CATCH CROP (OIL RADISH) FUNCTIONS IN LONG TERM CEREAL CROP ROTATION

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Abstract: The aim of our research work was to study the role of the oil radish catch crop (Raphanus sativus var oleiformis Pers) as second crop or stubble crop for green manuring in winter wheat-winter barley-maize crop rotation. The oil radish was grown after the harvest of winter barley in the crop sequence. The green biomass (t ha^{-1}), nitrogen (N) content in dry material (g kg^{-1}) of catch crop and the N (kg ha^{-1}) taken up by the catch crop were investigated for six years (1997-2002). The main goal was to measure the amount of remained N in the soil left by the main crop (WB) and the amount of N taken up by the oil radish catch crop. The maximum N uptake was about 120 kg ha^{-1} calculated on the average of the years but in the rainy 1998 the N removal reached the 200 kg ha^{-1} N. On the basis of the N balance calculation it is proved that incorporation of the catch crop in the crop sequence, the risk of N leaching diminishes, or can be minimal even if the level of N input is high, because the N removal of green biomass retains N in the soil and this way N turnover of the crop rotation remains balanced.

Keywords: oil radish catch crop, N fertilization, N loss, N uptake, N balance.

Introduction

In many regions of the world, soils are managed intensively during a certain period of the year mostly for the production of a particular crop. Following that period, little is done to keep the soil in optimal conditions. The problem is that major degradation processes, such as erosion, leaching and compaction are often most intense during the period without crop cover. A key question for crop production sustainability in the 21th century will be the extent to which agriculture will develop special agronomic practices to manage the uncovered period so that to minimize undesirable material flows from the agroecosystem. For example, cover crops can increase the net primary productivity, can have advantageous effect on the food chain quality and enhance the organic portion of nutrient cycle (Lal and Pierce, 1991).

To compile a proper crop rotation it is important to know how long time is available between the harvest of pre-crop and the sowing time of the next crop and how appropriate this period is for the following crop. In this term it is possible to strengthen the positive effects of fore crop and diminish the unfavourable effects of the inadequate pre-crop (Kismányoky, 2013). According to Kemenesy (1961), the positive and negative effects of green manure as a second crop are as follows: increasing the amount of labile humus, ameliorating soil structure, mobilizing soil nutrients, bonding nutrients in organic forms, N-fixing by legume crops, increasing the effects of fertilizers, loosening the soil by deep rooting, weed control, overshadowing the soil surface, improving and maintaining the biological activity of the soil, erosion control. On the other hand, the water and nitrogen reserve in the soil can be decreased. Experiments of Westsík (1965) performed in crop rotation on sandy soils is outstanding. He focused on the agro-technique of N-fixing crops such like lupines as a main and second crop.

Green manures improve soil quality not merely because of the incorporated organic crop parts, rich in nutrients, but owing to the strong root structure developed, too. The roots increase the organic carbon (OC) content in the deeper soil layers, and pave the way for the roots of the next crop as well. The roots of the following crop penetrate into the deeper soil layers and this way they will be able to resist the dry periods (Láng, 1962). Kahnt (1986) summed up in 12 points the favourable effects of green manuring, and emphasizes the importance of the organic matter and nitrogen

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accumulation, furthermore the mitigation of nutrient losses, first of all the N leaching. Further advantages and disadvantages of green manuring are summarized in the papers of Kismányoky (1996) and Tóth (2006).

According to the field experiments of Ujj (2006) the cultivation of oil radish as stubble crop for green manure is advisable to grow but the hazards should be taken into consideration such as sowing time, water demand of the next crop, weed control etc.

Oil radish as green manure and winter barley straw residues (plus added N) increased the OC content of soil by 0,2% in a long run compared to the control NPK treatments in crop rotation, but this increase didn't reach that of by farmyard manure application. The continuous OC input is important for humus dynamics and humus balance, which is more effective than adding a higher amount of organic manure occasionally (Kismányoky, 2013).

There is a proverb from Arizona which says: "It does not matter to the horse how much water is in the tank as long as replenishment is continuous". Organic matter feeds microorganisms that release nutrients from organic matter and minerals that improve soil structure and increase water-holding capacity. Green manure and cover crops are planted to support soil protection, to pick up soluble nutrients that might otherwise be leached. Therefore the principle in soil management is that soils should never be allowed „rest", something should always be grown on them (Cook and Ellis, 1987). The cruciferous summer crops with N fertilization shadow the soil surface, this way the decomposition of straw is accelerated under humid circumstances, while, on the other hand, slows down in dry conditions (Kahnt, 1986).

