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Effects Of Grass-Clover Silage Quality And Application Rate On Organic Potato Performance

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Abstract – Most organic farmers use animal manure as a source of crop nutrients. However, recent experiments have revealed that cut-and-carry fertilisers like grass-clover silage may provide a viable alternative. The objective of the current study was to investigate the performance of an organic potato crop on a sandy soil fertilised with grass-clover silages differing in C: N ratio (16, 17, 22 and 24) and nitrogen application rate (0, 57, 113 and 170 kg N ha^{-1}). The total tuber yield was highest for the silage with a C: N ratio of 16 (44 Mg ha^{-1}). However, the yield difference with the silage having a C: N ratio of 24 was not more than 10% (40 Mg ha^{-1}). In terms of N application rate, there was a linear increase in yield with N rate while the share of marketable potatoes also improved with N-rate. In the non-amended control, the potato yield was 30.5 Mg/ha, whereas with 170 kg N ha^{-1} this was 47.5 Mg/ha. The agronomic nitrogen efficiency (ANE; kg tubers per kg applied N) was not affected by either the C: N ratio or the N application rate. However, ANE values tended to be highest for the C: N ratio of 16 (115 kg tubers/kg N) and an application rate of 170 kg N ha^{-1} (100 kg tubers/kg N). Overall, crop performance and N-utilisation were more than adequate which underlines that grass-clover silage can be considered as a potential substitute for animal manure sources.

Keywords – : Organic potato production, C: N ratio, nitrogen application rate, potato yield, agronomic nitrogen efficiency.

I. INTRODUCTION

Potatoes (*Solanum tuberosum L.*) are one of the most important crops contributing to the world's food requirement (Gebru et al., 2017). Potatoes are the world's third largest food crop after rice and wheat (Devaux et al., 2020). In the Netherlands, the area allocated to organic potato production in 2020 amounted to 2054 hectares, which translates to only 1% of the total area under organic farming. The yield of organic potatoes shows large differences from year to year. As an example, the average organic potato yield in the Netherlands was 51 Mg ha^{-1} in 2017, whereas this was only 24 Mg ha^{-1} in 2016. However, the average conventional potato yields in the same years were 53 and 45 Mg ha^{-1}, respectively. The main reason for these large differences could be attributed to the severe incidence of potato late blight in the year 2016. Since the use of chemical fungicides is not allowed in organic production systems (Ghorbani et al., 2012), this poses a major challenge for organic producers.

In the context of organic production, organic fertilizers are essential to improve land productivity as they form the main source of affordable nutrients required to warrant adequate crop uptake (Ahmed et al., 2016). In spite of that, the decomposition rate of organic amendment depends on the nature of the organic materials and their subsequent nutrient release patterns. Besides, in Dutch organic agriculture, some farmers which have limited access to animal manure may apply organic plant-based pellets instead. A recent development in some countries is the use of fresh or ensiled cut-and-carry fertilizers based on harvested grass-clover herbage with the aim to enhance both soil and soil quality (Scholberg et al., 2009).

The N accumulation in grass-legume mixtures varies depending on the sown plant species and the actual growing conditions. In a field experiment carried out by Rasmussen et al. (2012) the N accumulation ranged from about 300 kg N ha^{-1} in grass-white clover mixtures up to 400 kg N ha^{-1} in alfalfa crops and grass-red clover mixtures. However, the contribution of grass-clover for N supply to the sown or planted crop depends considerably on the composition and the incorporation time of the used plant material source (Askegaard and Eriksen., 2007; Ball et al., 2007).

Last but not least, plant-based fertilizers are used to avoid the contamination risk of edible plant products with animal slurry (Sorensen and Thorup-Kristensen., 2011). Moreover, plant-based N-fertilizers tend to have favourable N: P ratios (>2) which better match targeted nutrient balances. Animal manures, on the other hand, tend to favour hyperaccumulation of phosphorus which is undesirable in the context of increasingly stringent environmental regulations.

To ensure optimal crop performance, plant-based fertilizer material must be rich in nutrients, well-kept, and carefully transported, evenly applied, and superficially incorporated into the soil. Mobile green manures consist of plant materials which are mown, stored, and applied as an alternative to chemical and animal fertilisers Results from different studies have revealed that green manures with relatively high nutrient concentrations and low C: N ratio's can significantly increase the crop yield in organic crop production systems (Niemsdorff and Muller., 2006; Thorup-Kristensen., 2006; Elfstrand et al., 2007; Sorensen and Thorup Kristensen., 2011). Green manure is applied as fresh or dried plant material. However, the fresh plant material tends to be bulky and is not easy to handle during application and first needs to be decomposed before nutrients are available to the crop (Sorensen and Thorup-Kristensen., 2011). Decomposition of plant materials is mostly influenced by soil humidity and soil temperature. Besides, the ratio's between N, P, S and C, cellulose, lignin and other resistant constituents influence their decomposition rate (Müller and von Fragstein Und Niemsdorff., 2006; Ha et al., 2008). Therefore, N availability rather than the amount of applied N causes differences in the final yield of cultivated crop (Sorensen and Thorup-Kristensen., 2011). This is due to relatively slow N release of plant residues caused by microorganisms. Animal-based products contain a substantial amount of inorganic N-forms that are partly soluble and mostly readily available (Olesen et al., 2009). In plant-based materials most of the nitrogen is still present as part of organic compounds which needs to be decomposed first (Scholberg et al, 2009). Soil-borne microorganisms (fungi and bacteria) assimilate especially readily available N-forms which are required for their own growth and multiplication before it subsequentially becomes available in mineral form which is suitable for uptake by the sown or planted crops. For this reason, low values of the C: N ratio in the applied plant material may result in augmented N release rates and an improved initial crop growth (Sorensen and Thorup-Kristensen., 2011).

