop like maize may not guarantee a regular seed distribution. Nonetheless, the overall mean seed density can be considered adequate for a class 400 silage maize in the environment of the experimental site, considering that the silage crop density is generally higher than that of the grain crop (Testa et al., 2016). Differences in seed density resulted in paired differences in the crop density at final harvest (Table 2), although also these differences were not significant in both years. In turn, differences in crop density were compensated for by differences in individual plant growth (Table 2). The lower the plant density, the higher the individual plant growth in terms of either plant height or stem diameter or DW at final harvest. This stands for both between-year and within-year comparisons. However differences were always not significant, except for plant height in 2014, which was higher in ST-VBS. Measurements on the individual plant growth carried out in 2015 at early stem elongation (June, 8th) and flowering (July, 22nd) (Figure 3) indicate that differences recorded at final harvest stood throughout the whole crop cycle, but were never significant, except for the individual plant FW at flowering. Overall, the main noticeable outcome was a higher variability between plots in ST-VBS (data not shown), the main responsible for the lack of significance in the differences between treatments. The above said compensative trend between individual plant growth and crop density resulted in a fresh biomass yield for silage never statistically different (Table 3). The dry matter percent concentration of biomass was not statistically different in 2014, statistically different in 2015, but differences partly counteracted the differences in fresh biomass, so that the dry biomass yield (as it can be easily calculated from data in Table 3) was not statistically different in both years.

Table 1. Actual seed density in 2014 and 2015 and seed depth in 2015 for silage maize established by no tillage plus precision line planting (NT-PLP), strip tillage plus volumetric band seeding (ST-VBS) and strip tillage plus precision line planting (ST-PLP). Probability stands for type 1 error rate of F tests in ANOVA.

Treatment	2014	2015	
	Seeds m^{-2}	Seeds m^{-2}	Seed depth (mm)
NT-PLP	13.4	11.0	45
ST-VBS	11.9	10.0	46
ST-PLP	-	11.3	58
Prob. F	0.223	0.408	0.022
$LSD_{0.05}$	3.12	2.49	0.81

Table 2. Actual crop density, plant height, stem diameter and individual plant DW at harvest for silage maize established in 2014 and 2015 by no tillage plus precision line planting (NT-PLP), strip tillage plus volumetric band seeding (ST-VBS) and strip tillage plus precision line planting (ST-PLP). Probability stands for type 1 error rate of F tests in ANOVA.

Treatment	2014				2015			
	Crop density	Plant height	Stem diameter	Plant DW	Crop density	Plant height	Stem diameter	Plant DW
	(plants m^{-2})	(m)	(mm)	(g plant^{-1})	(plants m^{-2})	(m)	(mm)	(g plant^{-1})
NT-PLP	13.0	2.56	19.7	199.8	8.9	2.97	23.2	297.6
ST-VBS	11.3	2.77	21.1	250.1	8.0	3.07	25.2	342.2
ST-PLP	-	-	-	-	9.6	3.06	22.3	278.5
Prob. F	0.265	0.026	0.4	0.051	0.055	0.522	0.187	0.191
LSD$_{0.05}$	3.68	0.178	3.73	50.60	1.29	0.274	3.61	77.22

Table 3. Fresh biomass yield and dry matter concentration at harvest for silage maize established in 2014 and 2015 by no tillage plus precision line planting (NT-PLP), strip tillage plus volumetric band seeding (ST-VBS) and strip tillage plus precision line planting (ST-PLP). Probability stands for type 1 error rate of F tests in ANOVA.

Treatment	2014		2015	
	Yield FW t ha^{-1}	Dry matter %	Yield FW t ha^{-1}	Dry matter %
NT-PLP	74.7	34.9	72.7	36.6
ST-VBS	85.9	33.2	66.7	41.1
ST-PLP	-	-	70.5	38.2
Prob. F	0.402	0.423	0.574	0.040
LSD$_{0.05}$	29.23	4.78	14.72	3.29

