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Research Article
Forage Quality of Triple Maize Crops with Winter Barley in Kyushu, Japan

[1]Yingkui Yang, [2]Bo Kun Li, [3]Sachiko Idota and [3]Yasuyuki Ishii

[1]Interdisciplinary Graduate School of Agriculture and Engineering,
[2]Graduate School of Agriculture,
[3]Faculty of Agriculture, University of Miyazaki, 889-2192 Miyazaki, Japan

Abstract

Background: Intensification of summer and winter forage cropping is an urgent requirement for reducing feeding costs for the beef and dairy cow industry in Kyushu, Japan. Based on the expectation of progression of global warming, the yield following quadruple cropping of triple maize crops with a winter barley crop was evaluated in a previous 2 years trial. **Materials and Methods:** Forage quality of the previous triple (spring, summer and autumn) maize with winter barley cropping was determined for 2 years in the region. Winter barley, sown in inter-rows in mid-November, was harvested in early to mid-March while spring maize, sown in early to mid-March, was harvested in early to mid-June, summer maize, sown from early to mid-June, was harvested in late August and autumn maize, sown from late August to early-September, was harvested in mid-November. **Results:** Yield of winter barley was around 900-930 g DM m^{-2}, spring maize was 1440-1800 g DM m^{-2} with 41-59% ear DM and summer maize was 820-1170 g DM m^{-2} with 41-44% ear DM. However, the autumn maize yield varied greatly from 330-810 g DM m^{-2} with 33-56% ear DM due to typhoon and cool weather damage. *In vitro* DM digestibility (IVDMD) in maize ears was higher than 75% and in leaf blades was higher than 60%, while for barley leaf blade, it was higher than 80%; the values for stems were lower than leaf blades for all crops of both species. The IVDMD was negatively correlated with Neutral Detergent Fiber (NDF) and Acid Detergent Fiber (ADF) concentration (r = -0.790 and -0.856, respectively) at the 1% probability level. By estimating Total Digestible Nutrient (TDN) concentration from ADF concentration based on regression equations, the TDN yield was 2750-2870 g DM m^{-2} $year^{-1}$ over 2 years. **Conclusion:** Triple maize with winter barley cropping can produce 4090-4330 g DM m^{-2} $year^{-1}$ with 66-67% TDN concentration in the region, which is recommended as a potential system for intensive ley farming.

Key words: Herbage quality, total digestible nutrient, triple-cropping maize, winter barley

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Corresponding Author: Yasuyuki Ishii, Faculty of Agriculture, University of Miyazaki, 889-2192 Miyazaki, Japan

INTRODUCTION

Continuous livestock production requires a stable supply of animal feed[1]. Eastern Asian countries depend on a supply of imported concentrate for animal production and thus, the price of imported feed has tended to increase as a result of adverse climatic conditions in the corn belt of the United States[2], competition from biofuel feedstuffs and an increasing price of petroleum for farm machinery[3]. Increase in yield and quality of forage production is achievable by increasing the duration of cultivation (through multi-crop production) to improve self-sufficiency in herbage production.

In the United States, drought sensitivity of maize (*Zea mays* L.) has increased as a result of global climate change though its yield has tended to increase[4] from 1995-2012. Combination of an early-maturing maize cultivar with early planting is proposed to avoid drought stress in mid-summer from evapotranspiration, leading to reduced irrigation cost in the United States[5]. Maize spaced in narrow 19 cm twin rows showed significantly increased Dry Matter (DM) yield compared with conventional 75 cm single-spaced maize due to the avoidance of drought by improved water use efficiency, also in the United States[6]. In Northern Italy, an increase in diversity of maize cultivars has reduced temporal variability in yield[7]. In Northern China, double cropping of wheat (*Triticum aestivum* L.) and maize has increased the gross margin to more than 50% when intercropping watermelon with maize, which can alleviate rural poverty in the region[8]. Under global warming, the cultivation area for triple-cropping systems is projected to be expanded significantly during the 21st century in China[9]. In the Philippines, double cropping of rice in the wet season and maize in the dry season could increase crop diversification while reducing water loss; narrow rows of maize with a spacing of 50×20 cm had the highest biomass and grain yields of several row spacing evaluated[10].