One of the major current concerns is soil pollution and/or contamination due to the use of excess chemical fertilizers and pesticides (Tabatabai et al., 2014). Use of solid cattle manure in organic agriculture was found to be the most effective way to increase the crop yield. However, the use of cattle slurry transmits pathogens that can contaminate edible plant products. Therefore, plant-based fertilizers may provide a promising alternative to avoid such risk (Sorensen and Thorup-Kristensen., 2011). Cut-and-curry fertilizers were shown to provide nutrients matching closer with the uptake pattern in time of the sown or planted crops. As a result, the risk of N leaching and volatilization will be reduced throughout the growth cycle of the used crop (Scholberg et al., 2009). Cut-and-carry fertilizers may therefore be a promising substitute for cattle slurry. The purpose of this study was therefore to assess the performance of a potato crop fertilised with grass-clover silage across both a range of N rates and varying C: N ratios.

II. MATERIALS AND METHODS

2.1 Experimental site

The experiment was conducted on the certified organic Droevendaal Research Facility of Wageningen University and Research. This farm covers 50 ha and its climate is temperate oceanic with an annual mean temperature of 11ºC and an annual mean precipitation of 830 mm. The soil type is silty sand with 3% clay (< 2 µm), 15% silt (2 - 50 µm) and 82% sand (> 50 µm). The weather conditions during the experiment are shown in Figure 1.

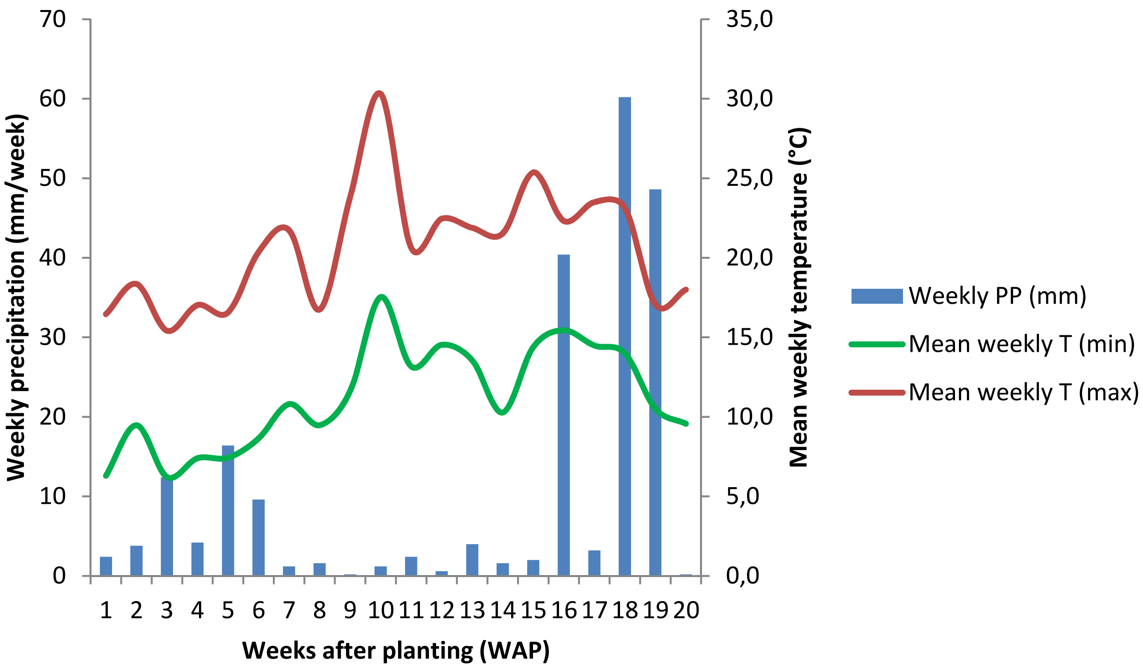

Fig. 1 Weekly precipitation (mm/week) and average temperature (°C) during the potato production period (4/22/2015 - 9/10/2015).

The experiment was designed as a Randomized Complete Block Design (RCBD) with four replicates and was conducted between 22 April 2015 and 10 September 2015. The experiment included two factors: C: N ratio and N application rate of the plant-based fertilisers. Both factors had four levels. Including the control, the experiment consisted of 13 treatments, which resulted in 52 plots. Besides, there was also a supplemental control plot (F14) which was used for additional measurements. The experimental unit was a plot covering 45 m^2 (15 m × 3 m), with four rows of potatoes.

In 2014, grass-clover fields were harvested four times. After mowing, the harvested grass-clover material was dried on the field for one to three days. Thereafter, the grass-clover was packed and stored as plastic-wrapped round bales to be ensiled during the winter period. Before planting the potatoes, the grass-clover silages were chopped and spread manually at application levels of 57, 113, and 170 kg N ha^{-1}. An innovative ecoplough (Kouwenhoven et al., 2002) was used to incorporate the grass-clover silages at a soil depth of about 15 cm. The potato variety used was Carolus which is a late organic variety with a good resistance to *Phytophytora infestans* (Agrico, 2015). The planting of the potato tubers took place on 22 April 2015, with an inter-row spacing of 0.75 m and an intra-row spacing of 0.29 m. This resulted in a targeted plant population of about 25,000 plants/ha (Agrico, 2015).

