Journal of Agricultural Science; Vol. 8, No. 9; 2016
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Effects of Oat (*Avena sativa*) and Hairy Vetch (*Vicia villosa*) Cover Crops on Nitrate Leaching, Soil Water, and Maize Yield in Subtropical Islands in Japan

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Received: May 6, 2016 Accepted: July 2, 2016 Online Published: August 15, 2016

doi:10.5539/jas.v8n9p44 URL: http://dx.doi.org/10.5539/jas.v8n9p44

Abstract

We determined the effects of oat (*Avena sativa*) and hairy vetch (*Vicia villosa*) winter cover crops on subsequent maize growth, soil erosion, water run-off, and nitrate leaching. Separate or combined plots of oat and hairy vetch cover crops were grown in winter, and maize was subsequently planted in all plots in the following summer season. The half-recommended N fertilizer (50 kg ha^{-1}) applied to zero-tillage maize produced the same biomass and yield as the control (i.e., natural fallow-maize with tillage and fertilizer application of 100 N kg ha^{-1}) when cultivated after hairy vetch (9.6 t ha^{-1}). In contrast, maize grown after oat showed 40.4% lower biomass and 65.4% lower yield. Compared to the control, runoff and soil erosion were 85.3-92.9% ($P < 0.001$) and 68.6-98.7% lower with cover crop mulch irrespective of cover crop species ($P > 0.05$), respectively. Cumulative nitrate leaching 60 cm below the soil surface was highest in the control, followed by (in descending order) hairy vetch-maize, hairy vetch + oat-maize, and oat-maize. NO_3-N release showed a twin-peak pattern in hairy vetch-maize plots at 18 and 37 days after sowing (DAS). Meanwhile, a single peak was observed in the control at 32 DAS immediately after top dressing at 31 DAS. The synchrony of N supply and crop demand were better in hairy vetch-maize than oat-maize or conventional cultivation owing to rapid maize growth under lower rainfall conditions.

Keywords: conservation griculture, cover crop, nitrate leaching, nitrogen balance, subtropical island

1. Introduction

Ishigaki Island is a subtropical mountainous island located from 24°20′-24°36′N and 124°04′-124°20′E. It is approximately 35 km long and 3 km wide in the south. As the island lies in the path of the warm Kuroshio current, its extensive reefs contain highly diverse coral species that highly attract many tourists. As in Okinawa (Sano, Shimizu, & Nose, 1984; Mucik, 1985), the coral reefs of Ishigaki are under great stress owing to human activity (Wood & Johannes, 1975). For example, construction work and the plowing of agricultural fields in coral regions produce extensive erosion, and municipal sewage and agricultural fertilizers cause eutrophication (Schnare, Ben, & Shields, 1984). Fertilizers rich in nitrogen, phosphorus, and potassium are spread at an annual rate of 1200-1600 kg ha^{-1} for sugarcane and pineapples, and 2400 kg ha^{-1} for rice (Kuhlmann, 1988). Environmental pollution caused by the agricultural industry occurs not only in Okinawa, but is also a widespread phenomenon in other coral regions.

Conservation agriculture involves minimal soil disturbance, permanent residue cover, and diverse crop rotations. Permanent soil cover through the use of cover crops and crop residue mulch retention combined with reduced tillage is suggest to be the best management practice for improving nutrient cycles and soil organic matter restoration, increasing available soil water, and controlling erosion (Hobbs, 2007; Hobbs, Sayre, & Gupta, 2008; Reicosky & Saxton, 2007).

Regarding diverse crop rotations, winter cover crops are increasingly being used to scavenge residual N in the soil after autumn crop harvesting to reduce N leaching and increase N supply for succeeding summer crops.

Therefore, the N fertilization rate can be either reduced or eliminated, reducing the cost of N fertilization. The effectiveness of cover crops in reducing N leaching and increasing N supply, which can be measured by simple C:N ratios, varies by species (Ford, Hargrove, & Neely, 1989; Vigil & Kissel, 1991). Grazing vetch, a high-N plant, is an ideal winter cover crop in irrigated maize-based smallholder conservation agriculture systems because of its ability to fix N in low-N soils, fast decomposition rate, and rapid nutrient release (Murungu, Chiduza, Muchaonyerwa, & Mnkeni, 2010b). Meanwhile, oat, a low-N plant, tends to provide greater biomass yields and residue persistence, consequently providing better soil cover against weeds and soil erosion (Murungu, Chiduza, Muchaonyerwa, & Mnkeni, 2010a).

Oat and leguminous (i.e., vetch) winter cover crops have different tissue chemistry (i.e., C:N ratio, and lignin and polyphenol content) and thus different decomposition characteristics (Murungu, Chiduza, Muchaonyerwa, & Mnkeni, 2010b). However, little is known about crop residue-soil-crop interactions with respect to N dynamics such as decomposition of the cover crops to verify C:N ratios, N release, absorption of mineralized nitrogen into the crop, N leaching, etc. in actual field conditions in subtropical islands.