In Japan, double cropping of maize production is one of the common forage cropping systems in Kyushu, Southern Japan[11], where no-till maize cultivation, developed by a no-till maize seeder, was introduced for the planting of summer maize[12]. In more intensive forage cropping systems, growing five forage crops in a 2 years system led to an increase in DM and Total Digestible Nutrient (TDN) yield of 22% compared with yield in the usual double cropping of maize with Italian ryegrass (*Lolium multiflorum* Lam.)[13].

Maize and two-rowed barley are the primary forage crops that can replace the supply of concentrates. Early March sowing of spring maize and late August to mid-September sowing of late-summer maize had never been carried out in the region. Early March sown maize still needs temperature conditions that meet the effective cumulative temperature (ECT, 10°C basis)[14] of the species to reach physiological maturity; however, the crop can avoid the early summer rainy season (Tsuyu) and typhoons, which should reduce the risks and attain the benefits of early spring sown maize. Miyazaki in Southern Kyushu has more than 2800°C of ECT in the growing season from 20 February to 30 November in a normal year, which meets the thermal conditions applicable to triple maize cropping. Early-maturity maize cultivars with less than 90 days of Relative Maturity (RM)[15] are popular in Hokkaido, one of the Northern main islands of Japan and can be cultivated when sown in either early spring or late summer in Southern Kyushu if the crop is tolerant to serious diseases that can occur locally. Two-rowed barley (*Hordeum vulgare* L.) has a growing season from sowing in mid-November, after the harvest of late-summer sown maize, reaching anthesis in early March, which is earlier than wheat[16] or oats[17]. Miyazaki has a cumulative temperature in degree-days of 800°C from 20 November to 28 February in a normal year, which is sufficient for the crop to reach anthesis[16]. Barley yield is 12.8 Mg ha^{-1} with less than 200 mm of precipitation and around 13°C in Turkey[18].

In our previous study[19], a quadruple cropping system of triple maize (sown in spring, summer and autumn) planted with narrow row spacing with winter barley was examined in two years for phenology and yield by allocating 3 months per crop; spring and autumn-sown maize crops can have 800°C of ECT, summer-sown maize, 1000°C and winter barley, 800°C in degree-days. In the present study, forage quality of the quadruple cropping system was examined for maize and barley with Total Digestible Nutrients (TDNs) calculated from Acid Detergent Fiber (ADF) concentration by regression in Southern Kyushu, Japan.

MATERIALS AND METHODS

Location of the experimental site and climatic conditions: The experiments were conducted as a 2 years study in an experimental field of the Faculty of Agriculture, University of Miyazaki, Miyazaki, Japan (31°49'40"N, 131°24'46"E, 28 m a.s.l.), which has a fine volcanic ash soil (Andosol). The experiments were initiated in November, 2013 and ended in November, 2015. Annual mean temperature was 17.4°C and annual precipitation was 2510 mm, averaged over 1980-2010, which ranked as one of the highest records for the nation[20]. Precipitation during both the maize and barley cropping season in 2014 was similar to that in a normal year, while it was higher than normal due to heavy rainfall and typhoon weather for the first and second maize crops in 2015 (Fig. 1).