With joint application of green manure and fertilizers the efficiency of fertilizers improves (Kismányoky, 1993). The green crops sown in the stubble take up the soluble nutrients remaining after the previous crop that might otherwise be leached (El Titi and Landes, 1990). This is the so called retaining effect, which is very important under rainy conditions (Gyuricza, 2008). Non-leguminous cover crops, although they do not fix N, can provide substantial N amounts as "sanitary crops", taking up the leftover N, or, in rare cases, the N fertilizer applied for the cover crop. With the catch crops we can prevent the leaching of soluble nutrients from the soil, e.g. the most part of nitrogen which develops during the summer season (Gyárfás, 1951). Without their use, some of these surplus nutrients may be lost due to leaching or erosion and under intensive fertilisation and humid climate conditions, agro-environmental problems would increase (Wolf-Snyder, 2003).

Management of nutrients by including a green manure crop is a rationale method to prevent nitrate losses, mostly under intensive fertilisation, and humid climate conditions. For groundwater protection purposes, farmers in Baden-Würtenberg (Germany) must, by law, maintain the water soluble nitrate fraction of the soils bellow 45 kg ha^{-1}. Catch cropping is a practical way to mitigate nitrogen leaching in an environmentally sound way. In integrated and organic farms green manure crops were grown to fix nitrate that had been left behind by the main crop or had been mineralized after harvest.

Taking into consideration the above mentioned principles, the aims of the research work was to study the role of oil radish (Raphanus sativus var oleiformis Pers) catch crop as second crop or stubble crop, for green manuring in cereal crop rotation. The crop rotation consisted of winter wheat-winter barley (WB)-maize. The oil radish came after the harvest of WB in the rotation. The green biomass (t ha^{-1}), nitrogen (N) content of oil radish based on in dry material (g kg^{-1}) and the amount of N (kg ha^{-1}) taken up by catch crop were analysed in the period of 1997 to 2002. The main goal of setting up the trial was to measure the amount of N remained in the soil after the main crop

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(WB) and the amount of N taken up by the catch crop. It was supposed that as an effect of the different fertilizer treatments of the pre-crop the amount of N remaining in the soil following the harvest would be different as well.

Material and methods

The study was conducted in the international mineral and organic nitrogen fertilization trial (IOSDV) located in Keszthely in the west part of Hungary (46°44' N 17 13 E, 112 m above sea level). The long term field experiment was set up in the autumn of 1983. The experiment has been maintained since that time. In this study the data derived from the period of 1997 to 2002 are analysed.

The soil type of the study site was Eutric Cambisol (IUSS, 2014), which is a Ramann –type brown forest soil according to the Hungarian soil classification system (Stefanovits et al., 1999). The texture of the plough layer is loam, containing 410 g kg^{-1} sand, 320 g kg^{-1} silt and 270 g kg^{-1} clay. The soil of the experiment showed low phosphorus supply (ammonium-lactate /AL/ soluble P_2O_5: 60-80 mg kg^{-1}), medium potassium supply (AL-K_2O: 140-160 mg kg^{-1}) and the humus (H) content fairly low (16-17 g kg^{-1}), with a pH_{KCl} value of 7.1. The bulk density is 1.53 g cm^{-3}. The 100 year average annual precipitation was 683 mm, but its distribution was often unequal, most average rainfall occurring in June (79 mm) while the lowest amount in January (35 mm). The long term annual mean temperature was 10.8 °C.

The factorial experiment has a strip-plot design with three replications. The size of the subplots is 48 m^2. The factorial treatments were mineral N fertilization (5 rates) combined with organic fertilizers (3 levels). Treatments were applied with three-year cereal crop rotation (maize-winter wheat-winter barley) system. The mineral N fertilizer rates were 0, 70, 140, and 280 kg ha^{-1} in case of maize, 0, 50, 150, and 200 kg ha^{-1} for winter wheat and 0, 40, 80, 120, and 160 kg ha^{-1} for WB. N rates are referred to as N0, N1, N2, N3, N4 indicating N doses hereinafter. Supplemental P and K fertilizers at rates of 100 kg ha^{-1} P_2O_5 and K_2O, resp. were applied on all experimental plots (even on the N control /N0/ plots).

