Research Article

Impact of maize conservation agricultural system on nitrogen losses through surface runoff and soil erosion in dryland

Fitri Wijayanti1, Syahrul Kurniawan2, Didik Suprayogo3*

1 Postgraduate Program, Faculty of Agriculture, Brawijaya University, Jl. Veteran no 1, Malang 65145, Indonesia
2 Soil Science Department, Faculty of Agriculture, Brawijaya University, Jl. Veteran no 1, Malang 65145, Indonesia
*corresponding author: Suprayogo@ub.ac.id

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Abstract: Nutrient loss in dry land through surface runoff and soil erosion is thought to dominate the watershed eutrophication. Conservation agriculture is expected to be able to reduce the nitrogen (N) loss into river systems. This study aimed to compare the N total input between conservation and conventional farming systems and to analyze N losses through surface runoff and soil erosion in conservation agriculture compared to conventional farming systems. The study was conducted at Agro-Techno-Park at Jatikerto, Brawijaya University from December 2017 to September 2018. The experiment was designed with three factors, i.e. (1) with and without biogeotextile, (2) No and conventional tillage, (3) application of four kinds of cover crop residues, with three replications. Results of the study showed that conservation agriculture was able to provide higher N inputs into the soil than conventional agriculture. The N loss through surface runoff was relatively low, ranging from 0.03 kg/ha to 0.45 kg/ha. N loss through erosion with conventional tillage and without biogeotextile reached 15 kg/ha to 32 kg/ha. No-tillage practices combined with the biogeotextile application significantly reduce N losses through soil erosion to only 0.3 kg/ha to 5 kg/ha. Conservation agriculture is one of the solutions to overcome the trade-off between the need for increased food production and environmental protection.

Keywords: biogeotextile, conservation farming, legume cover crop, no-till, N losses


Introduction

Land cover in the Brantas Watershed is dominated by dry land, which is 29% of the total area (Perum Jasa Tirta I, 2005). As an effort to meet the growing need for food, farmers on this dry land continue to increase their production through fertilization both inorganic and organic nitrogen (N). However, farmers application for practices of fertilizers and pesticides are higher than the recommended dosage. The use of N fertilizer turned out to have an impact on the decline in water quality in the river water of the Brantas watershed. On dry land agricultural system, the application of N fertilizer was allegedly mostly lost due to surface runoff and soil erosion. Surface runoff accompanied by sediment transport flows in the river system and enters the dam causing eutrophication. Valiant (2014) reported that NO₃ and NO₂ dissolved in the Sutami dam in the Brantas river flow system had exceeded the quality standards set by the Organization for Economic Co-Operation and Development (1982).

The application of fertilizer on annual crops has a negative effect on water quality, and it becomes a global concern nowadays (Bouraima et al., 2016). For example, as the most significant single contributor to N-nitrate sources in surface and groundwater pollution in the United States was the agricultural sector (Burkart and Stoner, 2001), Canada (Casson et al., 2008), Brazil (Portela et al., 2018) India (Lal and Mishra, 2015), China (Wang et al., 2019) and Nigeria (Oshunsanya et al., 2019). Rasouli et al. (2014) found the fact in Canada that
sediment in surface runoff and nutrient leaching contributed to 49% of N (from fertilizer) transports in surface waters. In many countries in the world, intensive use of N and P fertilizers in agricultural land resulted in river water pollution (EPA, 2017).

Today agriculture has a challenge that is to find the way for increasing food production to meet food needs as a result of increasing population and on the other hand, agricultural land does not contribute to water pollution. Soil erosion due to rainwater is one of the most widespread types of agricultural land degradation (Garcia-Ruiz et al., 2017), and the world's agricultural land which under soil erosion mild to severe is about 90% (Xiong et al., 2018). Tuan (2015) recommends that the study of the relationship of soil erosion and N balance of current agricultural practices is an urgent need to protect land resources, prevent soil degradation and on the other hand continue to maintain annual crop yields.