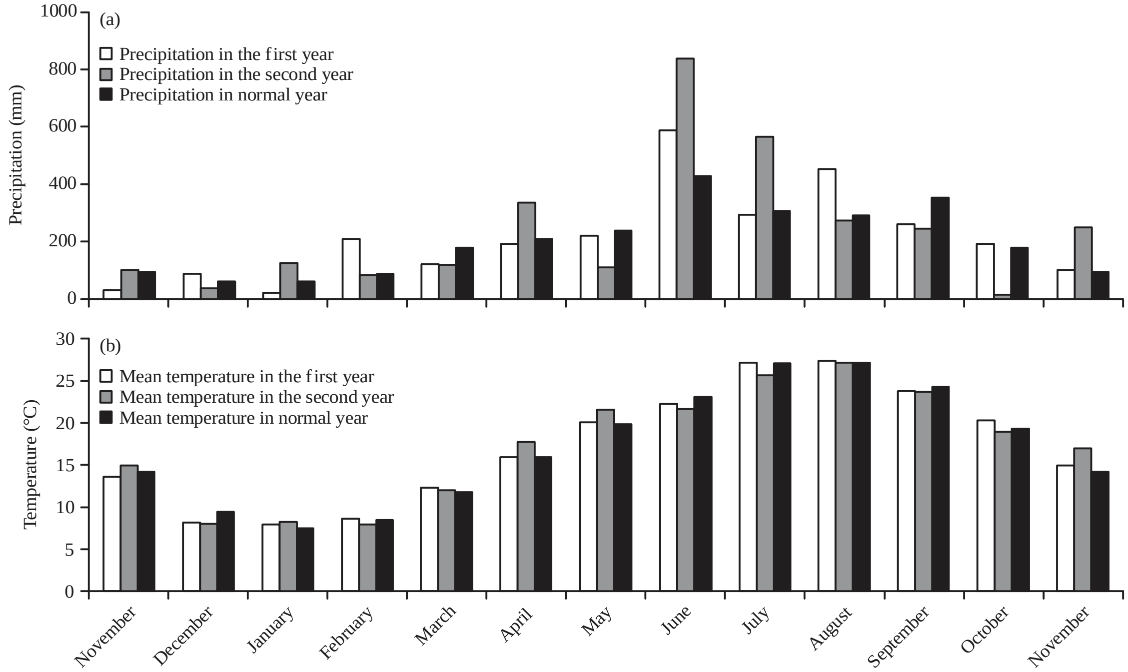

Fig. 1(a-b): Changes in (a) Monthly precipitation and (b) Monthly mean temperature in the first and second years of the experimental period and in a normal year, based on averages for 1980-2010. Source: Japan Meteorological Agency[20]

The temperature was similar to that in a normal year, except for a higher temperature for the early-spring maize crop in 2015 (Fig. 1). Cumulative Effective Temperature (CET) was calculated by the summation of the differences between daily Mean Temperature (MT) and base temperature (10°C) if the MT was above 10°C in the maize cropping seasons.

Experimental design and treatments: A multiple-cropping system of triple (spring, summer and autumn-sown) maize crops and winter barley in the region was tested for its potential in the region[19]. The experiments were designed under a split plot with sowing dates being the main-plot and cultivar the split-plot factors with four replications, except for winter two-rowed barley, using a single cultivar, Wasedorinijou (an early-maturing variety, Yukijirushi, Co., Ltd., Sapporo, Japan). Plot size was 3×3.5 m (10.5 m^2) with 50 cm narrow row spacing for both barley and maize. Before planting of every crop, the soil was tilled using a cultivator to a depth of around 20 cm followed by flattening the soil by hand, except for inter-row direct seeding of winter barley with no tillage in November, 2014. Fermented manure was supplied at 30 Mg FW ha^{-1} containing 1.3% N and slaked lime at 1.5 Mg ha^{-1}. Barley was sown uniformly at 70 kg ha^{-1} on 13 November, 2013 and on 13 November, 2014.

For spring and autumn sowing of maize, three cultivars released for cultivation in Hokkaido were examined: The extremely early-maturing LG3215 (relative maturity (RM) 75, Snow Brand, Yukijirushi, Co., Ltd., Sapporo, Japan) and Solide (RM 78, Snow Brand) and the early-maturing Anjou 284 (RM 90, Snow Brand) in 2014, while the cultivars examined were limited to Solide and Anjou 284 in 2015, due to the low yield of LG3215 in 2014. For summer sowing of maize, the cultivars examined, also released for Hokkaido, were early-maturing KD510 (RM 100, Kaneko Seeds Co., Ltd., Maebashi, Japan) and NS105 Super (RM 105, Kaneko Seeds) in both 2014 and 2015. The switch from winter barley to spring-sown maize was conducted in two growth phases of winter barley, i.e., the milk-ripe, harvested on 10 March and the dough-ripe, on 26 March, 2014. Maize was seeded at two seeds per spot for every crop, while the intra-row spacing was fixed at 15 cm for spring and autumn-sown maize and at 20 cm for summer-sown maize. After harvest of the barley crop, spring maize was seeded on 17 March as an early-sown plot and on 29 March as a regular-sown plot in 2014 and was seeded on 3 March as an extremely early-sown plot and on 17 March as an early-sown plot in 2015. Maize plants were thinned to one plant per spot at the 3rd-5th leaf stage for each crop. The switches from spring to summer-sown maize and from summer to autumn-sown maize were conducted when maize reached the dough-ripe or milk-ripe stage, except for autumn-sown maize, which was harvested uniformly on 21 November, 2014 and on 16 November, 2015.