Therefore, in the present study, we conducted field experiments to (1) verify the effects of two different types of cover crops on the growth of a succeeding zero-tillage cereal crop, soil erosion, and water run-off, and (2) evaluate the effects of the cover crops on N leaching with respect to N balance in a subtropical island in Japan.

2. Materials and Methods

2.1 Site Description and Experimental Design

This study was conducted at sloping fields of the Japan International Research Center for Agricultural Sciences (JIRCAS), Tropical Agriculture research Front (TARF), Ishigaki Island, Okinawa Prefecture, Japan. The climate is characterized by high rainfall, high air temperature, and high relative humidity. The mean air temperature in 2011 ranged from 15.5 °C in January to 28.6 °C in July. Rainfall in summer is strongly affected by typhoons. Annual rainfall in 2011 was 2269 mm.

An artificial sloping field with three blocks of different slopes (2°, 3.5°, and 5°) was constructed in 2003. The soil used was "Kunigami mahji," which is classified as a red-yellow soil in the Japanese soil classification system; it corresponds to Ultisol in the United States Department of Agriculture (USDA) soil taxonomy (Hamazaki 2005). The soil has a sandy clay loam texture with an average bulk density of 1.45 mg m^{-3}, average solid phase of 57%, and pH of 5.7-6.8, it has poor soil carbon content (0.53%). The soil is characterized by a fragile structure and high susceptibility to crushing (Miyara, Shimo, Gibo, & Onaga, 1999), making it susceptible to soil erosion. The plots were delimited using 20-cm-high wave plastic plates that prevent water movement from one plot to another. 5 plots (14 m long in the slope direction and 4.2 m wide) were delineated.

Table 1. Experimental design

Winter crop	Summer crop	Tillage	Crop residue	Fertilizer	Abbreviation
hairy vetch + oat (hvo)	maize	zero tillage (Z)	Slash and mulch	half of recommendation (1/2F)	hvoZ-1/2F
hairy vetch (hv)	maize	zero tillage (Z)	Slash and mulch	half of recommendation (1/2F)	hvZ-1/2F
oat (o)	maize	zero tillage (Z)	Slash and mulch	half of recommendation (1/2F)	oZ-1/2F
fallow (f)	maize	tillage (T)	Incorpration	recommendation (1F)	fT-1F
fallow (f)	maize	tillage (T)	Incorpration	no application (0F)	fT-0F

Note. The recommended dose of N fertilizer is 100 kg ha^{-1}. For the half treatment, 50 kg N ha^{-1} was applied.

The experimental design is shown in Table 1. Three factors (fallow system, tillage system, and fertilization dose) were combined to form six treatments. The hvZ-1/2F, oZ-1/2F and hvoZ-1/2F indicate zero-tillage (Z) summer maize cultivation with application of a half-recommended N fertilizer (1/2F) after winter hairy vetch (hv), oat (o), and both of hairy vetch and oat (hvo) cultivation. The residues of winter hairy, oat or the both were slashed and mulched prior to planting summer maize. The fT-1F and fT-0F indicate tillage (T) summer maize cultivation with application of a recommended (1F) or non N fertilizer application (0F) after natural fallow (f). The residue of natural fallow was incorporated prior to summer maize. The treatments were applied randomly to the five plots on each slope block (i.e., the same treatments in different slopes were considered three replicates if no significant differences were observed among them). Fallow was considered to be naturally developed weed fallow. Hairy vetch (*Vicia villosa* Roth) and oat (*Avena sativa*) were line-planted on November 24, 2010, with 0.35 m in between lines. Sowing densities for hairy vetch and oat were 40 and 80 kg ha^{-1}, respectively. Before sowing maize, the weeds in fT-1F and fT-0F were incorporated by the tillage of 15-20 cm soil depth using a cultivator after being killed by herbicide (Roundup maxload, Nissan Chemical Industries, Ltd., Tokyo, Japan). Hairy vetch and oat biomass were sampled to determine the total dry matter for each plot. Prior to maize sowing, planting lines approximately 10 cm wide were opened manually with hand hoes to displace hairy vetch or oat biomass. Maize (*Zea mays* L., var. KD742; Kaneko Seeds, Maebashi, Japan) was sown on April 11, 2011, with 0.7 m in between lines and 0.2 m between plants. The recommended dose of N fertilizer was 100 kg N ha^{-1} (Nagumo, Issaka & Hoshikawa, 2006). Half of the N fertilizer was applied during maize sowing, with basal-buried ammonium sulfate approximately 5 cm below the soil surface and 10 cm apart from each planting hill. As a base, phosphorus pentoxide (P_2O_5, 60 kg ha^{-1}) and 100 kg ha^{-1} potassium oxide (K_2O) were also applied together with N fertilizer. The remaining N was applied 31 days after sowing in the same manner but varying according to the treatment. For the half treatment, 50 kg N was also divided by half and applied for both the base and topdressing.