Surface runoff and soil erosion carry nutrients mainly in dryland continue to dominate in the watershed eutrophication process. Schuman et al. (1973) stated that N loss through sediment in surface runoff was about 92% of the total and the largest at the beginning of the growing season then gradually reduced with the age of annual crops. For that loss of nutrients from dry land in the annual planting system is needed to conduct a study. Likewise, information about efforts to reduce the contribution of N fertilizer to river water pollution is also still limited (Bashagaluke et al., 2018). The N contained in aquatic ecosystems is derived in part from the majority of N fertilizers eroded from agricultural land (Sorando et al., 2018; Gai et al., 2019). Zhang et al. (2018) stated the main factor responsible for the water pollution by N and phosphorus in watersheds systems is soil erosion. This opinion is contrary to the results of the study of Lal and Mishra (2015) who stated that nutrient loss is very low in sediments compared to losses dissolved in surface runoff. However, it is very important to minimize nitrogen concentration in surface runoff and sediment for protecting the waters and preventing eutrophication (Zeng et al., 2007). Agricultural system management is not only aimed to increase production but also need to consider prevention and control of water pollution through surface runoff and soil erosion. Soil management has a great influence on nutrient loss through soil erosion (Bertol et al., 2003). Zhang et al. (2018) have conducted a study on reducing the dose of fertilizer, the results of which are still able to maintain annual crop production and can simultaneously reduce water pollution. The legume-based planting system in combination with inorganic fertilizers and biochar management can effectively reduce nutrient losses 38% lower than conventionally grown corn (Bashagaluke et al., 2018). The combination of “orong” plant (local name) and fertilizing doses according to recommendations can significantly reduce nutrient losses from agricultural land, improve water quality and maintain optimal yields on sloping land (Oshunsanya et al., 2019). Rasouli et al. (2014) emphasized the importance of rules for over-fertilization control by farmers. Tuan (2015) states that the practice of conservation agriculture is a part of sustainable farming system practices that can maintain and even increase the production of annual agricultural crops and on the other hand can control land degradation.

Conservation agriculture has goals that are to achieve sustainable and profitable agriculture and to improve farmers' income, through three principles of conservation agriculture, namely minimal tillage, year-round land cover (can be through mulch) and crop rotation (FAO, 2013). Application of conservation agriculture is expected to be able to cope with pressures that occur both in terms of the environment and the need for food (Paudel et al., 2014). In this study, the practice of conservation agriculture through a combination of no-tillage, biogeotextile for covering soil surface and cover crop or crop rotation is expected to have a good impact for better annual crop yields and control N losses through surface runoff and soil erosion. A conservation agriculture system consisting of minimum processing, mulch and groove making a positive impact not only on corn yields but also stability in the semi-arid region (Kiboi et al., 2017). No-tillage increases the percentage of macroaggregates and maintains water content, at a depth of 0-15 cm per percent of the macroaggregate mass that can be filled with water is 12.77% in treatments without tillage at wheat rotation rather than conventional at wheat rotation (Song et al., 2016). In the research of Prasuhn (2012), it was shown that 88% of erosion occurred in conventional treatment with plough, 9% in land without plowing with a soil surface cover <30%, 1% in land with mulch application with residual surface cover >30%, and 2% on land without tillage an soil surface cover >30% (Mhazo et al., 2016). The use of mulch to reduce erosion by water in various conditions with reduced average runoff volume sediment, and nutrient loss, in some cases up to 90% in total (Prosdocimi et al., 2016). Amorpha fruticosa, Lespedeza bicolor and Medicago sativa legumes are significantly able to improve the chemical and biological properties of the soil (Wang et al., 2017). The combination of improved soil management and legume planting can reduce soil loss by 99% and nutrient loss by 96% (Medicago sativa, 2010). The application of conservation agriculture can increase crop

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production and change the biogeochemical processes in the soil so that it can reduce the loss of dissolved nutrients (Wagena and Easton, 2018).

This study aimed to investigate how conservation farming practices can provide better N inputs than conventional agriculture and reduce N losses through surface runoff and soil erosion to surface water bodies. Information from this research will increase for a better understanding of the role of conservation agriculture to reduce pollution in water. The research is also expected to provide basic support for local farmers and global information to address the challenges of how to increase food production, and on the other hand, agricultural land does not contribute to water pollution.