2.2 Field measurements and laboratory analysis

Pre-experimental analysis

Determination of chemical composition of grass-clover silage

In order to know the exact C: N ratio of the grass-clover silages they were analysed on 11th March 2015. For this purpose, dry matter, organic matter, ash, total carbon and total nitrogen of the silage material were measured using standard procedures (Drakopoulis et al., 2014) in order to determine the exact C: N ratio of each of the silages.

Initial soil analysis

Before applying the silages, soil analysis was conducted to determine the initial soil status. In each experimental block, 10 samples were collected in the 0-30 cm soil layer according to a zig-zag pattern by using a soil auger. Hereafter, the soil samples from each block were mixed to obtain a single sample. From every sample a sub-sample was taken and analysed for their contents of SOM, N, P, and K. Besides, the soil-pH (H_2O) was determined using standard procedures (Drakopoulis et al., 2014).

Crop performance measurements

In order to obtain representative measurements while avoiding border effects, two internal rows were used for determining plant emergence, leaf area index, leaf chlorophyll content at 7, 9, 11, and 13 weeks after planting. At the end of the experiment, total tuber yield, tuber grading, tuber quality and the agronomical nitrogen efficiency were determined using procedures outlined by Drakopoulis et al. (2014). In order to avoid border effects, the two external rows and the 3 first and 3 last plants of the two internal rows were excluded for performing yield measurements. For the destructive measurements sampling of both the above-ground fresh weight and the above-ground dry weight. Sampling took place at 8, 10, and 14 weeks after planting. To this end, 6 plants located behind the 3 first plants and before the 3 last plants in two internal rows were harvested. The net plot had two inside rows where the plants were spaced at a distance of 0.75 m in the inter-rows and 0.30 m in the intra-rows.

Statistical analysis

Data analysis was conducted by using Genstat 17th edition (VSN International Ltd., Hemel Hempstead, UK). Analysis of variance (ANOVA) was used to evaluate the main effects and their interactions. Mean separation was conducted using Fisher's Protected LSD-test ($P<0.05$). Linear and quadratic regression analyses, R^2, R^2 adjusted and significance levels were computed using Genstat.

III. Results and discussion

Chemical composition of grass-clover silage

Grass-clover harvested in May 2014 had the lowest N content, whereas both the dry matter content and C: N ratio were highest (Table 1). For grass-clover harvested between October and November 2014 the observed average N content was 2.6 %. In this case, the dry matter content, carbon content and the C: N ratio were lowest, while the ash content was highest. Grass-clover harvested in June and July 2014 and in August and September 2014 had intermediate C: N ratio's of 22 and 17, respectively.

Silage	Harvest time	DM %	Ashes %	OM %	C %	N_{tot} %	C/OM (-)	C/N (-)
1	May	73	9	91	44	1.8	0.48	24
2	June-July	64	9	91	44	2.0	0.48	22
3	August-September	47	11	89	46	2.7	0.52	17
4	October-November	19	22	79	41	2.6	0.52	16

Table 1. Chemical composition of the grass-clover silage in terms of dry matter (DM) (%), ash (%), organic matter (OM), carbon (C), total nitrogen (N_{tot}), C/OM and C/N

Initial soil measurements

The initial soil organic matter SOM was 3.6% which is relatively high for a sandy soil but this is to be expected for an organic farm where organic amendments are frequently used. The soil was relatively low in mineral N (3.2 kg N ha^{-1}), but this is not uncommon on sandy soils during spring time due to N leaching during the winter season. The soil pH (H_2O) was 6.2 and thus optimal for both crop growth and decomposition of organic material. The available soil P content was relatively low (2 kg P ha^{-1}) whereas the available soil K content was adequate (176 kg K ha^{-1}).

Plant emergence and leaf chlorophyll content

Plant emergence was not affected by the C: N ratio and N application rate, and interactions between these factors were also insignificant (Table 2). The uniformity in germination was in all probability due to the use of certified homogenous seed potatoes. The sprouting of the potato tubers is generally induced by phytohormones (gibberellins) (Sonnewald et al., 2011). During germination the plant growth thus depends mainly on the level of stored reserves of the seed tubers and at this stage is therefore independent of the soil N dynamics (Bewley et al., 2013).

At 7 weeks after planting (WAP) leaf chlorophyll content (i.e., SPAD value) was similar for all application rates and C: N ratios (Table 2). At 11 and 13 WAP, the SPAD values were similar for C: N ratios of 16 and 17. However, these SPAD values were higher than those measured at C: N ratios of 22 and 24. This can be related to the high mineralization rates of grass-clover silage at C: N ratios 16 and 17. The SPAD reading thus may be used as a simple and non-destructive measure to identify pronounced N deficiencies in potato. However, its use to detect marginal deficiencies is limited. At 9 and 11 WAP, leaf chlorophyll contents were lower for the C: N ratio of 24. This was possibly due to a decreased N uptake by the potato plants. In grass-clover silage, N is available (supplied) in organic and inorganic forms. The use of organic materials with C: N ratio's above 20 may temporarily immobilizes N, whereas with a lower C: N ratio N may become available more rapidly thereby enhancing initial growth (Whitmore, 2006). In case of immobilization, the microbes compete with growing crops for the available soil N. The SPAD values at 11 and 13 WAP increased from low N application to high N application rate (Table 2). Previous studies have shown that the leaf chlorophyll content increases with higher applied N rates (Semiha, 2009; Zebarth et al., 2002). At 13 WAP, there was a decline in leaf chlorophyll content. This result was consistent with previous studies where also the leaf N contents decreased with time (Jarrel and Beverly, 1981; Güler and Güzel, 1994 and Semiha, 2009). This may be related to a continuous increase in crop dry matter accumulation whereas soil N being slowly depleted. This resulted in a gradual N dilution in the crop as was also observed in tomato (Scholberg et al., 2000).