A soil sedimentation container was installed at the lowest edge of each plot to collect soil sediments during periods of rainfall to determine soil loss. Sediments were collected and weighed after drying in an oven at 70 °C for three days. Runoff water collected in the sedimentation containers overflowed into a second container with a V-type weir (30°, 20 cm wide). To determine water runoff, the water level in the second container was monitored at 1-min intervals by a GY-type sensor (UIZ-ECH20, UIZIN, Tokyo, Japan) and converted into water discharge.

2.2 Data Collection and Analysis

During the maize growing periods, leaf age, plant height, and leaf greenness (soil and plant analyzer development [SPAD] value) measured by a chlorophyll meter (SPAD-502 Plus, Konica Minolta Sensing Ltd., Osaka Japan) as well as stem diameter at the bottom of the above-ground part were measured at an average interval of 26.5 days.

At harvest (July 26, 2011), 20 hills in each plot were randomly selected and sampled; separated into leaf, stem, and cob parts; and dried in an oven (GT-150, Fujiwara Scientific Co. Ltd., Tokyo, Japan) at 70 °C for three days to determine maize yields and total dry matter. Plant samples were ground using a vibrating sample mill (TI-2000, CMT Co. Ltd., Fukushima, Japan) to determine the total N content. N content was determined by the dry combustion method using an NC analyzer (Sumigraph NC-95A, Sumika Chemical Analysis Service, Osaka, Japan).

Lysimeters consisting of two plastic boxes arranged on top of each other and bonded with silicone adhesive were constructed to collect percolated water. The inside width and length of both boxes were 320 and 420 mm, respectively. The inside depths of the upper and lower boxes were 300 and 150 mm, respectively. The bottom of the upper box had 16 holes with 63 mm in diameter and was covered with polyester spunbond (Lovesheet®, Unitika Ltd., Osaka, Japan) on a sheet of expanded metal. There were two vertical holes on a wall of the lower box with attached tubes for water collection and air venting. The two lysimeters were installed in the middle of the hvoZ-1/2F, hvZ-1/2F, oZ-1/2F, and fT-1F plots at the 5° slope. Two lysimeters per plot were fabricated: one in the maize row, and the other between the maize rows. They were buried 30 cm below the soil surface so that the bottom of the upper box was 60 cm below the soil surface. The upper box was refilled with the original soil. Approximately two days after rainfall, the percolated water stored in the lower box was collected using an air pump. After measuring the volume of the percolated water, the NO_3-N concentration was determined by a spectrophotometer (U-2000, Hitachi, Japan). The leached N was determined by multiplying the percolated water volume by the NO_3-N concentration.

NO_3-N in percolated water was only considered to calculate N balance, because the concentration was almost equal to that the total N. The runoff water was also collected. Because the N concentration of runoff water was zero, it was also ignored in the N balance estimates. Furthermore, N in the soil sediment was not considered.

In the plots where the lysimeters were installed, total N balance during the maize cropping period was calculated as follows:

Total N balance = total N input (fertilizer N + biomass N) – total N output (N uptake by maize + leached N) (1)

where, biomass N is N derived from hairy vetch, oat, or weeds.

The litter decomposition of hairy vetch and oat was investigated using a litter bag technique (Wagger 1989). Around the beginning of the cropping periods (April 12, 2011), 5 litter bags were buried approximately 5 cm below the soil surface or surface-placed in hvoZ-1/2F and fT-1F of the 5° sloping plots, respectively, with four replicates. Each litter bag contained 10 g (d.w.) hairy vetch or oat leaf tissue collected from the previous cultivation cut into 1-cm pieces. The collected litter was packed with three different over-layered bags made of different materials with different hole sizes. A material of the innermost bag was monofilament polyester mesh with 1-mm square holes, and the middle and outer bags were monofilament nylon meshes with 2- and 3-mm square holes, respectively. One surface-placed and one buried litter bag were harvested from the plots on five separate occasions. After collection, the litter adhering to each bag was carefully removed, and the litter contained within the bag was weighed. The weighed litter was then oven-dried at 70 °C for 48 h to determine the dry weight and hence calculate the initial litter remaining.

All statistical analyses were performed using JMP version 9.0.0 (SAS Institute, Cary, NC, USA). Differences between treatments were determined by ANOVA and Student's *t*-test where appropriate. The level of significance was set at $P < 0.05$.

3. Results

3.1 Effects of Cover Crops on the Growth of Succeeding Maize, Soil Erosion, and Water Run-Off

There were no differences in the biomass of cover crops among slopes. The total biomass of hairy vetch and oat in hvoZ-1/2F was 15.3 t ha^{-1}, which was significantly higher than that in hvZ-1/2F (9.6 t ha^{-1}) and oZ-1/2F (8.1 t ha^{-1}) ($P < 0.05$). The N contents of hairy vetch and oat plants were 4.9% and 1.9% (d.w.), respectively.

Maize exhibited different growth patterns among treatments (Figure 1a).