Agronomic practices and data collection: Compound fertilizers, containing N, P_2O_5 and K_2O at 14% each were broadcast at 40 kg of each element per hectare per application at the tillering, maximum tiller number and booting stages for winter barley and were broadcast at 50 kg of each element per hectare per application at the 3rd-5th leaf stage, the 7-9th leaf stage and the heading or silking stage for maize. Phenological attributes of plant height, tiller number and fresh weight were determined for two individual quadrats of 0.25 m^2 for barley and on a per plant basis for two maize plants for each replication of both the time of fertilization and time of plant harvest. After measuring fresh weight, plants were fractioned into Leaf Blade (LB), stem inclusive of leaf sheath (ST) and withering fraction (W) for barley with the addition of tassel (T) and ear (E) for maize and then dried by a ventilation oven at 70°C for 72 h to determine the percentage of Dry Matter (DM). The ripened percentage of maize was calculated by the number of ripened grains, which was judged by the presence of endosperm, relative to total number of maize grains.

Dried plant samples were ground to pass through a 1 mm sieve. Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF) and Acid Detergent Lignin (ADL) were determined by a detergent method[21]. *In vitro* DM digestibility (IVDMD) was determined by a pepsin-cellulase assay[22] using a filter-bag method. Total Digestible Nutrient (TDN) concentration for winter barley was estimated by the following regression equation from the ADF concentration[23]:

$$\text{TDN} = 87.57\text{-}0.737\times\text{ADF}$$

and the corresponding regression equation for triple maize crops was[24]:

$$\text{TDN} = 89.89\text{-}0.752\times\text{ADF}$$

Statistical analysis: After one-way analysis of variance, differences in means were evaluated by Fisher's least significant difference test at the 5% level using Excel Statistics 2010 software (Social Information Service, Tokyo, Japan).

RESULTS AND DISCUSSION

Yield ability: Weight and DM content of plant fractions, relative maturity and ripened grain percentage of maize cultivars with CET are shown in Table 1. The CET in the maize cropping season in both 2014 and 2015 matched the relative maturity in the examined cultivars (1 day of RM was equal to 10°C), except for the regular sowing of autumn-sown maize in 2014.

In the first year, as shown in Table 1, winter barley yielded 930-1090 g DM m^{-2} and the yield increased with later harvest. On the other hand, spring maize had a higher yield of 1490-1800 g DM m^{-2} with 53-59% ear DM for early sowing compared with 1170-1510 g DM m^{-2} with 49-55% ear DM for regular sowing, since the regularly sown maize was harvested on 1 July after damage due to a heavy rainy season with 600 mm of precipitation in June. The lower maize yield from early sowing than regular sowing was correlated with the lower ear DM percentage and ripened grain percentage in Solide. Maize DM yield increased significantly with maturity[25]. Summer maize had a lower yield of 980-1170 g DM m^{-2} with 41-42% ear DM for early sowing than regularly sown maize, which had a yield of 1240-1290 g DM m^{-2} with 57-58% ear DM; however, the ripened grain percentage was much lower for the regular sowing due to the earlier stage of maturity in blister/milking. The lower yield of summer maize than spring maize was due to two typhoon strikes, one on 9-10 July and 8-10 August. The lowest percentage of broken plants was correlated with the highest DM yield for several maize hybrids[26]. Autumn maize yield decreased greatly from 120-380 g DM m^{-2} with 0-42% ear DM, which was higher for the early sowing than the regular sowing due to damage by typhoons on 5 October and 12-13 October and to cool weather at the maturity stage. In the autumn sowing, the ripened grain percentage could not be determined because at harvest, the early-sown maize was still at the blister stage and the regular-sown maize was at the silking stage.