Table 2. Effect of C: N ratio (16, 17, 22, and 24) and N application rate (0, 57, 113 and 170 kg N ha-1) on plant emergence (days after planting, DAP : 50% of plants emerged) and leaf chlorophyll content (SPAD value).

	Plant emergence (DAP)	**Leaf chlorophyll content (SPAD value)**			
		7 WAP[1]	**9 WAP**	**11 WAP**	**13 WAP**
C: N ratio (F)[2]					
24	38.9	50.8	41.8 a	43.3 a	36.8 a
22	40.0	51.2	43.2 b	44.8 b	36.9 a
17	39.5	50.2	43.0 b	46.5 c	38.2 b
16	39.3	51.6	42.9 b	47.1 c	39.3 b
Significance[3]	ns	ns	*	***	**
Application rate (R)					
0	39.2	49.4	42.1	41.6 a	33.0 a
57	39.7	51.7	42.6	43.7 a	35.7 b
113	39.8	51.0	42.8	45.9 b	38.3 c
170	38.7	50.2	42.9	46.7 b	39.4 c
Significance	ns	ns	ns	***	***
F × R	ns	ns	ns	ns	ns

[1] WAP = Week after planting.

[2] Different letters indicate significant differences according to Fisher's protected LSD-test *($P < 0.05$)*.

[3] *, ** and *** refer to *P* values < 0.05, < 0.01 and < 0.001, respectively ; ns = not significant.

Above-ground plant fresh weight, above-ground plant dry weight and Leaf Area Index (LAI)

Above-ground plant fresh weight was not affected by the C: N ratio at 8 and 14 WAP (Table 3). However, at 10 WAP, fresh above-ground plant weight increased with decreasing C: N ratio's. At this time, probably there was a positive relation between plant uptake of soil nutrients and N release from grass-clover silage. The above-ground plant fresh weight was higher in the treatment with C: N ratio 16 compared to the treatment with C: N ratio 24, whereas the C: N ratio's of 17 and 22 resulted in intermediate values. In terms of N application rate, the above-ground plant fresh weight increased with N-rate at 8, 10, and 14 WAP (Table 3 and 7). Vos and Biemond (1992) stated that the growth of potato plants is extremely responsive to N fertilization. N enhances sympodial growth and delays the senescence process of both the individual leaves and the entire plant.

We observed a significant interaction effect between C: N ratio and N application rate on above-ground plant dry weight (Mg ha^{-1}) at 14 WAP (Table 3). The above-ground plant dry weight was higher at C: N ratios of 17 and 24 as well at an application rate of 170 N kg ha^{-1} compared with the non-amended control. The above-ground plant dry weight was stimulated by increased N application rates in all treatments (Table 4). At 10 WAP, the highest value of above-ground plant dry weight was the same as with a C: N ratio of 16 and 17, while these were lower than values recorded with a C: N ratio of 24. Above-ground plant dry weight at C: N ratio 22 had an intermediate value (Table 3). In terms of N application rate, there were no effects on the above-ground plant dry weight at 8 WAP. However, at 10 and 14 WAP, the above-ground plant dry weight values for plots that received 170 kg N ha^{-1} were significantly higher than plots of lower N application rates or the non-amended control.

There was a significant interaction effect between C: N ratio and N application rate on LAI (m^2 m^{-2}) at 14 WAP (Table 4). The LAI was higher with the C: N ratios of 17 and 24 with the rate of 170 N kg ha^{-1} than the non-amended control. The LAI increased with increasing N application rate in all treatments (Table 4). However, LAI was not affected by the C: N ratio at 8 and 14 WAP (Table 3). In terms of N application rate, the LAI increased with N rate at all sampling dates. Potato plants that received 170 kg N ha^{-1} had significantly higher LAI values than plants grown under lower N application rates and non-amended control. This finding is similar to results by Njam et al. (2010) who found that the above-ground dry matter accumulation and leaf area index are mostly influenced by N fertilization.

Table 3. Effect of C: N ratio (16, 17, 22 and 24) and N application rate (0, 57, 113 and 170 kg N ha^{-1}) on above-ground plant fresh weight (Mg ha^{-1}), above-ground plant dry weight (Mg ha^{-1}) and leaf area index (LAI) (m^2 m^{-2}).