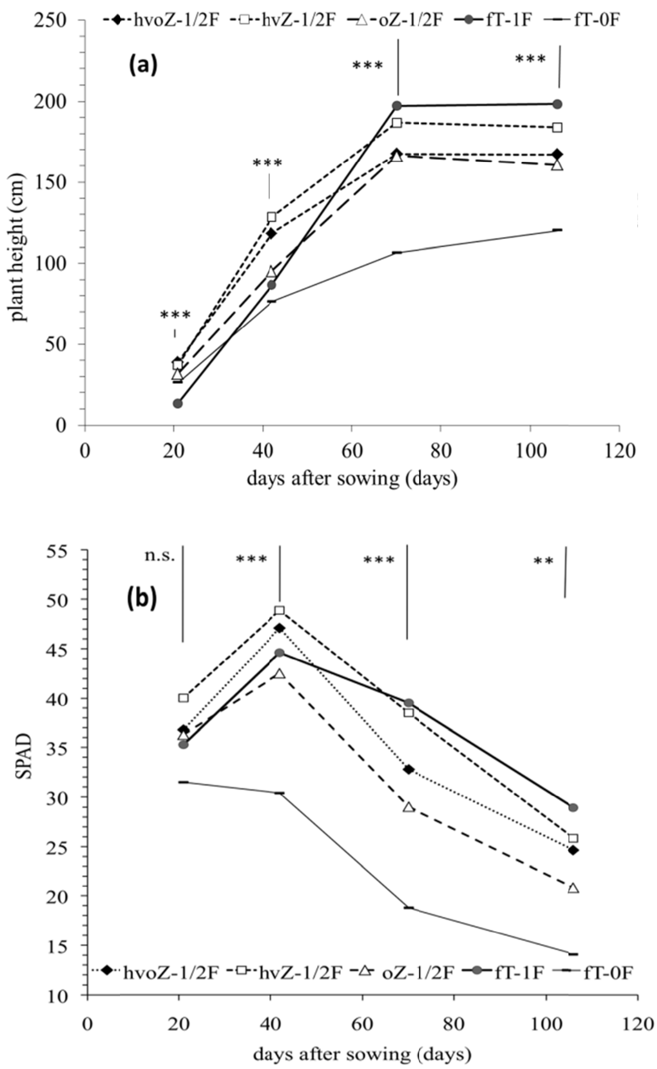

Figure 1. Changes of (a) maize height and (b) leaf chlorophyll (SPAD) among treatments

Note. ***, ** and n.s. indicate significantly differences by student t-test at P < 0.001, 0.001 < P < 0.01 and not significant, respectively.

During the first half-stage from 21-42 days after sowing (DAS), maize in hvZ-1/2F exhibited greater growth than maize in oZ-1/2F, fT-1F, and fT-0F. During the latter half-stage from 70-106 DAS, the growth of maize in fT-1F caught up to that in hvZ-1/2F, which was significantly taller than maize in hvoZ-1/2, oZ-1/2F, and fT-0F. The chlorophyll content of maize leaves also differed among treatments (Figure 1b). At 21 DAS, there were no differences among treatments. At 42 DAS, maize leaves in hvZ-1/2F, hvoZ-1/2F, and fT-1F had the greatest chlorophyll content, followed by oZ-1/2F and fT-0F ($P < 0.001$). From 70–106 DAS, the chlorophyll contents in fT-1F, hvZ-1/2F, and hvoZ-1/2F were the greatest, followed by oZ-1/2F and fT-0F ($P < 0.001$).

The decomposition rates of oat and hairy vetch varied more with respect to placement than species (Figure 2).

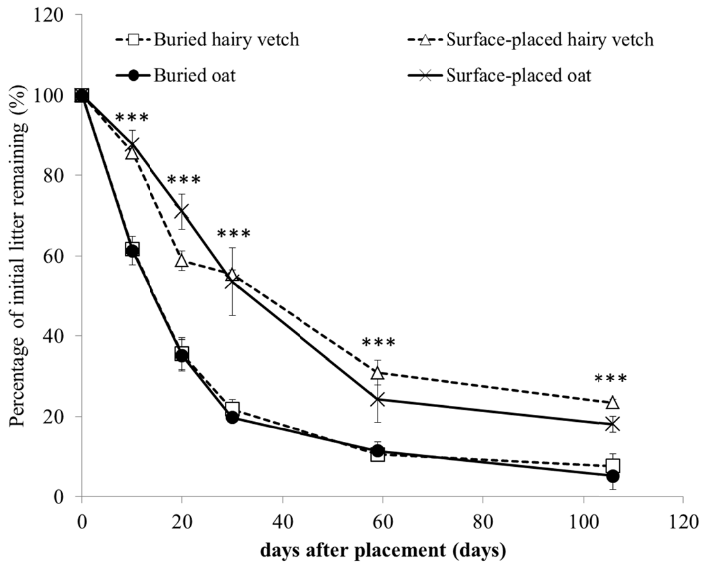

Figure 2. Changes of litter decomposition with respect to cover crop

Note. *** indicates significantly differences by student t-test at P < 0.001.