Organic fertilizer treatments were applied as complementary fertilization with the mineral NPK fertilizers having three different variants: (I) no organic fertilizer application (control), (II) application of 35 t ha^{-1} farmyard manure (FYM) in every third years before maize, (III) straw incorporation (St) completed with 10 kg ha^{-1} mineral N for each t of straw/ stem. After WB, on the „St" plots oil radish (Raphanus sativus var. Oleiformis) was sown into the WB stubble for green manuring (Gm).

In this paper the effect of the oil radish catch crop (Figure 1.), incorporated in the crop rotation is presented, based on the (III) St+Gm variant block including N0-N4 treatments in the 5th, 6th and 7th crop rotation periods (1997 to 2002). It was grown after WB main crop

a) b)

Figure 1. Study field (a)) and flowering of oil radish (b)).

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as second crop (stubble sowing). Following the harvest, WB straw was chopped and incorporated into the soil at the same time with the sowing of catch crop. The sowing was carried out at the beginning of August with15-20 kg ha^{-1} seeds of the oil radish variety, without any fertilization. At the end of October green samples were taken from the oil radish biomass (one sample from 2x1 m^2/plots) for plant analysis. Dry matter content was determined in exsiccator. The N content of dry matter was measured by Kjeldahl method (Buzás, 1988).

For the calculation of N balance, on the input side we took into consideration the N rates of fertilization (N0-N4) before WB, the N content of straw of the fore crop wheat, which was chaffed and ploughed into the soil before WB, and the complementary amount of N fertilizer - 1 kg N for 100 kg dry material - , which was applied to secure the degradation of the straw manure. In the output side of N balance we considered the removed N by WB grain and straw, and the amount of N taken up by the catch crop biomass.

To define significant differences between different nitrogen fertilization rates Tukey tests were performed on the green biomass of oil radish, N uptake and N content by years and all year. Tukey HSD test at the 5% significance level was applied using the R package agricolae (de Mendiburu, 2014). Statistical analysis and graphs were prepared with R statistics (R Core Team, 2013).

Results and discussion

Green biomass production

The green biomass of oil radish increased continuously with increasing N fertilization rates in every year (Table 1). There is a strong correlation (0.876-0.999) between the N fertilization rates of previous main crop (WB) and the amount of remaining N fertilizer in the soil. The green biomass production varied between 10-40 t ha^{-1} according to the N fertilization of WB. Antal (1999) produced 15-25 t ha^{-1} green material of oil radish on sandy soil. The effect of the cropping years (rainfall) were even more determinate, defining the growing intensity of oil radish's vegetative parts.

On the other hand, according to the analysis of Ujj (2006), the green mass of catch crop as second crop was not always directly proportional to the intensity of nitrate uptake. Gyuricza (2008) found similar results in field trials, the mass of green manure crops was about 25-45 t ha^{-1}. He highlighted that green manure usually decreases the water content of topsoils, but during the winter time it becomes balanced. In the 2nd and 3rd variants the soil N significantly increased the green production of oil radish in every year compared to the control plots and to the previous variant, except in 1998. The variant 4th did not significantly increase the green biomass compared to variant 3, except in 1998. There was no significant difference between variant 4 and 5.

Table 1. Mean green biomass of oil radish (t ha^{-1})

Green biomass by year(t ha^{-1})	**N fertilization rates (kg ha^{-1})**					**Mean green biomass (t ha^{-1})**
	0	**40**	**80**	**120**	**160**	
1997	10.20^{d}	16.53^{c}	18.33^{bc}	20.43^{ab}	21.67^{a}	17.43
1998	10.33^{c}	16.20^{c}	26.73^{b}	35.90^{a}	42.87^{a}	26.41
1999	18.53^{d}	22.87^{cd}	27.70^{bc}	31.53^{ab}	36.53^{a}	27.43
2000	16.00^{c}	28.07^{b}	35.23^{a}	38.07^{a}	38.20^{a}	31.11
2001	10.77^{d}	14.30^{cd}	23.40^{bc}	31.67^{ab}	34.23^{a}	22.87
2002	21.27^{c}	31.53^{b}	34.73^{ab}	36.33^{a}	36.50^{a}	32.07
Mean green biomass (t ha^{-1})	14.52^{d}	21.58^{c}	27.69^{b}	32.32^{ab}	35.00^{a}	26.22