	Above ground plant fresh weight (Mg ha^{-1})			**Above ground plant dry weight (Mg ha^{-1})**			**LAI (m^2 m^{-2})**		
	8 WAP[1]	**10 WAP**	**14 WAP**	**8 WAP**	**10 WAP**	**14 WAP**	**8 WAP**	**10 WAP**	**14 WAP**
C: N ratio (F)[2]									
24	8.3	19.7 a	27.1	0.74	1.88 a	2.50	0.49	1.09 a	1.80
22	9.0	22.1 ab	26.0	0.76	2.18 ab	2.40	0.52	1.29 ab	1.72
17	9.8	25.1 bc	26.6	0.87	2.46 bc	2.47	0.54	1.49 b	1.71
16	10.8	25.8 c	26.8	0.96	2.55 c	2.48	0.62	1.50 b	1.74
Significance[3]	ns	**	ns	ns	**	ns	ns	*	ns
Application rate (R)									
0	7.4 a	12.8 a	14.7 a	0.63	1.35 a	1.40 a	0.40 a	0.65 a	0.96 a
57	8.9 a	19.6 b	20.2 a	0.78	2.02 b	1.85 a	0.52 ab	1.14 b	1.34 a
113	8.3 a	24.1 c	27.8 b	0.75	2.34 bc	2.54 b	0.49 a	1.37 bc	1.80 b
170	11.2 b	25.8 c	31.9 c	0.97	2.44 c	3.00 c	0.63 b	1.52 c	2.10 c
Significance	*	***	***	ns	**	***	*	**	***
F × R	ns	ns	ns	ns	ns	*	ns	ns	*

[1] WAP = Week after planting.
[2] Different letters indicate significant differences according to Fisher's protected LSD-test ($P < 0.05$).
[3] *, ** and *** refer to P values < 0.05, < 0.01 and < 0.001, respectively ; ns = not significant.

Table 4. Interaction between C: N ratio (16, 17, 22 and 24) and N application rate (0, 57, 113 and 170 kg N ha^{-1}) on above ground plant dry weight (Mg ha^{-1}) and Leaf Area Index (LAI) (m^2 m^{-2}) at 14 WAP.

		Above ground plant dry weight (Mg ha^{-1})	**LAI (m^2 m^{-2})**
		14 WAP	**14 WAP**
Treatment C:N ratio	**Fertilizer rate (kg N ha^{-1})**		
Control	0	1.40 a	0.96 a
24	57	1.60 a	1.13 ab
24	113	2.72 e	1.98 d
24	170	3.18 fg	2.31 e
22	57	2.04 bc	1.41 bc
22	113	2.64 e	1.87 d
22	170	2.53 de	1.89 d
17	57	1.74 ab	1.33 bc
17	113	2.18 cd	1.46 c
17	170	3.48 g	2.35 e
16	57	2.02 bc	1.49 c
16	113	2.62 e	1.88 d
16	170	2.82 ef	1.85 d
LSDs		0.372	0.286

Interaction between C: N ratio and N application rate was significant. Different letters indicate significant differences according to Fisher's protected LSD- test ($P < 0.05$).

Total tuber yield and agronomic nitrogen efficiency (ANE)

We found a slight increase in total tuber yield with decreasing C: N ratios (Figure 2a). The total tuber yield was higher at the low C: N ratios (16 and 17) whereas the highest C: N ratios (24 and 22) had the lowest tuber yield (Figure 2a). This likely resulted from enhanced early N availability to potato plants during initial crop growth with low C: N ratio's. In terms of N application rate, tuber yield increased linearly with N application rate and total tuber yield (Figure 3a). Application of 170 kg N ha^{-1} resulted in the highest total tuber yield (47.5 Mgha^{-1}) which translates to a 56% increase compared to the non-amended control which yielded 30.5 Mg ha^{-1} Application rate of 57 and 113 kg N ha^{-1} resulted in intermediate values of 35.8 and 40.5 Mg ha^{-1} respectively. Maier et al. (1994) found a similar increase in tuber yield with increasing N rates.

In terms of marketable yield, the use of low C: N ratio material increased the marketable yield compared to silage with a high C: N ratio (Table 5). Regarding N application rate, the marketable yield was higher for 170 kg N ha^{-1} and lower for the control, while 57 and 113 kg N ha^{-1} had intermediate values (Table 5). Nitrogen contributes to an increase in the number of tubers by enhancing individual stem vigour (Gabr and Sarg, 1998). Similarly, Jamaati-e-Somarin et al. (2010) reported that increasing nitrogen application rates enhance the number of stolons, the number of tubers and therefore consequently the final potato yield. It is evident that in the current experiment, the yield increased for the treatments that had low C: N ratio and high N application rate. This might have been caused by the early N availability supplied at high amounts for the treatments with low C: N ratios and high N application rates during initial crop growth.

Regarding tuber size distribution, the C: N ratio did not affect the yield of small and cull tubers. However, there was a significant effect on the yield of large tubers (Table 5). In terms of N application rate, there was no effect on the yield of cull tubers. A significant effect was observed for yield of large tubers (> 40 mm) and small tubers (15-40 mm). The amount of small tubers appears to be reduced at higher N applications. The number of large tubers was higher in 170 kg N ha^{-1} treatment compared with other treatments. Ojala et al. (1990) stated that with low N availability during initial growth of potatoes, tuber initiation and late tuber bulking reduces the final and large tuber yield. Total tuber yield, marketable yield and yield of large tubers increased with higher N application rates. These results are consistent with the previous reports of Jenkis and Nelson (1999), Maier et al. (1994), and Semiha (2009).

The agronomic nitrogen efficiency (ANE; kg tubers per kg N applied) was not significantly affected by either the C: N ratio nor the N application rate (Figures 2b and 3b). The results showed that ANE under C : N ratio of 16 (i.e. 115 kg tubers per kg N applied) was about three times higher than in a previous experiment with solid cattle manure (39 kg tubers per kg N applied) and lucerne pellets (59 and 39 kg tubers per kg N applied) (Drakopoulos, 2014; Terra, 2015).