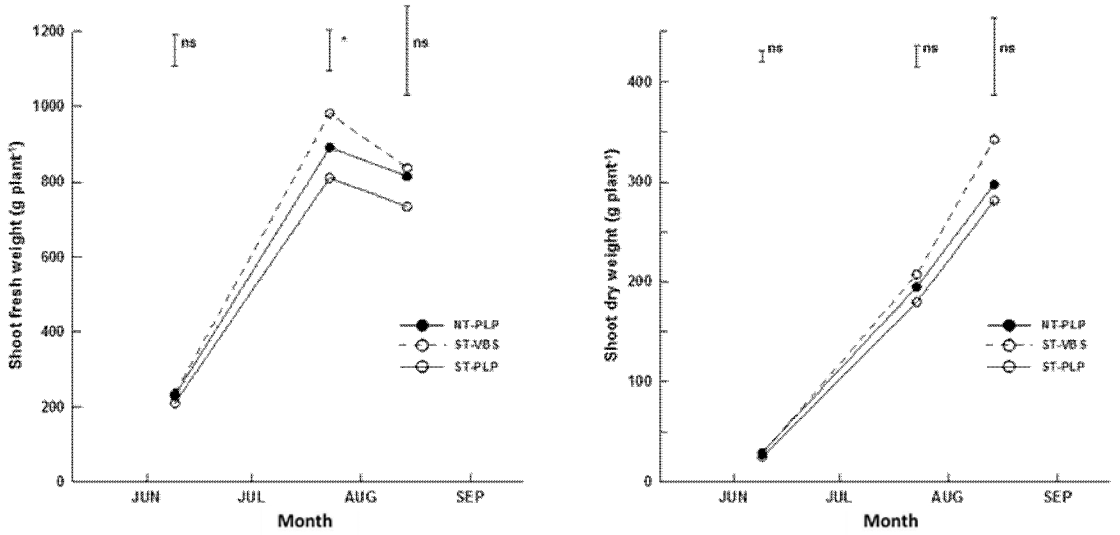

Figure 3. Individual plant fresh (left) and dry (right) biomass accumulation in 2015 for silage maize established by no tillage plus precision line planting (NT-PLP), strip tillage plus volumetric band seeding (ST-VBS) and strip tillage plus precision line planting (ST-PLP). Differences between treatments were always not significant except for shoot FW at flowering ($P<0.05$). Vertical bars represent LSD at $P=0.05$.

The lack of difference between the tillage systems confirms findings obtained either in the same (Trevini et al., 2013) or in other environment (Licht and Al-Kaisi, 2005b). However, the above-ground biomass yield obtained with all treatments was higher than that reported by Trevini et al. (2013). It is worth to notice that, standing the lack of difference between the strip- and no-tillage, the latter would come out more convenient, because it implies lower costs. However, no tillage is expected to give increased cons with repeated application along years, such as weed proliferation, soil compaction in shallow layers, phosphorus deficiency in deep soil layers and more uncertainties in crop establishment due to delayed soil heating (and thus germination) and uneven plant emergence (Vyn and Janovicek, 2001; Licht and Al-Kaisi, 2005b; DeJong-Hughes and Vetsch, 2007; Trevini et al., 2013). With this regard, it has to be considered that our positive outcome observed with the no-tillage was obtained in soils where seedbed preparation in the previous years had been carried out by minimum or strip tillage (see Materials and Methods).

The additional ST-PLP treatment in 2015 allowed to separate the effect of tillage from that of sowing. Comparing data obtained in ST-VBS and ST-PLP we can conclude that, in a seedbed prepared by strip tillage, the silage maize crop performed substantially the same with either volumetric band seeding or precision line planting. The little effects of the sowing treatments on individual plant growth and crop yield was somehow expected because, overall, plant spacing and density was not much different between treatments and it has been demonstrated that, within a certain range of row spacing and plant density, yield is not substantially affected by row and plant arrangement (Nelson and Smooth, 2009; Budakli-Çarpici et al., 2010; Gözübenli, 2010).

The main drawback of the volumetric band seeding could be related to the irregular seed distribution which may imply a less uniform plant size and ripening for silage and biogas processing. However, our data indicate that differences in biomass composition between treatments were not statistically significant in both years and not relevant anyway (Table 4). This would confirm than for a given crop density, plant arrangement has only marginal effects on biomass composition and fibre content of maize (Karlen et al., 1985b; Cox et al., 2006; Budakli-Carpici et al., 2010). According to data in Table 4, the biomass composition can be considered as adequate for both animal feeding and biogas production (Schittenhelm, 2008; Aioanei and Pop, 2013; Feedipedia, 2016).

Table 4. Biomass composition at final harvest for silage maize established in 2014 and 2015 by no tillage plus precision line planting (NT-PLP), strip tillage plus volumetric band seeding (ST-VBS) and strip tillage plus precision line planting (ST-PLP). Probability stands for type 1 error rate of F tests in ANOVA.

Treatment	Biomass composition (% on DW)											
	2014						2015					
	Starch	Protein	Lipids	ADF	NDF	Ash	Starch	Protein	Lipids	ADF	NDF	Ash
NT-PLP	25.0	6.7	1.9	26.2	44.0	5.2	36.2	6.7	2.8	22.5	39.0	3.9
ST-VBS	27.5	6.6	2.3	25.1	42.7	4.7	35.2	6.6	3.0	24.9	41.8	3.7
ST-PLP	-	-	-	-	-	-	39.2	7.0	3.3	21.4	42.5	4.6
Prob. F	0.247	0.717	0.066	0.397	0.537	0.067	0.116	0.651	0.712	0.111	0.222	0.099
$LSD_{0.05}$	4.60	0.74	0.40	2.78	4.73	0.55	4.18	1.22	1.61	3.49	4.82	0.89

Conclusions

Results, obtained in two seasons with different weather patterns, allow to conclude that a silage maize crop can perform successfully when established by strip tillage associated with volumetric band seeding. If similar results are demonstrated, as expected, for high density crops like winter cereals, the same hybrid machine could be used to strip-till and sow both them and silage maize, with obvious environmental and economic benefits. In fact, this would allow to adopt a conservative technique while containing the machinery pool and would give an additional advantage in that it would allow to optimize operation management in the farm and sow at due time, which is crucial in case of rapid sequence of crops, as it is for rotations devoted to forage and biogas production.

Further studies are needed to assess whether similar success is achievable in grain maize or other wide-spaced crops and in soils with different texture and organic matter content.

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