Buried litters decomposed more rapidly than surface-placed litters from 10 DAS to end of cropping ($P < 0.001$): 41.2% of surface-placed hairy vetch decomposed at 20 DAS, while 29.0% was decomposed in surface-placed oat. After 59 DAS, the decomposition of surface-placed hairy vetch was slower than that of oat ($P < 0.01$): 76.4% and 82.0% of the leaves decomposed in surface-placed hairy vetch and oat, respectively, at end of cropping (106 DAS).

The above-ground biomass of the succeeding maize was 13.6 t ha^{-1} in hvZ-1/2F, which was the same as that in fT-1F (13.3 t ha^{-1}, control) and not significantly different from that of hvoZ-1/2 (Figure 3).

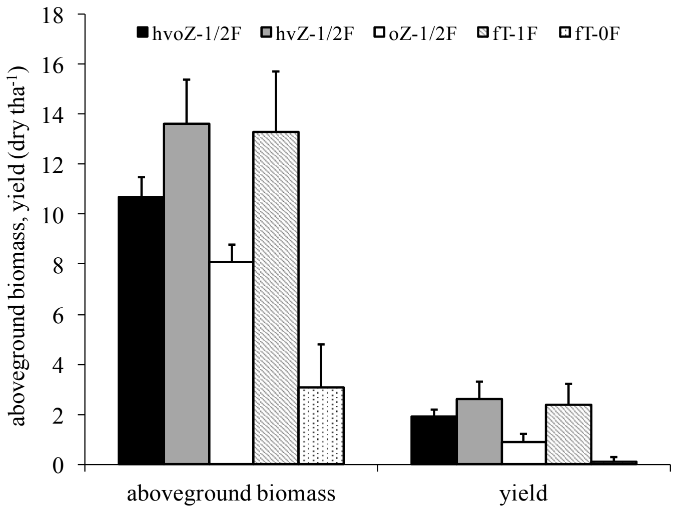

Figure 3. Above-ground biomass and yields of maize among treatments

In contrast, the above-ground biomass was 40.4% lower (P < 0.05) in oZ-1/2F and 77.2% lower (P < 0.05) in fT-0F than that in hvZ-1/2F. The yields of maize in hvZ-1/2F (2.6 t ha^{-1}), fT-1F (2.4 t ha^{-1}), and hvoZ-1/2F (1.9 t ha^{-1}) were the highest among treatments (P < 0.05). In contrast, the maize yield was 65.4% lower in oZ-1/2F and 88.9% lower in fT-0F than that in hvZ-1/2F.

The effects of treatments and slope on soil erosion and water runoff are shown in Table 2.

Table 2. Soil erosion and runoff

		Soil erosion (t ha^{-1})	Runoff (mm)
Treatment (T)	hvoZ-1/2F	0.70	13.1 c
	hvZ-1/2F	0.63	7.9 c
	oZ-1/2F	0.03	16.4 c
	fT-1F	2.23	111.3 b
	fT-0F	5.73	147.6 a
Slope (S)	2° slope	0.20	53.6
	3.5° slope	1.94	55.9
	5° slope	3.46	68.3
T	T	n.s.	***
S	S	n.s.	n.s.

Note. Letters indicate difference between treatments at the 5% level by student t-test.

*** and n.s. indicate significantly differences by student t-test at P < 0.001, and not significant, respectively.

Runoff was 85.3-92.9% lower in hvoZ-1/2F, hvZ-1/2F, and oZ-1/2F than that in the fT-1F (P < 0.001). In contrast, runoff was 32.6% higher in fT-0F (P < 0.001). Runoff showed a trend of increasing with increasing slope, although there was no statistical significance. Soil erosion in hvoZ-1/2F, hvZ-1/2F, and oZ-1/2F were 68.6-98.7% lower than that in the control (P > 0.05). In turn, soil erosion in fT-0F was 157% of the control (P > 0.05). Soil erosion showed an increasing trend with increasing slope, although there was no statistical significance.

3.2 N Leaching

The changes of cumulative percolated water, NO_3-N concentration in percolated water, and cumulative amount of nitrate leaching among treatments are shown in Figure 4. The total rainfall during the cropping period was 823 mm. The total percolated water was greatest in fT-1F (696 mm), followed by hvoZ-1/2F (593 mm), oZ-1/2F (555 mm), and hvZ-1/2 (506 mm) (Figure 4a). The cumulative percolated water in fT-1F exceeded that among all treatments at 26 DAS, remaining up to the end of cropping.