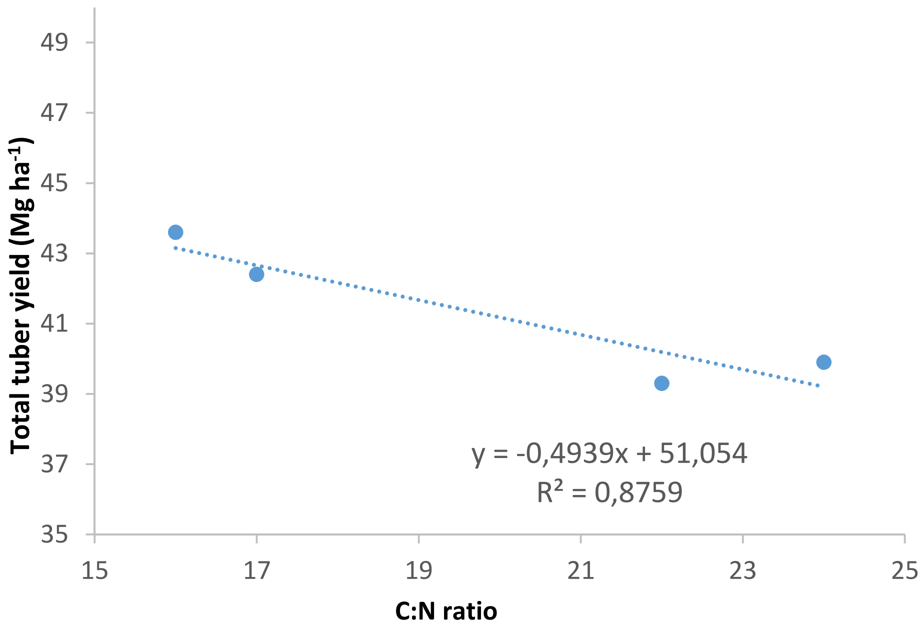

Fig. 2a. Relationship between C: N ratio of applied grass-clover silage and total tuber yield (Mg ha^{-1}).

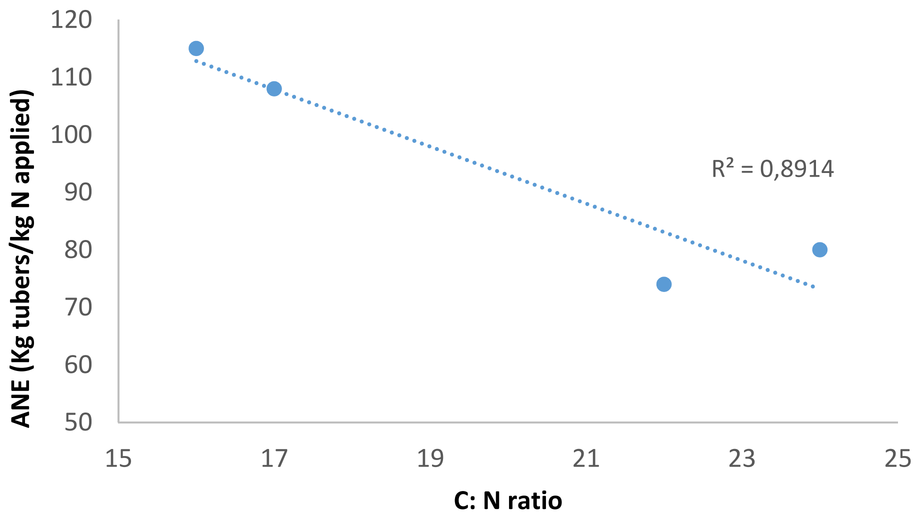

Fig. 2b. Effect of C: N ratio on Agronomic nitrogen efficiency (ANE) (kg/kg).

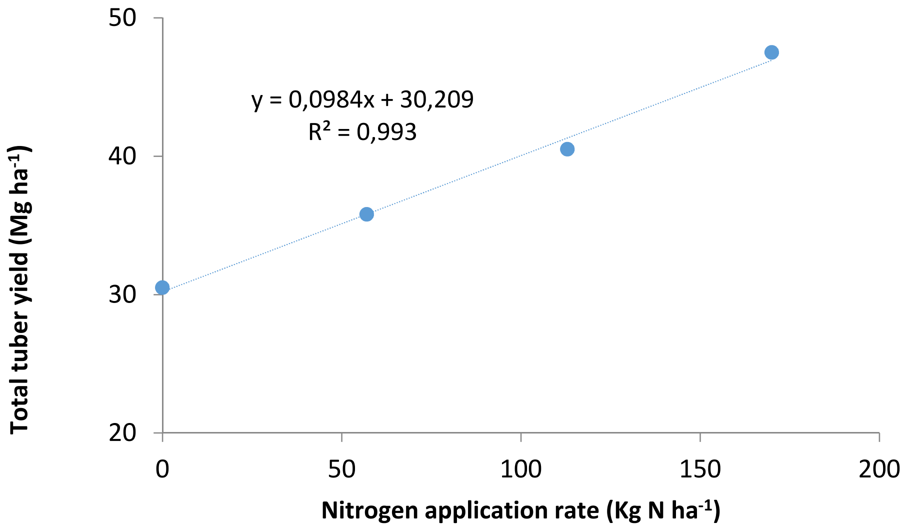

Fig. 3a. Relationship between nitrogen application rate (Kg N ha^{-1}) and total tuber yield (Mg ha^{-1}).

