# Optimizing a green manure-based row cropping system for organic cereal production

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**Abstract:** *Lack of sufficient Nitrogen (N) supply and high weed pressure are two main challenges which often cause low and unstable yields in organic farming. In a field experiment, a new strategy for combining cover crops for nitrogen supply and environmental-sound weed control was tested in a new row cropping system. To optimize the use of undersown legume-based cover crops (CCs) and precise interrow hoeing techniques, we tested six CC mixtures and three sowing times (with barley seeding, or about three or six weeks later) corresponding to 0 - 2 passes of interrow hoeing for weed control.*

*Four of six tested CC mixtures (persian clover/ winter radish, red clover/orchard grass, lucerne/chicory and kidney vetch/dyer's woad) in the row cropping system significantly increased grain yield of the succeeding barley by 0.56 - 0.73 Mg DM ha$^{-1}$ compared to the traditional cropping system with autumn tillage, yielding 3.43 Mg DM ha$^{-1}$. The three-week delay sowing time was suitable for the growth of legume species and allowed one pass of interrow hoeing to obtain an integrated weed management. The number of hoeing passes did not significantly affect the weed biomass. CCs on average reduced N leaching to below the barley's root zone by 16 kg N ha$^{-1}$, compared to the autumn tillage. Most of tested cover crops were equal to the autumn tillage approach for the effect of the perennial thistles (Circium arvense) control. An extra application of repeated interrow hoeing in autumn may improve weed control effect in this system.*

***Keywords:*** *Row crop, green manure, catch crop, N leaching, N effect, weed control*

## Introduction

Organic agriculture is considered as a prototype for sustainable agricultures where agro-ecological processes and self-sufficiency in nutrient supply are basic principles (Bellon and Penvern, 2014). In order to obtain a multifunctional cropping system for soil fertility, pest and weed management in organic crop production, a combination of different agronomic methods is needed, such as crop rotations, green manuring, intercropping and mechanical measures (Rasmussen et al., 2005; Lockeretz, 2007; Bedoussac et al., 2014). However, fertility building measures and weed management measures in organic cropping systems is not always compatible, making optimization of these measures difficult, and thus resulting in lower crop yield (Malender et al., 2016). In Northern European countries, the need for mechanical weed control against perennial weeds such as creeping thistle (*C. arvense*) in the autumn restricts the use of green manure-based CCs, a key resource of N supply, as well as causing environmental damage through enhancing N leaching and soil degradation. Therefore, the aim of the current study is to develop a novel row intercropping system for organic cereal production through the extended and optimized use of green manure-based CCs and smart-reduced tillage methods for sufficient N supply and weed control.

## Materials and methods

A two-year field experiment (2014 - 2015) was established in a long-term organic research area at the University of Copenhagen's research facility in Taastrup, Denmark (55°40'N, 12°18'E). The soil type was a sandy loam. The experiment was laid out in a randomized complete block design with 14 treatments and three replicates (Table 1). The experimental factors included (1) row cropping or conventional cropping system with 0.24 and 0.12 m row-distances, respectively, (2) with and without CC, (3) CC species, (4) sowing times (with barley seeding, or about three or six weeks later) corresponding to 0 - 2 passes of interrow hoeing before CC sowing for the purpose of the integrated weed management. To mimic the common intensive soil tillage activities of farmers for weed control, two out of four fallow treatments of both cropping systems were stubble cultivated to a depth of 15 cm three times during September-October. In the CC treatments, CCs remained on the field over winter and then were incorporated by ploughing to 20 cm depth in March 2015. A pure stand spring barley was established in April 2015. Despite two consecutive years of spring barley is not an ideal crop rotation, it made easy to assess the yield improvement in the following year. In practice, spring cereal/ley, grass-clover, winter cereal and grain legume are often rotated in Danish cropping systems.

To measure the effect of the new CS on biomass production of CCs, weed (thistle and other weeds) and crop yield, the above-ground plant biomass from two areas of 0.5 x 0.5 m per plot was collected at barley harvest in both years and in November 2014 (as a maximum biomass production measurement of CCs) and again in March 2015 (as a regrowth measurement of CCs). Their dry matter (DM) and C:N contents were then determined. The soil inorganic N content-Niorg (ammonium-N and nitrate-N) of three different soil layers (i.e. 0-50 cm, 50-100 cm and 100-150 cm) were measured twice, in November 2014 and in May 2015. The amount of inorganic N in the soil profile (0 to 1.5m depth) in November accounted for the risk of N leaching while the inorganic N measured in May accounted for the N supply capacity for the succeeding crop. Statistical analysis was performed using the R software (R Core Team, 2017). A two-way, mixed model ANOVA and a Tukey-HSD ($p < 0.05$) as a post-hoc test were applied. Data transformation was applied if required.