Between different N fertilization rates significant differences at 0.05 level are marked with different letters

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Table 2. Mean nitrogen content of oil radish based on dry material (g kg^{-1})

N content by year (g kg^{-1})	N fertilization rates (kg ha^{-1})					Mean N content (g kg^{-1})
	0	40	80	120	160	
1997*	18.10	18.60	23.00	20.50	25.40	21.12
1998	24.00^{b}	26.57^{b}	34.37^{a}	33.43^{a}	39.10^{a}	31.49
1999	10.30^{a}	11.37^{a}	11.70^{a}	10.83^{a}	11.87^{a}	11.21
2000	20.30^{a}	21.80^{a}	24.57^{a}	27.60^{a}	25.70^{a}	23.99
2001	37.40^{a}	34.30^{a}	39.53^{a}	45.57^{a}	48.23^{a}	41.01
2002	22.17^{a}	20.37^{a}	21.47^{a}	23.20^{a}	26.63^{a}	22.77
Mean N content(g kg^{-1})*	22.04^{a}	22.16^{a}	25.77^{a}	26.85^{a}	29.49^{a}	25.78

*For year 1997 only the mean values were available, therefore in Tukey test data of year 1997 could not be considered due to missing values.
Between different N fertilization rates significant differences at 0.05 level rates are marked with different letters.

It is proved by the green biomass production of catch crop that the amount of the remaining soil N is in accordance with the N rates given by the fertilization of the previous main crop – which was WB in our study. Eichler et al. (2004) considered the cover crops as a good solution to avoid the N leaching. In their field experiments the cover crops decreased the N losses by 240 kg ha^{-1} year^{-1}. The order of their N use efficiency was the following: oil seed radish, rapes, phacelia.

Correlation between green biomass of oil radish and N fertilizer dose is between 0.876 and 0.999 varying with years. Different levels of the green production by the studied years indicate the influence of the cropping years upon the success of second cropping. Successful growing of catch crops depends on many factors, among others the water consumption of main crop, the amount and distribution of summer rainfall, the quality of seed bed and the proper time of sowing are determinant.

N content of catch crop

The N content of oil radish increased parallel with the N fertilizer rates of the previous main crop (WB) and with the presumed higher soil N content from the zero plots to the high rates of N treatments (N4). The N content of oil radish biomass increased from 20 to 30 g kg^{-1} as an average. Actually, the lower limit was 10 g kg^{-1} N but the upper limit was almost 50 g kg^{-1} N in the whole dataset (Table 2.).

The variability of N concentration in the green plant tissue presumes that also the total N uptake (kg ha^{-1}) of catch crop would be variable, further to that the total biomass production (t ha^{-1}) is an independent and determinant variable factor, as well. Correlation coefficient between N content of catch crop's dry material and N taken up by catch crop is 0.759-0.974 varying with years.

N removal by catch crop

From the environmental and sustainable land use point of view the N uptake is a very important indicator in the crop rotation considering the whole productivity of the rotation and the efficiency of N fertilization.

Based on the average of the studied cropping years it can be observed that the N removal by the catch crop is increasing with increasing N fertilizer doses of the preceding crop (Table 3 and Figure 2). Correlation coefficient between catch crop's green biomass and N uptake by catch crop is 0.880-0.994 varying with years. This connection is mostly linear on average and annually, as well. The lowest value was 22 kg ha^{-1} and the highest amount of removed N was about 200 kg ha^{-1}. It is evident that the quantity of the removed N varied by years, as the amount of green biomass (Table 1.) and the N content of dry material (Table 2.) altered as well, however these are the main components of the final amount of N taken up.