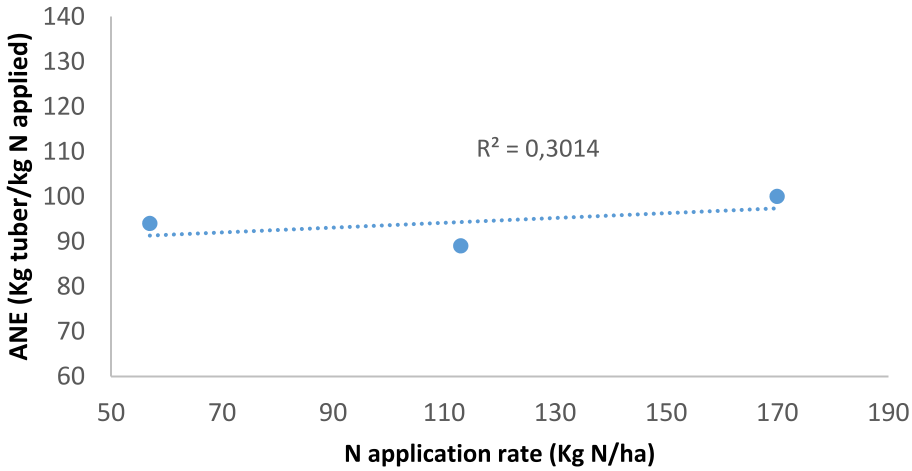

Fig. 3b. Effect of N application rate (kg N/ha) on Agronomic nitrogen efficiency (ANE) (kg/kg).

Table 5. Effects of C: N ratio (16, 17, 22 and 24) and N application rate (0, 57, 117 and 170 kg N ha^{-1}) on marketable yield (Mg ha^{-1}), tuber grading (Mg ha^{-1}) and agronomic nitrogen efficiency (ANE) (kg tubers/kg N) of potato

		Tuber grading (Mg ha^{-1})[1]			ANE (kg /kg)
	Marketable yield (> 15 mm)	Large (> 40 mm)	Small (15-40 mm)	Culls	
C: N ratio (F)					
24	37.7 ab	30.6 ab	7.1	2.2	80
22	37.3 a	29.8 a	7.5	2.0	74
17	40.7 bc	33.7 b	6.9	1.7	108
16	41.3 c	33.8 b	7.5	2.3	115
Significance[2]	*	*	ns	ns	ns
Application rate (R)[3]					
0	29.1 a	20.6 a	8.5 b	1.4	-

57	33.9 b	25.7 b	8.2 ab	1.9	94
113	38.5 c	31.2 c	7.2 a	2.1	89
170	45.4 d	39.0 d	6.4 a	2.1	100
Significance	***	***	*	ns	ns
F×R	ns	ns	ns	ns	ns

[1]Tuber grading : Small = 15-40 mm ; Large = > 40 mm ; Culls = tubers with damages and or infestation regardless of their size. Marketable yield = Small and large tubers.

[2] *, ** and *** refer to *P* values < 0.05, < 0.01 and <0.001, respectively ; ns = not significant.

[3] Different letters indicate significant differences according to Fisher's protected LSD-test (*P* < 0.05).

Tuber quality

There was no effect of C: N ratio on tuber quality (i.e., specific gravity and starch content) (Table 6). In terms of N application rate, there was a small effect of N application rate on tuber quality. The highest value of tuber specific gravity was observed at lower N application rate and in the non-amended control compared to high N application rate treatments. The specific gravity was reported to decrease with increasing nitrogen availability (Ojala et al., 1990). Westermann et al. (1994) also reported that the specific gravity of potato often decreased with increasing N levels.

Regarding the starch content, the lowest N application rate and non-amended control yielded slightly higher starch content in tubers than the highest N application rate. These results are consistent with those of Tein et al. (2014), who found that the starch content was lower in large tubers compared to small tubers. It is evident that increasing N application rate increases the tuber size but decreases the specific gravity and starch content of potato. Previous studies by e.g. Drakopoulos et al. (2014) showed that the highest specific gravity and starch content of potato were found for the non-amended control and low N application treatments compared to the treatments with high N application in organic potato production. Westermann et al (1994) also reported the similar effects of N on starch content of potato.

Table 6. Effect of C: N ratio (16, 17, 22 and 24) and application rate (0, 57, 113 and 170) on tuber quality, i. e. specific gravity (-) and starch content (%) of potato.

	Tuber specific gravity (-)	**Tuber starch content (%)[1]**
C : N ratio (F)		
24	1.07	13.1
22	1.07	13.2
17	1.08	13.3
16	1.07	13.2
Significance[2]	ns	ns
Application rate (R)[3]		
0	1.08 b	13.6 b
57	1.08 b	13.6 b
113	1.07 a	13.2 a
170	1.07 a	12.9 a
Significance	**	**
F × R	ns	ns

[1]Starch content = -1.39 + 0.196 [1000 × (specific gravity-1)]. (Simmonds, 1977)

[2] *, ** and *** refer to *P* values < 0.05, < 0.01 and < 0.001, respectively ; ns = not significant.

[3]Different letters indicate significant differences according to Fisher's protected LSD-test (*P* < 0.05).

Crop parameters for prediction of final tuber yield

For practical purposes, it is relevant to identify simple indicators which correlate well with the total tuber yield. For this purpose, regression analyses were carried out between above-ground crop growth measures, ANE and total tuber yield (Table 7).