In the second year, as shown in Table 2, winter barley yielded 900-1010 g DM m^{-2}, which was almost the same as in the first year and was higher with later harvest, while the DM content of whole plants lower at 13-14% compared with 22% in the first year. Spring maize had a yield of 1440-1640 g DM m^{-2} with 41-45% ear DM for the extremely early-sown crop compared to a higher yield of 1740-2020 g DM m^{-2} with 43-52% ear DM for the early-sown crop, since the early-sown maize was able to be harvested on 19 June before damages from heavy rain (900 mm) later that month. Ripened grain percentage was higher with a range of 87-93% in all cultivars of every maize crop in 2015. Summer-sown maize had a higher yield of 980-1100 g DM m^{-2} with 44-46% ear DM for NS105 Super than the 800-820 g DM m^{-2} with 34-44% ear DM, for KD510 due to higher RM. However, DM yield of summer maize in 2015 decreased from that in 2014 due to heavy precipitation of 840 mm in June and 570 mm in July, 2015. Autumn-sown maize reached the milk-ripe stage and a yield of 670-890 g DM m^{-2} with 45-56% ear DM, with no genotypic differences in yield.

Table 1: Yield and maturity of winter barley and spring, summer and autumn-sown maize in the first year of cropping in 2013-2014

					Dry matter content (%)						Dry matter yield (g m^{-2})					
Crops and cultivar	Relative maturity (days)	Effective cumulative temperature (°C)	Maturity at harvest	Ripened (%)	Leaf	Stem	Withering	Ear	Tassel	Overall	Leaf	Stem	Withering	Ear	Tassel	Total
Winter barley																
Wasedorinijou			Milk		12.7	12.0	22.2	13.6		22.1	149.0	666.9	8.8	104.4		929.1
Wasedorinijou			Dough		13.6	14.8	25.0	14.2		22.3	96.5	749.4	24.9	220.4		1091.2
Early sowing of spring-sown maize																
LG3215	75		Dough	83.6	14.5	16.0	1.9^{c}	16.4	19.3^{b}	16.0	209.5^{b}	395.6^{b}	0.5^{b}	867.7	15.1^{b}	1488.4^{b}
Solido	78	802.3	Dough	80.3	15.2	16.1	4.9^{b}	16.1	19.6^{b}	15.9	205.8^{b}	402.7^{b}	2.4^{b}	893.9	16.1^{b}	1520.9^{b}
Anjou284	90		Dough	79.6	16.6	16.8	8.1^{a}	16.8	22.9^{a}	16.7	267.8^{a}	542.6^{a}	6.6^{a}	960.2	22.4^{a}	1799.6^{a}
Regular sowing of spring-sown maize																
LG3215	75		Dough	86.0	15.1	16.5	4.2	28.6	17.7	21.1	149.1	346.1	2.1	654.1	15.5	1166.9
Solido	78	886.3	Dough	73.1	14.3	16.0	4.2	28.7	20.5	20.7	158.0	395.2	5.0	712.3	16.8	1287.3
Anjou284	90		Dough	78.9	14.1	15.9	5.4	30.0	13.6	19.9	216.9	525.7	5.4	740.6	23.9	1512.5
Early sowing of summer-sown maize																
KD510	100	1151.6	Milk/dough	82.4	21.8	16.6*	6.5	23.4	29.0	19.9	233.5*	433.3*	6.9	476.0	16.9	1166.6*
NS105 Super	105		Milk/dough	79.2	18.9	13.7	14.1	22.5	22.5	17.6	176.7	362.2	18.8	411.8	14.6	984.1
Regular sowing of summer-sown maize																
KD510	100	1222.6	Blister/milk	25.7	20.3	15.0*	31.5	28.5	34.9	21.9	196.2*	330.5	20.3	729.1	9.6	1285.7
NS105 Super	105		Blister/milk	23.6	20.3	12.1	39.5	31.6	35.6	21.2	147.6	315.3	47.7*	716.4	12.9	1239.9
Early sowing of autumn-sown maize																
LG3215	75		Blister	NS	23.3	15.3	60.9	10.9	39.7^{a}	14.6	53.3	93.0	17.7	122.8	4.3	291.1
Solido	78	751.7	Blister	NS	24.6	16.3	51.6	10.3	14.8^{b}	14.8	62.3	146.3	24.0	138.1	5.0	375.7
Anjou284	90		Blister	NS	23.2	14.6	58.1	9.3	42.2^{a}	13.9	60.0	132.5	25.3	110.0	6.7	334.4
Regular sowing of autumn-sown maize																
LG3215	75		Silking	NS	19.4	11.7	57.0	4.2	35.7^{a}	13.4	39.8	73.1	9.3	25.8	7.3	155.5
Sorido	78	643.3	Silking	NS	17.7	9.7	41.1	0.0	33.1^{a}	12.7	36.3	71.0	8.0	0.0	5.3	120.6
Anjou284	90		Silking	NS	17.6	8.0	57.7	0.0	18.4^{b}	11.8	46.3	59.1	8.2	0.0	8.0	121.6