Many other researchers published analogous

Table 3. Mean nitrogen uptake by catch crop oil radish (kg ha^{-1})

N uptake by year (kg ha^{-1})	N fertilization rates (kg ha^{-1})					Mean N uptake (kg ha^{-1})
	0	40	80	120	160	
1997	22.13^{d}	36.90^{c}	50.63^{b}	50.27^{b}	66.03^{a}	45.19
1998	29.87^{c}	51.83^{c}	110.37^{b}	143.33^{b}	201.23^{a}	107.33
1999	23.00^{c}	31.17^{bc}	41.30^{ab}	41.00^{b}	51.93^{a}	37.68
2000	39.00^{c}	73.47^{bc}	103.73^{ab}	126.33^{a}	117.90^{a}	92.09
2001	48.27^{c}	58.37^{c}	111.53^{bc}	173.87^{ab}	197.87^{a}	117.98
2002	55.50^{a}	77.00^{a}	82.50^{a}	100.83^{a}	116.93^{a}	86.55
Mean N uptake (kg ha^{-1})	36.29^{d}	54.79^{cd}	83.34^{bc}	105.94^{ab}	125.32^{a}	81.14

Between different N fertilization rates significant differences at 0.05 level rates are marked with different letters.

results. Boguslawski (1981) found that the oil radish as stubble crop, without N fertilization, yielded 3-5 t dry matter (31-51 t ha^{-1} green biomass) containing 20-40 kg ha^{-1} N. Mikó (2009) carried out field trials with a couple of catch crops, in which green material of the oil radish was 20-150 t ha^{-1}, providing 60-325 kg ha^{-1} N uptake without and with fertilization. The source of N residue in the soil is manifold but mostly it is due to the positive N balance of the previous main crop. Catch crops tend to improve the soil nutrient status by maintaining slow release of nutrients, in this way they are not readily lost to leaching or denitrification, contributing to the mitigation of environmental risks. The key factor seems to be the green manure (e.g. oil radish) sown in the stubble field as catch crop, therefore their role is increased nowadays. For ground water protection the water-soluble nitrate

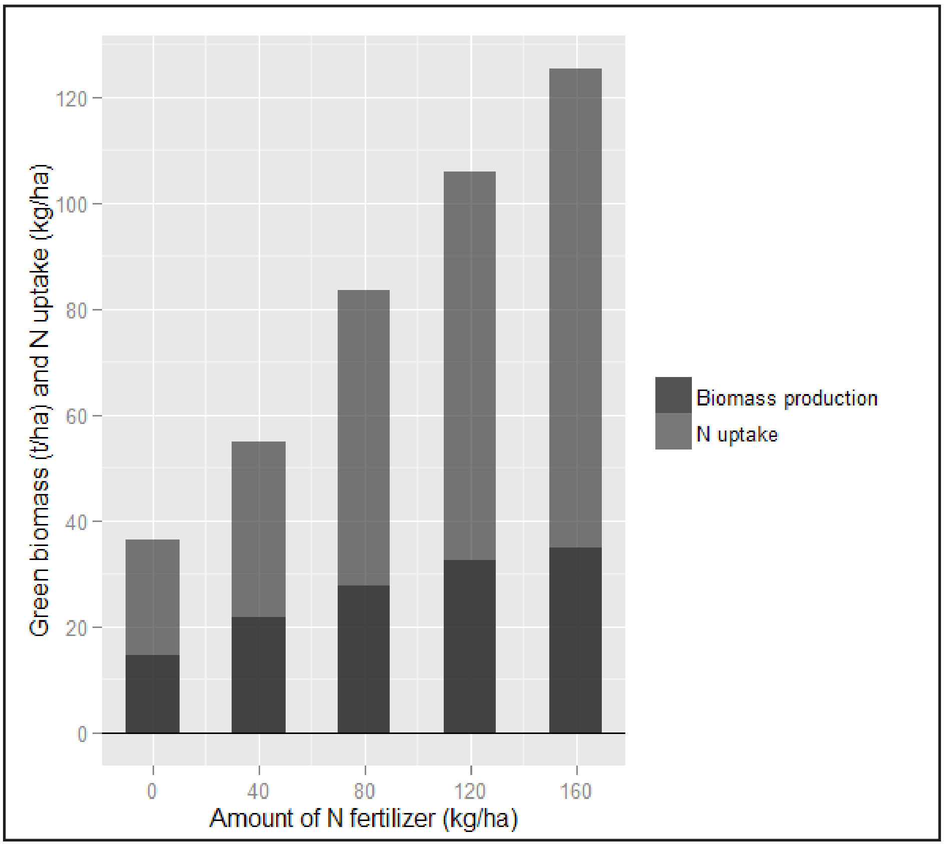

Figure 2. Mean green biomass and nitrogen uptake of oil radish catch crop applying increasing nitrogen fertilization to the winter barley (main crop) based on data of 1997-2002