**Table 1.** Summary of treatments in this study.

| Treatment number | Cover crops with treatment operations | Sowing time | Inter-row hoeing (number of passes) | Seed rate (Kg ha$^{-1}$) |
|---|---|---|---|---|
| 1 | Tillage-0.12m[a] | | 0 | |
| 2 | Fallow-0.12m[a] | | 0 | |
| 3 | White clover/Ryegrass-0.12m[a] | at barley sowing | 0 | 5+5 |
| 4 | Tillage | | 0 | |
| 5 | Fallow | | 0 | |
| 6 | White clover/Ryegrass | 3 week delayed | 1 | 5+5 |
| 7 | Red clover /Orchard grass | 3 week delayed | 1 | 5+5 |
| 8 | Ryegrass | 3 week delayed | 1 | 10 |
| 9 | Kidney vetch/Dyer's woad | 3 week delayed | 1 | 5+5 |
| 10 | White clover/Ryegrass | 6 week delayed | 2 | 5+5 |
| 11 | Red clover/Orchard grass | 6 week delayed | 2 | 5+5 |
| 12 | Lucerne/Chicory | 6 week delayed | 2 | 5+5 |
| 13 | Persian clover/Stauderug | 6 week delayed | 2 | 5+50 |
| 14 | Persian clover/Winter radish | 6 week delayed | 2 | 5+5 |

[a] Treatments with 0.12m belong to the traditional cropping system of 0.12 m row width. The remaining treatments without stating 0.12m belong to the row cropping system of 0.24 m row width.

## Results

Four CC mixtures (persian clover/ winter radish, red clover/orchard grass, lucerne/chicory and kidney vetch/dyer's woad) in the row cropping system increased grain yield of the succeeding barley by 0.39 - 0.86 Mg DM ha$^{-1}$ while the two common white clover/rye grass and sole rye-grass mixtures in this cropping system reduced the grain yield by 0.15 on average and 0.54 Mg ha$^{-1}$ respectively, compared to the tilled cropping system-0.12m, yielding 3.43 Mg ha$^{-1}$ (Fig.1). The four mentioned CC mixtures also had higher barley grain yields than the common white clover/rye grass in the traditional system with 2.67 Mg DM ha$^{-1}$. The grain N content followed the pattern of grain yield.

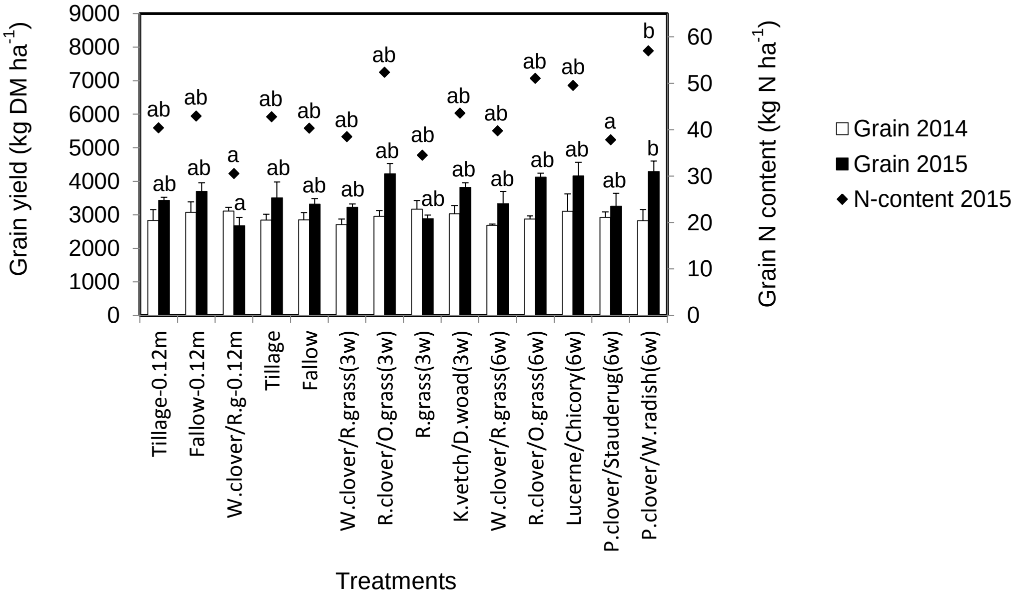


**Figure 1**. Grain yield of pre-crop spring barley in 2014 and grain yield and grain N content of the succeeding barley in 2015. Error bars show standard error (n=3). Different letters are significantly different (*P<0,01*)