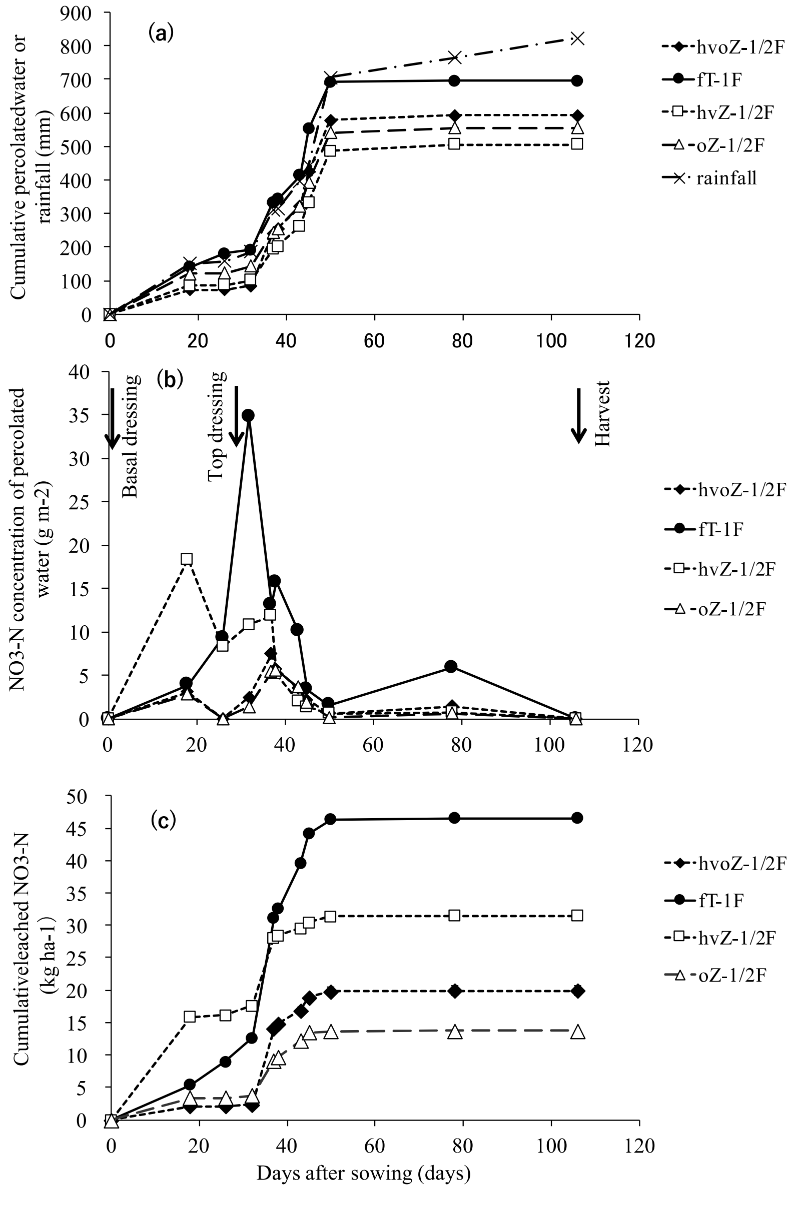

Figure 4. Changes in (a) cumulative percolated water; (b) nitrate-nitrogen (NO_3-N) concentration of percolated water and periodical rainfall; (c) cumulative amount of NO_3-N leached

There was very little rainfall from sowing to 14 DAS (18.5 mm). After heavy rainfall at 15 DAS (131.5 mm), little rain fell up to 32 DAS (7.5 and 28.5 mm up to 26 and 32 DAS, respectively, Figure 4a). Another large period of rainfall (122.5 mm) occurred from 32-37 DAS, and more than 40 mm rainfall continued with two weeks interval until harvest. NO_3-N release patterns differed between cover crop-maize and conventional cultivation. The release in cover crop-maize exhibited twin peaks at 18 and 37 DAS. Meanwhile, a single peak was observed in fT-1F at 32 DAS, which was greater than the first peak of hvZ-1/2F and appeared immediately after the application of top dressing at 31 DAS (Figure 4b).

Cumulative nitrate leaching was highest in hvZ-1/2F ($P < 0.05$) from the beginning to 32 DAS, followed by fT-1F, oZ-1/2F, and hvoZ-1/2 (Figure 4c). At 37 DAS, six days after top dressing, nitrate leaching in fT-1F increased rapidly, exceeding that in hvZ-1/2F, and remained highest until end of cropping. After the small first peaks of NO_3-N concentration in hvoZ-1/2F and oZ-1/2F at 18 DAS, cumulative nitrate leaching in hvoZ-1/2F increased rapidly at 32 DAS and remained third highest among treatments until the end of the cropping periods; this was followed by oZ-1/2F. Thus, the cumulative nitrate leaching from 38 DAS to harvest from highest to lowest was fT-1F > hvZ-1/2F > fvoZ-1/2F > oZ-1/2F.

3.3 N Balance

The total N balance including leached N during the maize cropping period of hvoZ-1/2F, hvZ-1/2F, oZ-1/2F, and fT-1F in the 5° slope are shown in Table 3.