According to R-squared, R-squared adjusted and *P* value, it is evident that emergence date, above-ground fresh weight, above-ground dry weight, LAI and ANE had low predictive power and thus are not suitable to predict final tuber yield (Table 7). However, leaf chlorophyll content appears to be the best predictor of the total tuber yield since at 13 WAP, the linear and quadratic regressions accounted for 80 % and 79 % of the observed variability in tuber yield, respectively (Table 7). As earlier shown by Daugthry et al. (2000), the chlorophyll content of the leaf is closely correlated with the plant N status. Thus, lower SPAD value among the treatments is indicative of lower leaf N content which may result in lower total tuber yield. Similarly, Semiha (2009) found that the total tuber yield of potato was significantly correlated with leaf chlorophyll content.

Table 7. Regression analysis to assess tuber yield prediction potential for selected crop parameters.

	Regression	R^2	$R^2_{Adjusted}$	Equation	Significance[1]
Emergence date					
	Linear	0.146	0.068	$y = 30.59 + 0.1191x$	ns
	Quadratic	0.290	0.147	$y = –7.6 + 1.053x – 0.00536x^2$	ns
Leaf chlorophyll content					
7 WAP[2]	Linear	0.093	0.011	$y = 129.8 – 1.76x$	ns
	Quadratic	0.128	nd[3]	$y = –3024 + 123x – 1.23x^2$	ns
9 WAP	Linear	0.095	0.013	$y = –60.8 + 2.37x$	ns
	Quadratic	0.226	0.071	$y = 5701 – 268x + 3.16x^2$	ns
11 WAP	Linear	0.673	0.643	$y = – 53.6 + 2.08x$	***
	Quadratic	0.674	0.609	$y = – 155 + 6.5x – 0.049x^2$	**
13 WAP	Linear	0.821	0.804	$y = – 42.4 + 2.207x$	***
	Quadratic	0.824	0.789	$y = – 117 + 6.22x – 0.054x^2$	***
Above ground fresh weight					
8 WAP	Linear	0.433	0.382	$y = 22.36 + 1.921x$	*
	Quadratic	0.489	0.387	$y = 57.5 – 6.08x + 0.437x^2$	**
10 WAP	Linear	0.691	0.663	$y = 17.58 + 1.013x$	***
	Quadratic	0.710	0.652	$y = 31.4 – 0.39x + 0.0335x^2$	**
14 WAP	Linear	0.693	0.665	$y = 20.82 + 0.775x$	***
	Quadratic	0.694	0.632	$y = 18.4 + 0.96x – 0.004x^2$	**
Above ground dry weight					
8 WAP	Linear	0.459	0.410	$y = 21.54 + 22.9x$	*
	Quadratic	0.490	0.388	$y = 52.1 – 57x + 49.6x^2$	*
10 WAP	Linear	0.526	0.483	$y = 19.14 + 9.62x$	**
	Quadratic	0.547	0.457	$y = 36.6 – 8.7 x + 4.55x^2$	*
14 WAP	Linear	0.686	0.657	$y = 21.68 + 7.8x$	***
	Quadratic	0.687	0.625	$y = 18.3 + 10.8x – 0.63x^2$	**
Leaf Area Index					
8 WAP	Linear	0.434	0.383	$y = 21.58 + 35x$	*
	Quadratic	0.507	0.409	$y = 65.1 – 140x + 168x^2$	*
10 WAP	Linear	0.618	0.584	$y = 22.16 + 14.01x$	**
	Quadratic	0.619	0.543	$y = 20.6 + 16.6x – 1.01x^2$	**
14 WAP	Linear	0.636	0.603	$y = 21.95 + 10.86x$	**
	Quadratic	0.642	0.571	$y = 15.4 + 19.2x – 2.49x^2$	**
ANE	Linear	0.259	0.185	$y = 30.59 + 0.1191x$	ns
	Quadratic	0.496	0.384	$y = –7.6 + 1.053x – 0.00536x^2$	*

[1] *, ** and *** refer to *P*-values < 0.05, < 0.01 and < 0.001, respectively ; ns = not significant.
[2] WAP = weeks after planting.
[3] nd = not determined.

IV. Conclusions

The aim of this research was to investigate the effect of C: N ratios (16, 17, 22, and 24) and nitrogen application rates (57, 113 and 170 kg N ha^{-1}) on organic potato performance. Treatments with high C: N ratio's resulted in lower above-ground biomass production and total tuber yield compared to the treatment with low C: N ratio. From 9 to 13 WAP, leaf chlorophyll content was lower in treatments with high C: N ratios compared with low C: N ratio, probably due to lower initial N availability. Therefore, this may provide insight as to which C: N of grass-clover silage is required for optimal N release to ensure that N-release is synchronised with crop demand in time. High nitrogen input increased leaf chlorophyll content, above-ground plant fresh weight, above-ground plant dry weight, LAI, total tuber yield and large tuber yield. The agronomic nitrogen efficiency was not significantly affected by either the C: N ratio nor N application rate but it was three times higher than in a previous experiment with solid cattle manure. Based on this result it appears that crop-based N-sources may provide a viable option for closing on-farm N-cycles and efficient N-utilization. The use of grass-clover material with low C: N ratio and high N application rate may result in faster N release which influences crop performance and total tuber yield. Therefore, grass-clover silage may be a potential substitute of animal manure. This study confirms its effectiveness in agriculture in terms of nutrient utilization by the crop and total tuber yield.

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