Materials and Methods

Research site

The research was conducted in dryland of Agro-Techno-Park, Brawijaya University, Jatikerto village, Kromengan District, Malang Regency, East Java, Indonesia (Figure 1) from December 2017 to September 2018. This site is located at the coordinates of 8° 07’ 36” south latitude and 112° 31’ 46” east longitude. The type of soil at the research location is Alfisol (Prasetyo et al., 2014). The annual rainfall based on 10 years data (2006 - 2015) ranged from 1598 mm to 3540 mm (with an average relative humidity of 77.5%). The type of climate based on Schmidt Ferguson is type C. Laboratory analysis was done in the Soil Chemistry Laboratory, Soil Science Department, Faculty of Agriculture, Brawijaya University.

Research design and treatment

This study used a factorial randomized block design. Three factors tested were (1) without and with the use of biogeotextile, (2) types of cover crop residue inputs, (3) conventional tillage (in accordance with farmer practices) and no-tillage. This plot of research had been two years establishment, then this measurement was in the second year. Biogeotextile was made with three layers with a two outer layer made from the leaves of “Mendong” (Fimbristy lisumbellaris) which was filled with leaves of Imperata (Imperata cylindrica). Biogeotextiles were designed to provide input with organic biomass 10 t/ha.

Figure 1. Location of field research in Agro-Techno-Park, Brawijaya University, Jatikerto, Malang, East Java, Indonesia.
Cover crop residues applied were without cover crop, cowpea (Vigna unguiculata), “Orok-orok” (Crotalaria juncea), Gude beans (Cajanus cajan), “Koro Benguk” (Mucuna pruriens). The total number of treatment combinations was 2 x 5 x 2 = 20 treatments, each treatment was repeated 3 times so that in total there were 60 experimental plots. The size of each trial plot was 18 m².

The maize variety “Pertiwi” was planted with a spacing of 75 cm x 20 cm. Biogeotextile was applied by covering the soil on the entire surface of the planting areas and planting holes were made. Cover crop residue was obtained from cover crop planting in each plot which was planted at the beginning of the dry season in the previous planting season. At the time of preparation for planting, the cover crop was harvested and returned to the experimental land after the treatment was designed. For the no-tillage treatment, weeds were only cleared by hand weeding. The conventional tillage was prepared by making 6 simple mounds of soil (30 cm high) for planting. All plots were fertilized according to farmers’ practices with dosages of N = 90 kg/ha, P₂O₅ = 30 kg/ha, and K₂O = 25 kg/ha, where the P fertilizer was given at planting while N and K fertilizers were given 1/3 parts at 7 days after planting and 2/3 parts were given at 40 days after planting. Crops maintenance included soil tillage, weeding and bounding at 30 days after planting for the conventional tillage treatment only. The hand weeding was done in the no-tillage and biogeotextile treatments. The measurement of N losses through surface runoff and erosion was measured in a 2 m x 1 m area of erosion plot (A) connected with a runoff collector that was made of plastic jerry cans.

**Sampling and analysis of runoff, erosion, cover crop and maize**

For the determination of N input was determined three kinds of inputs namely, artificial fertilizer, cover crop residue, and biogeotextile biomass input. N input of fertilizer was determined from the recommendations applied by local farmers, it was 90 kg/ha N-area. N Input from cover crop was obtained from biomass multiplied by N content of cover crop legume-plant residues in previous plantings. N total content of legume cover crop referred to previous research by Mustikaningrum et al. (2018) which Vigna unguiculata, Crotalaria juncea, Cajanus cajan, Mucuna pruriens have N content 2.77%, 1.69%, 1.77%, and 1.81% respectively. N Input from biogeotextile was obtained from 10 t/ha biomass of Imperata cylindrica and Fimbristy lisumbellaris with mix both of them with N content was 1.2 %. Determination of nitrogen carried in surface runoff and soil erosion was carried out by the analysis of surface runoff and erosion samples. Soil erosion measurement is carried out by taking a sediment every rainy day, as well as for surface runoff. Surface runoff was determined by measuring the volume of surface runoff that is collected in jerry cans (V) at each rain event during maize growth. To determine the N content in runoff and soil erosion was sampled 1 litre of runoff and then filtered to separated between water-runoff and sediment. The sample water-runoff (Nr) and sediment (Ns) in each rainfall event were analyzed by the Kjeldahl method (Kjeldahl, 1883). N loss through surface runoff was determined as follows:

\[
N_{Ro} = \left(\frac{V}{A} \times 10000\right) \times Nr \quad \ldots (1)
\]

where:

\[N_{Ro} = \text{Total N loss through surface runoff (kg/ha)}\]
\[V = \text{Volume of water collected in jerry cans (m³)}\]
\[A = \text{Erosion plot area (m²)}\]
\[Nr = \text{Total Nitrogen content in 1 (one) litre of surface runoff (kg/m³)}\]

N-soil loss through soil erosion is determined as follows:

\[
N_{So} = \left(\frac{V}{A} \times 10000\right) \times S \times N_s \quad \ldots (2)
\]

where:

\[N_{So} = \text{Total N loss through soil erosion (kg/ha)}\]
\[S = \text{Total sediment in 1 (one) litre of surface runoff (kg/m³)}\]
\[N_s = \text{Total Nitrogen content sediment (kg/kg)}\]

The N content in maize biomass was determined from the weight of harvested maize biomass multiplied by N content of its maize biomass. The harvest of maize biomass was measured by dry weight of total biomass at each plot experiment. N content of maize biomass at sampled each plot experiment was analyzed by the Kjeldahl method (Kjeldahl, 1883).

**Data analysis**

The data obtained during the research were compiled using the Microsoft Excel program. Prior to statistical analysis, the normality of existing data was tested to determine the distribution of data. Analysis of variance of 5% ANOVA was conducted to determine the effect between treatments. If there were significant differences at the 5% level, then there would be a further test of Duncan between treatments. To find out the relationship between N input and N-in maize
biomass, N loss through surface runoff and soil erosion were done using correlation tests. Genstat 18 edition program and software of Sigma Plot version 10 were used to perform statistical analysis.

Results and Discussion

Input of nitrogen

In conventional farming systems (with conventional tillage and without biogeotextile applications), maize crop only got N input from the application of artificial fertilizer of 90 kg/ha. If in this system cover crops were planted in the dry season before planting maize, N input only increased by 101 kg/ha (\textit{Cajanus cajan} cover crop) to 146 kg/ha (\textit{Crotalaria juncea} cover crop) (Figure 2a). The cover crop residue was only able to increase 1.1 to 1.6 times N input compared without applying the cover crop in the conventional farming system. Likewise, if it was treated without tillage and without biogeotextile, the growth of cover crops planted during the dry season also provided insufficient addition of soil N inputs (Figure 2b). Cover crop only provided input of 91 kg/ha (cover crop gude) to 128 kg/ha (cover crop scrambled) or increased by 1.0 to 1.4 times compared without planting a cover crop. This shows that the cover crop with no-tillage growth to produce biomass in the dry season is lower than conventional tillage.

![Figure 2. Comparison of total N inputs in maize cropping systems with different N input of cover crop residue namely C (control/without cover crop), CC (\textit{Cajanus cajan}), MP (\textit{Mucuna pruriens}), CJ (\textit{Crotalaria juncea}), VU (\textit{Vigna unguiculata}). Different letters above the bar graph show significant differences with the Duncan test with a confidence interval of 0.05%.