The total CC biomass (legume + non-legume) in Nov 2014 varied between treatments (346 – 983 kg ha$^{-1}$) and differed in the fraction of legume biomass among the three sowing times (Fig. 2). Red clover/orchard grass and persian clover/winter radish produced highest biomass and the lowest biomass was in the pure stand ryegrass. In the mixtures, leguminous species producing highest biomass included red clover, white clover and kidney vetch at the three-week delayed sowing time (407 – 639 kg ha$^{-1}$) while non-legume species such as winter radish, rye grass and orchard grass were more prominent at the six-week delayed sowing time (258 – 814 kg ha$^{-1}$).

CCs strongly reduced the total weed biomass in the establishment year, but had no effect on weed biomass in the following cereal crop. For the perennial thistles weed, due to their uneven distribution on the field, before comparing means, we subtracted this variation by making the ratio of thistle biomass in August 2015 to the corresponding biomass in August 2014. As the result presented in Fig. 3, most of tested cover crops (except sole ryegrass and kidney vetch/dyer's woad) had an equal effect with the autumn tillage approach to control the creeping thistles (*C. arvense*) in the following season.

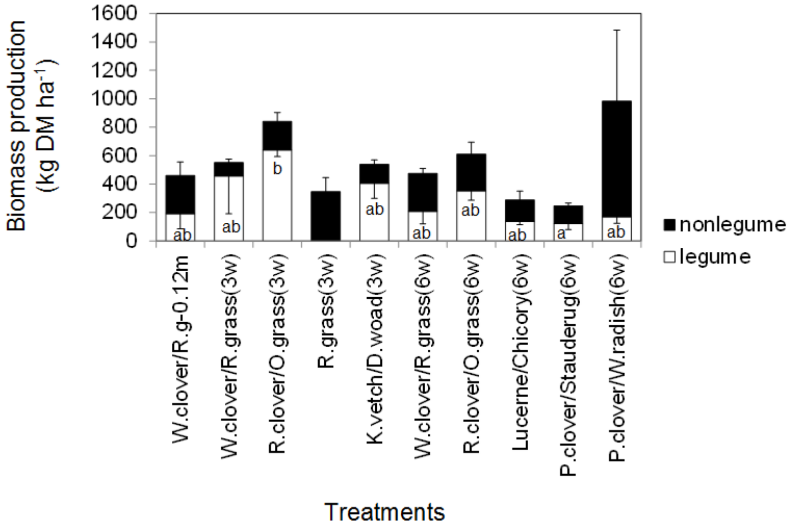


**Figure 2**. Biomass production of catch crop species in the mixtures in November 2014. Error bars show standard error (n=3) for each crop species in the mixture. Bars with different letters within each plant group are statistically significant at *P <0.01* (Tukey's test).

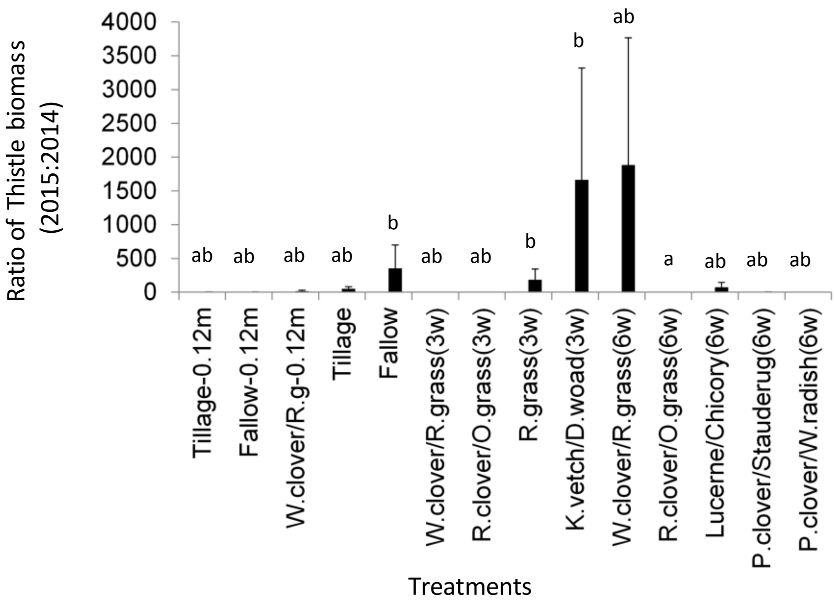


**Figure 3**. The ratio of creeping thistle (*Circium arvense*) biomass in August 2015 to their corresponding biomass in August 2014 of each treatment. Error bars show standard error (n=3). Bars with different letters are statistically significant at *P <0.01* (Tukey's test).