Table 3. Total nitrogen (N) balance at the 5° sloping plots during the maize cropping periods

Treatments	hvoZ-1/2F	hvZ-1/2F	oZ-1/2F	fT-1F
Total dry matter (kg ha^{-1})	10580	13359	7937	13099
Total N input (kg N ha^{-1})	455	518	208	100
Biomass N (kg N ha^{-1})	405	468	158	0
Fertilizer (kg N ha^{-1})	50	50	50	100
Total N output (kg N ha^{-1})	124	158	75	170
Uptake N by maize (kg N ha^{-1})	104	127	61	123
Leached N (kg N ha^{-1})	20	31	14	47
Total N balance	331	360	133	-70

The total N input in hvZ-1/2F was greatest, followed by hvoZ-1/2F, oZ-1/2F, and fT-1F. The high N inputs in hvZ-1/2F and hvoZ-1/2F were mainly from both maize and cover crop biomass, while that in fT-1F was entirely from fertilizer. In turn, the total N output was highest in fT-1F, followed by hvZ-1/2F, hvoZ-1/2F, and oZ-1/2F. The total N outputs in all plots were mainly from N uptake by maize. Leached N in fT-1F was highest, followed by hvZ-1/2F, hvoZ-1/2F, and oZ-1/2F. Thus, the total N balance was positive in (descending order) hvZ-1/2F > hvoZ-1/2F > oZ-1/2F and negative in fT-1F.

4. Discussion

4.1 Effects of Cover Crops on the Growth of Succeeding Maize, Soil Erosion, and Water Run-Off

The hairy vetch leaves decompose rapidly during the early cropping stage (20 DAS, Figure 2). The leaf chlorophyll measurements (Figure 1b) indicate that mineralized N in hvZ-1/2F was properly absorbed by the succeeding maize (42 DAS) and contributed to maize growth (21-42 DAS, Figure 1a). Accordingly, maize in hvZ-1/2F gained 13.6 t ha^{-1} of above-ground biomass and achieved a grain yield of 2.6 t ha^{-1}, which is similar to that of conventional cultivation (i.e., fT-1F, Figure 3) despite the application of half the recommended fertilizer. In contrast, the mineralized N content in oZ-1/2F might be absorbed less by the succeeding maize (42-106 DAS, Figure 1b) compared to that in hvZ-1/2F because of the smaller N content of the plant. The contribution of mineralized N to maize growth was also smaller (21-106 DAS, Figure 1a) relative to that in hvZ-1/2F. Accordingly, compared to maize in hvZ-1/2F, maize in oZ-1/2F gained 40.4% less above-ground biomass and achieved 65.4% less grain yield. Thus, the mineralized N content of a mixture of hairy vetch and oat in hvoZ-1/2F might have maintained the same level as that in hvZ-1/2F and fT-1F from 42-106 DAS (Figure 1b), although the maize height was smaller in hvoZ-1/2F during the latter stage (i.e., 78 and 106 DAS) after rapid growth in the earlier stage (i.e., 20 and 42 DAS) than the maize in fT-1F (Figure 1a). Accordingly, the above-ground biomass and grain yield in maize were similar to those in hvZ-1/2F and fT-1F (Figure 3).

These results indicate that hairy vetch is more effective than oat at increasing maize biomass and yield because of its higher N content. The residue of hairy vetch mineralized rapidly, and inorganic N was sufficiently up taken by maize, contributing to its growth. Meanwhile oat produced less organic N despite producing greater biomass and did not contribute substantially to maize growth. Several reports corroborate the advantages of crop residue with low C:N ratios on the growth of subsequent cereal crops (Dube, Chiduza, & Muchaonyerwa, 2012; Danso & Papastylianou, 1992; Sainju, Singh, Whitehead, & Wang, 2007).

4.2 N Leaching

The ratio of percolation to runoff + percolation (calculated from Table 2 and Figure 4a) ranged from 86.2-98.5%. This result indicates that even if heavy rain causes runoff, most of the rain is percolated. Hence, the range of cumulative percolated water is narrow (Figure 4a), whereas the range of cumulative nitrate leaching is wider (Figure 4c) because of the differences in the NO_3-N concentration of percolated water (Figure 4b). The resultant biomass production, effect of winter cover crops on succeeding summer maize growth (Figure 3), and cumulative nitrate leaching closely reflect the characteristics of the two cover crops, verifying the role of C:N ratio reported previously (Dube, Chiduza & Muchaonyerwa, 2012; Wagger, 1989; Sainju, Singh, Whitehead & Wang, 2007; Danso & Parastylianou, 1992). Sainju et al. (2007) report that hairy vetch cover crop increases soil mineral N as well as succeeding cotton and sorghum N uptake compared to rye (high C:N ratio) but also increases the potential for N leaching. Accordingly, the authors propose that the potential for N leaching can be reduced and crop N uptake can be optimized by mixing vetch and rye. In the present study, cumulative nitrate leaching was higher in hvZ-1/2F than hvoZ-1/2F and oZ-1/2F, but 34% lower than that in fT-1F (Figure 4c) regardless of the high above-ground biomass and yield of fT-1F (Figure 3). These results indicate that hairy vetch cover crop is a better option than conventional cultivation with respect to the cost benefit of replacing half the required volume of fertilizer with residue.