Biogetextile application provided 125 kg/ha of N input in the maize cropping system. The N input from biogeotextile was sourced from stuffing biogeotextile namely \textit{Imperata cylindrica} and mendong as the outer layer biogeotextile material. Biogeotextile applications in the previous planting season were also able to provide better cover crop growth in the dry season with soil N input from the cover crop as much as 48 kg/ha (\textit{Crotalaria juncea}) to 261 kg/ha (\textit{Mucuna pruriens}) with conventional tillage (Figure 2c). In conventional tillage systems with biogeotextile applications with cover crop residues, the total N input in the maize cropping system increased 264 kg/ha (\textit{Crotalaria juncea}) to 476 kg/ha (\textit{Mucuna pruriens}) or able to increase 2.9 up to 5.3 times higher than maize crop systems without biogeotextile, conventional tillage and without cover crop protection. Biogeotextile
applications combined with no-tillage provided the best soil N input. The maize crop got N input from the cover crop as much as 51 kg/ha (Crotalaria juncea) to 343 kg/ha (Mucuna pruriens) (Figure 2d). In without tillage, biogeotextile applications and cover crop residues increased N input in the maize cropping system 266 kg/ha (Crotalaria juncea) to 558 kg/ha (Mucuna pruriens) or increased 3.0 to 6.2 times higher compared to maize cropping systems without biogeotextile, conventional tillage and without cover crop residue.

The result of this study indicated that the application of biogeotextile and without tillage in the previous planting season was able to provide better soil moisture and soil fertility conditions than without biogeotextile, conventional tillage and without cover protection. Better soil moisture and soil fertility conditions can provide better media for germination and cover crop growth in the dry season. The better of germination and growth of cover crop will certainly provide relatively higher biomass cover crop production. If the residual cover crop is returned to the land, it will also provide a higher input of soil N. This shows that soil conservation agriculture practices can support improved soil fertility. Naab et al. (2017) report that the provision of previous crop residues can improve soil quality compared to conventional agriculture. Minimum tillage and return of plant residues can increase soil N content in the upper soil (0-50 cm of soil depth) (Mrabet et al., 2012). Provision of plant residues at the soil surface as mulch is an important component of conservation agriculture that can increase carbon inputs and enhance ecosystem benefits such as soil fertility, improved groundwater relationships, and biological properties (Palm et al., 2014).

**Loss of N through surface runoff and soil erosion**

The loss of dissolved N through surface runoff in one cycle of maize cropping system was relatively low, ranging from 0.03 kg/ha to 0.45 kg/ha (Figure 3).
N losses through surface runoff in the vegetative phase are relatively higher than the generative phase of maize plant growth (Figure 3). Conventional tillage resulted in higher N losses through surface runoff than without tillage (Figure 3a and Figure 3c compared to Figure 3b and Figure 3d). The application of maize cultivation without tillage and combined biogeotextile applications significantly reduced losses through surface runoff compared to conventional tillage and without biogeotextile (Figure 3d).

In the maize cropping system, loss of total N transported through soil erosion was much higher than loss through surface runoff. The N losses through erosion with conventional tillage and without biogeotextile reached 15 kg/ha to 32 kg/ha (Figure 4a). N losses through soil erosion in the tillage period until the vegetative growth period was relatively higher than in the generative phase. The maize cultivation without tillage and or combined with biogeotextile applications can reduce N losses through soil erosion to only 0.3 kg/ha to 5 kg/ha (Figures 4b, 4c and 4d). The results of this study were similar to those of Cassson et al. (2008) which states that the loss of N through soil erosion on the annual crop with no-tillage treatment was between 0.63 kg/ha/year to 9.8 kg/ha/year compared to conventional tillage of 0.1 kg/ha/year to 14.9 kg/ha/year.

Maize cultivation with no-tillage and the application of biogeotextile are part of the application of conservation agriculture. The reduction in the total of N losses in the conservation agriculture system was caused by the control of surface runoff and soil erosion. Nyamadzawo et al. (2012) reported that conservation agriculture is able to reduce surface runoff by 19% to 21% than conventional agriculture. The minimum tillage treatment was
able to reduce erosion by 3.8 t/ha (Van Pelt et al., 2016). Minimum tillage is able to reduce surface runoff by 30-50% and soil erosion by 50-70% compared to conventional tillage with disk ploughing and reduce surface runoff by 24-53% and erosion by 43-65% compared to land treated using chisel ploughing (Mrabet et al., 2012).