All CC treatments successfully depleted soil Nitrate-N at all three depths in November 2014, compared to the tilled treatment, whereas soil ammonium-N in the soil profile was not different between treatments (Fig. 4). In the tillage plots, 19 kg N ha-1 was found in the soil layer of 1-1.5 m in November, the CCs reduced this by 16 kg N $ha^{-1}$ on average. In the following spring, the upper 1m soil Niorg benefits from four of six tested CCs, the effect ranged from 9 to 16 kg N $ha^{-1}$ while the two mixtures of kidney vetch/dyer's woad and white clover/rye grass had negative effects on available soil N for the succeeding cash crop. We found a positive correlation between barley yield in 2015 and the spring topsoil Ninorg of 0-1 m ($y= 22.66 x + 2046.61$, $R^{2}= 0.2546$, $p< 0.05$), but not dependency on the subsoil N below 1 m.

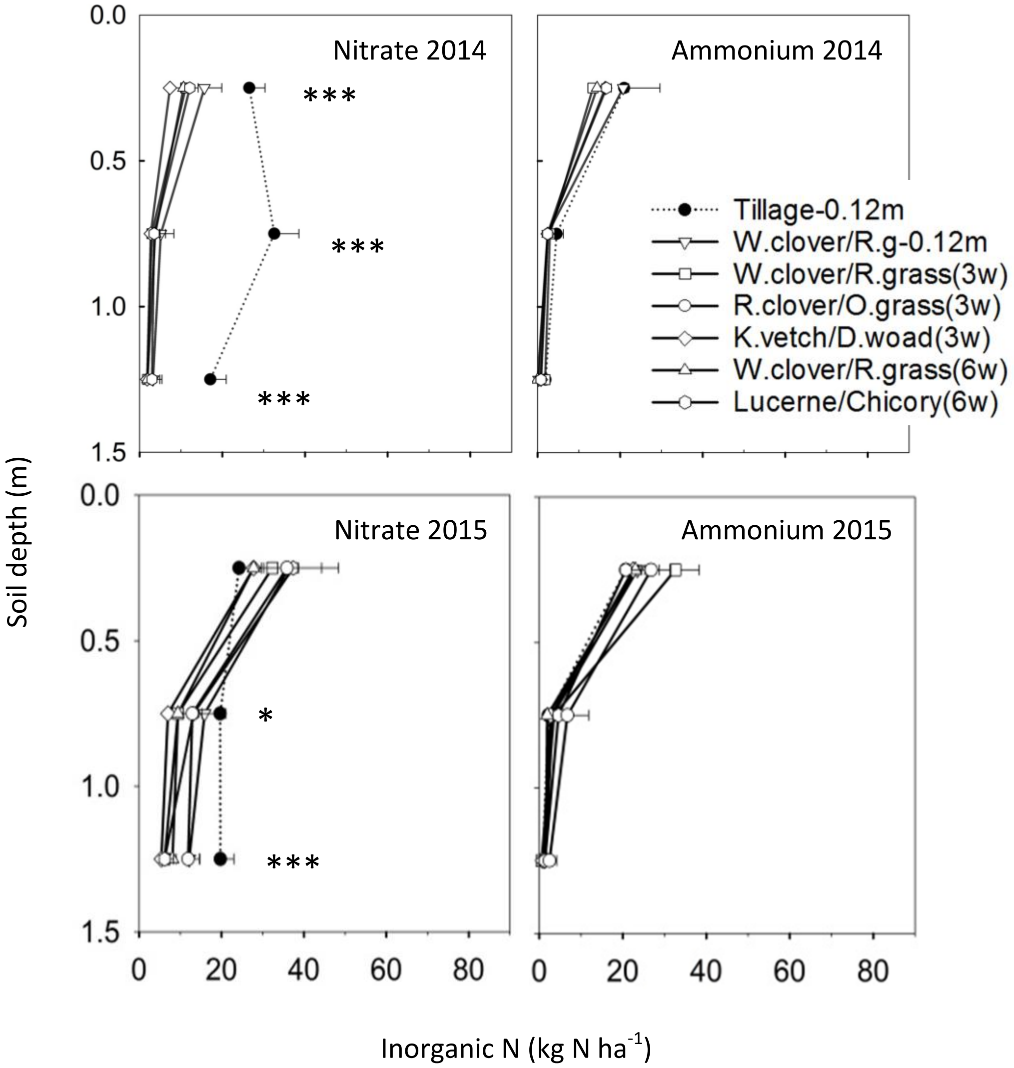


**Figure 4**. Soil Nitrate-N and ammonium-N contents at different soil layers of different treatments in November 2014 and May 2015. Error bars show standard error (n=3). Stars indicate statistically significant differences between treatments at each soil depth with *(*P<0.05*), **(*P<0.01*) and ***(*P<0.001*) with Tukey's test.