The results show that 41.2% of surface-placed hairy vetch decomposed only at 20 DAS (Figure 2). The litter bag decomposition study indicated that the release of N from both surface and buried residues from winter legumes was sufficiently rapid to significantly benefit summer crops under humid subtropical conditions (Wilson & Hargrove, 1986). Stute and Posner (1995) also report that the decomposition of legume crops and release of mineralized N can be observed from 2-5 weeks regardless of tillage or non-tillage after cutting the cover crop in spring in southeastern USA. In addition, as the distribution of fertilizer N is quite localized owing to spot application, the leaching of fertilizer N may have been limited because of limited contact with percolated water (Nagumo & Nakamura, 2013). Therefore, spot application may delay nitrification, probably because of the high osmotic pressure at the application spot at least during the earlier stage. Hence, the different release pattern between cover crop-maize and conventional cultivation might be due to the difference in the localization of cover crop and mineral fertilizer as described by Nagumo and Nakamura (2013).

4.3 N Balance

Nitrate leaching in fT-1F increased rapidly, exceeding that in hvZ-1/2F at 37 DAS and remained highest until end of cropping (Figure 4c). Therefore, total N output was highest because of the high leached N in fT-1F, followed by hvZ-1/2F and the other treatments (Table 3). Total N release in fT-1F finally became negative owing to poor biomass N input and highest leached N content. In addition, 23.4% of hairy vetch remained even at the end of cropping, possibly contributing to nutrition in the subsequent cultivation. Thus, these results suggest hairy vetch cover crop contributes to store N in the soil. Dube et al. (2012) conclude that grazing vetch cover crops may be better suited than oat to low-N-input conservation agriculture systems for soil organic matter. Zibilske and Bradford (2007) mention that the beneficial effects of conservation tillage are directly related to soil chemical content and C and N accumulation. Owing to its low C:N ratio, hairy vetch incurs a risk of rapidly releasing nutrients (Murungu, Chiduza, Muchaonyerwa, & Mnkeni, 2010b, Nagumo & Nakamura, 2013). In the present study, despite the equivalent above-ground biomass and yield achieved with hairy vetch cover crop compared to conventional cultivation, less N was released (Table 3). This is possibly due to the synchrony of N supply and crop demand. During the first half-stage (21-42 DAS), maize in hvZ-1/2F grew faster than fT-1F. From sowing to 14 DAS, maize was suspended under lower rainfall conditions (18.5 mm). The maize that was covered well with hairy vetch, which maintained soil moisture compared to bare soil in fT-1F, successfully germinated and grew rapidly owing to rapid N release. This synchrony of nitrogen release from hairy vetch and rapid maize growth in the earlier stage resulted in less N leaching than that in fT-1F under lower rainfall conditions. Meanwhile, maize grown under conventional cultivation grew very slowly (Figure 1a) because of the lower rainfall during the earlier stage; therefore, it could not properly absorb N released from mineral fertilizer immediately after the application of top dressing (at 31 DAS), in turn causing larger nitrate release at 32 DAS (Figure 4b). Some parts of the abovementioned hypothesis are supported by the literature. Scenario analysis with PASTIS has confirmed the importance of moisture conditions in the decomposition of mulched residues (Coppens, Garnier, Findeling, Meckx, & Recous, 2007). Zibilske and Bradford (2007) report that water holding capacity is significantly greater (by > 12%) with non-tillage than plow tillage. Furthermore, positive relationships were observed between nitrate loss and rainfall patterns and fertilizer/pig manure application (Biro, Varga, Hartl, & Nemeth, 2005). In addition, hairy vetch cover crop is reported to desiccate early decomposed litter faster (Wagger 1989). When information-intensive management approaches are used, fertilizer-based systems can potentially outperform the synchrony achieved by legume-based rotations (Crews & Peoples, 2005). Accordingly, it has been suggested that the inclusion of perennials in cropping systems holds the greatest promise for decreasing the risk of N loss in future farming systems. Further study on the selection and combination of cover crops, irrigation management to control decomposition of litter, and timing and quantities of organic and inorganic fertilizer application will help establish best management practices in conservation agriculture systems in subtropical islands in Japan.

5. Conclusion

Winter hairy vetch cover crop is more effective than winter oat at increasing subsequent summer maize biomass and yield because of its higher N content. The residue of hairy vetch mineralized rapidly, and inorganic N was sufficiently up taken by maize, contributing to its growth. Meanwhile oat produced less organic N despite producing greater biomass and did not contribute substantially to maize growth. The synchrony of N supply and crop demand might be better in hairy vetch-maize than oat-maize or conventional cultivation owing to rapid maize growth under lower rainfall conditions. In addition, hairy vetch cover crop is a better opion for conservation agriculture than conventional cultivation with respect to the cost benefit of replacing half the required volume of fertilizer with residue.

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