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Table 4. Nitrogen balance of winter barley production without and with catch crop oil radish

Elements of N balance		N fertilization rates (kg ha^{-1})				
		0	40	80	120	160
Inputs	Winter wheat straw manure (3-5% N) (N kg/ha)	9.2	12.3	21.2	25.9	26.9
	C/N compensation (1 kg N/100 kg DM) (N kg/ha)	28.4	35.7	45.3	53.0	56.7
	Winter barley N rates (N kg/ha)	0.0	40.0	80.0	120.0	160.0
Total input		**37.6**	**88.0**	**146.5**	**198.9**	**243.6**
Output without catch crop	Winter barley uptake (N built in grain and straw) (N kg/ha)	-45.5	-62.5	-89.0	-104.4	-116.9
Output with catch crop	Winter barley uptake (N built in grain and straw) (N kg/ha)	-45.5	-62.5	-89.0	-104.4	-116.9
	Catch crop uptake (N kg/ha)	-36.3	-54.8	-84.0	-105.9	-125.3
Balance without catch crop (N kg/ha)		**-7.9**	**25.5**	**57.5**	**94.5**	**126.7**
Balance with catch crop (N kg/ha)		**-44.2**	**-29.3**	**-26.5**	**-11.4**	**1.4**

fraction must be maintained below the limit of 50 kg ha^{-1} in fall. The amount of N taken up by the catch crops might be different. According to Józsa (1985) about 70-100 kg ha^{-1} N were taken up by the different catch crops during the green manuring. The yield of stubble sowing of mustard and rapes were about 20 t ha^{-1} with the amount of 55-65 kg N ha^{-1}. Sowing these crops at the beginning of August, it corresponds to 100 kg N ha^{-1} (Kahnt, 1986). Our results are in accordance with it.

N balance (winter barley-oilseed radish)

The effect of green manure on retaining soil nitrogen was calculated in a N balance model (Table 4.). The input side of the balance consisted of the N fertilizer rates of WB, the N content of preceding crop's straw and the quantity of added N fertilizer for decomposition (C/N) of straw manure. On the other hand the output included the amount of N uptake in grain and straw (balance without catch crop), further to it the balance with catch crop included the N uptake of catch crop biomass as well.

Figure 3. shows that except the zero plots (N0) the balance without catch crop is positive in each variant and it is increasing parallel with the N doses of the preceding crop. It means that in case of the highest N treatment there is 126 kg ha^{-1} N surplus in the soil on average of the years. In case of N1-N4 the N use efficiency without catch crop is decreasing continuously with the increasing N fertilization; 71%-61%-52%-48%. Consequently: the higher the fertilizer rates of the previous crop, the lower the N efficiency of the N fertilization is, and higher the amount of N residue in the soil.

Taking into account the amount of N removed by the green biomass of oil radish the balance with catch crop can be calculated. The balance demonstrates that the catch crop eliminated the surplus N fertilizer from the soil completely. It is presumably incorporated into the green manure in organic form. Subsequently, after ploughing down oil radish and transformation of N in the soil, N would be available to the afterward plants. In this way it is possible to retain the N residue against leaching (Torstensson, Aronsson, 2000), which promotes environmentally sound agriculture (Askegaard et al., 2005). Based on these results it can be stated that the N surplus in the soil can be mitigated successfully by stubble