## Discussion

Our finding shows that the new row cropping system with a wide range of CC mixtures could improve both grain yield and grain N content. The grain yield of the succeeding barley crop increased by 633 kg $ha^{-1}$ on average as compared to the traditional cropping system with or without CC. Within a long-term organic crop rotation study in three locations across Denmark, Doltra and Olesen (2013) also found that the spring barley mean grain yield benefits from catch crops varied from 100 to 1500 kg DM $ha^{-1}$. Grain yield correlated to the topsoil Ninorg pool which was affected by CC management. According to Thorup-Kristensen and Nielsen (1998) and Thorup-Kristensen and Dresbøll (2010) the effect of CCs on N supply for the succeeding crop (Neff) depend on their rooting depth, quantity and quality of the CC biomass (related to the choice of CC species, sowing time and incorporation time), regrowth capacity (related to species and incorporation time).

From our result, the idea of delaying sowing date of CC by 6 weeks to allow two passes of interrow hoeing for weed control may not be necessary because weed biomass, both perennial thistle and other weed species, were not significantly affected by the number of hoeing passes. Furthermore, the fraction of legume biomass in the mixtures seemed to be reduced by late CC sowing, and in particular the legume species preferred the three-week delayed showing time. Most of non-legume species can regrow fast in spring (especially those of Poaceae and Brassicaceae family) and this can reduce the N supply for the succeeding crop because the CCs can take up spring mineral N from the soil, which should be available for the crop, and thereby causing a strong pre-emptive competition for N (Thorup-Kristensen and Dresbøll, 2010). In our study, although the biomass and N content of the kidney vetch/dyer's woad mixture was as twice as those of Lucerne/chicory, 341 kg DM $ha^{-1}$ lower grain yield was observed in the kidney vetch/dyer's woad treatment due to the high spring regrowth capacity of both species in this mixture. This pre-emptive competition may be prevented by an earlier CC termination date. Therefore, choosing optimal sowing and termination dates is a vital tool to improve Neff of CCs, in which we should prioritize the $N_2$-fixing activity of legume species.

CC reduced the Ninorg leached below the barley's root zone by 16 kg N $ha^{-1}$, compared to the tilled plots. We expected deep-rooted species could make differences in their ability to reduce subsoil Ninorg in autumn or improve topsoil Niorg pool in the spring. However, we did not detect differences among CC mixtures. Unlike our result, Vos et al. (1998), Thorup-Kristensen (2001) and Thorup-Kristensen and Rasmussen (2015) found that N depletion and N supply of different single CC species were strongly dependent on differences in root growth. In the study of Thorup-Kristensen and Rasmussen (2015), deep-rooted species like dyer's woad and chicory had a much higher capacity to deplete subsoil Nitrate of 1 - 2.5 m than a control treatment without CC and a ryegrass treatment. From below 1.5 m depth, this variation among the mentioned CC species was much higher. They also observed the roots of ryegrass and legume species at below 1m depth, but with a much lower rooting intensity (≤ 8 at 0.8 – 1.6 m depth and ≤ 1.1 root intersections per meter grid line at 1.6 – 2.4 m depth) than chicory and dyer's woad (18 - 35 root intersections per meter grid line at each depth). From this result and in combination to the fact in our study that the soil nitrate level was low at our study site and a high autumn precipitation, we would expect to be able to detect the variation of the N uptake capacity among CC treatments in deeper soil layers below 1.5 m.

In summary, the row cropping system with a row width of 0.24 m is suitable for the growth of CCs. This study also provides a wide range of CC mixtures for sufficient N supply in the arable organic crop production. In order to maximize the Neff of CCs, we recommend that the undersown CCs should be sown at three weeks after the main crop sowing date to optimize legume growth and conduct spring CC incorporation as early as possible. The intensive autumn tillage should be avoided to minimize N leaching loss. For future work, we can improve the effect of our cropping system by employing interrow hoeing between the CCs rows after main crop harvest.

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