Keesstra et al. (2019) reported that the application of mulch (in this study is the application of biogeotextile) can reduce surface runoff from 50.5% to 65.6% compared to without mulch. Application of straw mulch reduced sediment transport from 16.7 g/L to 3.6 g/L and the soil erosion rates from 439 g to 73 g compared with no mulch. Decreased surface runoff and soil erosion have an impact on reducing N losses as a result of non-tillage treatment and biogeotextile applications. In mulching applications, biogeotextiles more recommended than using plastic mulch (Zribi et al., 2015).

N losses through surface runoff were much lower than N losses through soil erosion (Figure 3 and Figure 4). Atkinson and Ragland (1968) stated that if organic material is undergoing mineralization or artificial fertilizer added to moist soil it will quickly dissolve in the soil, where 70% in the form of NH$_4^+$-N and 10% in the form of urea and quickly converted to NH$_4^+$, and 20% in the form of NO$_3^-$-N. In the soil, NO$_3^-$-N moves freely following the flow of water, while NH$_4^+$-N is adsorbed by clay minerals in the soil (Atkinson, 2000; Ansorena et al., 2002; Ouyang et al., 2017). The N content in the soil is positively correlated with the amount of clay (Hua et al., 2011).

Relationship of total $N$ inputs and $N$ in maize harvest biomass

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Relationship of total $N$ inputs with $N$ content in maize biomass at harvest.

Figure 5. Relationship of total N inputs with N content in maize biomass at harvest.

Relationship of total $N$-soil input and $N$-soil loss through surface runoff and soil erosion

N losses through surface runoff in both the vegetative and generative growth phases are relatively lower than N losses through soil erosion (Figure 6). The loss of N through soil erosion with increasing N input, as a result of biogeotextile and return of cover crop residues treatment, was relatively decreasing drastically (Figures 6 d, e and f). This indicates that biogeotextile application can reduce N losses through soil erosion. This condition can certainly increase the efficiency of N inputs that can be utilized by corn plants. The use of biogeotextile is a solution to the problem of agricultural crops in the season with excessive use of artificial fertilizers which results in a low nutrient use efficiency that disturbs the...
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environment (Cui et al., 2013). The impact of N losses from agricultural land on environmental systems in river waters needs to be reduced (Sutton et al., 2011; Zhang et al., 2013; Oita et al., 2016). Improving the nutrient use efficiency is the simplest and most effective way to lower these environmental impacts, and biogeotextile application is one solution. Wang et al. (2018) review results show that the use of mulch (in this context biogeotextile) can increase nutrient use efficiency. The use of geotextile as solid mulch increases plant uptake of N compared to without mulch during vegetative growth (Liu et al., 2015).

![Graphs and charts showing N losses through surface runoff and soil erosion](image)

Figure 6. Relationship of total N inputs with N losses through surface runoff in (a) vegetative phase, (b) generative phase, (c) total N losses, and through soil erosion in (d) vegetative phase, (e) generative phase, (f) total N losses in one cycle of maize planting season.

**Conclusion**

Conservation agriculture is able to provide higher N inputs than conventional agriculture in a dry land. The application of biogeotextile and legumes cover crop residues significantly contributes N input. The loss of dissolved N through surface runoff in one cycle of maize cropping system is relatively low, ranging from 0.03 kg/ha to 0.45 kg/ha. N losses through soil erosion with conventional tillage and without biogeotextile reached 15 kg/ha to 32 kg/ha. The no-tillage combined with the biogeotextile application can significantly reduce N losses through runoff or erosion to only 0.3 kg/ha to 5 kg/ha. Addition of N inputs other than artificial fertilizers, namely through the cover crop residues and decomposition of biogeotextile material up to 350 N kg /ha, can increase N uptake of maize crops. Loss of N through soil erosion with increasing N input, as a result of biogeotextile treatment and return of cover crop residues, relatively decreases dramatically. For this reason, the practice of conservation agriculture is one of the solutions to overcome the trade-off of meeting the need for food production and environmental protection in the annual crop farming system on dry land.

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