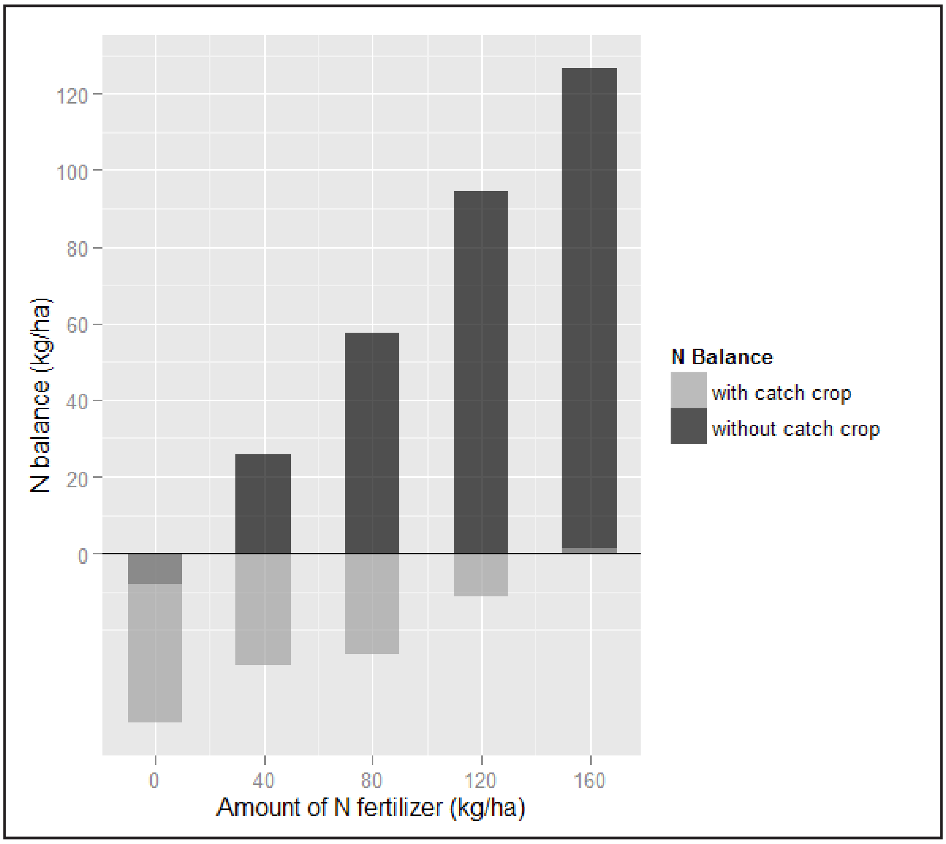

Figure 3. Nitrogen balance with and without oilseed radish catch crop applying increasing nitrogen fertilization to the winter barley (main crop) based on mean data of 1997-2002.

sown oil radish which takes up the residue N from the soil. Large quantity of N is left in the soil after the previous crop if the N fertilization was excessive resulting positive N balance.

Conclusions

Based on our study large quantity of N is left in the soil after the previous crop if excessive N fertilization is applied which results positive N balance. N fertilization rate of preceding crop higher than 120 kg ha^{-1} did not improve significantly the green biomass of oil radish in our study. Under the climatic conditions of the studied years oil radish reached its potential production when 120 kg ha^{-1} N fertilization was given to the previous crop. Mean N removal by catch crop oil radish was increasing with increasing fertilization rates during the studied six years. Maximum N uptake was 120 kg ha^{-1} based on the average of the years, but in the rainy 1998 year the N removal reached the 200 kg ha^{-1}. Significant differences were mostly observed between variants where difference in N fertilization rates was 80 kg ha^{-1}. N fertilization rates are highly correlated with green biomass (0.876-0.999) and catch crop's N uptake (0.929-0.991) and are also correlated with N content of dry material with varying correlation strength by years (0.637-0.956). N content of oil radish was between 0.92 and 5.47 % depending on the N fertilization rate of the preceding crop and climatic conditions. When catch crop is sown between winter barley and a spring row crop, such as maize, excess N in the soil will not be lost by leaching or released into the atmosphere but will be used by the catch crop. In our study the amount of N taken up by the catch crop increased with increasing N fertilization rates of the previous crop.

The N balance calculations proved that catch crop application in the crop sequence could avoid the risk of N leaching even if the level of N input was high, because N turnover of the crop rotation remains balanced by the green biomass' N uptake.

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Our study verifies that the N surplus in the soil can be mitigated successfully by stubble sown oil radish which takes up the residue N from the soil. In this way excess N - which would cause environmental pollution due to leaching or erosion - can be fixed in the catch crop, which amount can be beneficial for the crop following the catch crop. In this way, further to environmental considerations, also the cost of fertilization can be reduced due to decreasing N loss by the catch crop. The only investment needed for catch crop production is the cost of the seed, which is one order magnitude less than that of N fertilizer per ha. Considering it and the favourable effects of catch crop e.g. on soil structure, weed and erosion control, we can assume that integrating catch crop in the crop rotation will decrease the costs of plant production and increase net primary production in a long run.

For the better understanding of the catch crop's influence on plant production's N balance, analysis of meteorological data, nitrate leaching, nitrogen content and yield of row crop which follows the oil radish catch crop could be analysed as well in the future.

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