$^{a-c}p<0.05$, $^{*}p<0.05$ among cultivars in the same cropping season and system

Table 2: Yield and maturity of winter barley and spring, summer and autumn-sown maize in the second year of cropping in 2014-2015

Crops and cultivar	Relative maturity (days)	Effective cumulative temperature (°C)	Maturity at harvest	Ripened (%)	Dry matter content (%)						Dry matter yield (g m^{-2})					
					Leaf	Stem	Withering	Ear	Tassel	Overall	Leaf	Stem	Withering	Ear	Tassel	Total
Winter barley																
Wasedorinijou			Early heading		10.7	10.5	33.6	11.8		13.5	290.5	585.3	3.9	20.1		899.8
Wasedorinijou			Full heading		11.7	12.1	28.7	12.7		13.2	211.4	706.1	16.9	78.6		1013.0
Extremely early sowing of spring-sown maize																
Solido	78	717.0	Dough	89.0	21.7*	16.7	55.7	22.1*	35.4	19.8*	217.6	549.7	9.0	643.2	16.2	1435.7
Anjou284	90		Dough	90.0	20.0	15.5	56.5	17.5	41.4	17.2	273.8*	647.5	18.2*	680.5	21.7*	1641.7
Early sowing of spring-sown maize																
Solido	78	856.9	Dough	88.5	20.2	14.5	21.5	31.1*	33.7	21.5*	286.9	649.2	23.7	1049.2*	14.3	2023.3*
Anjou284	90		Dough	90.2	20.4	14.8	27.6	22.6	35.4	18.7	254.3	658.5	53.0*	753.6	20.3	1739.7
Early sowing of summer-sown maize																
KD510	100	1142.3	Milk	95.0	23.4	19.4*	50.4	17.1	44.3	19.2	138.1	294.8	5.8	365.4	17.4	821.5
NS105 Super	105		Milk	93.8	23.4	16.0	55.2	20.4*	49.8	19.1	146.6	351.9	8.1	454.3	17.4	978.3
Regular sowing of summer-sown maize																
KD510	100	1080.4	Milk	89.4	25.1	19.3*	67.8	42.4	15.9	19.2	157.5	341.9	11.3	271.5	13.8	796.0
NS105 Super	105		Milk	93.4	24.7	15.5	60.1	59.8	22.0*	19.6	194.0	396.8	8.9	483.5*	17.6	1100.8*
Early sowing of autumn-sown maize																
Solido	78	960.2	Silking/milk	88.6	24.3	15.9	59.7	21.8	30.1	20.5	95.8	222.1	34.8	451.1	8.2	812.0
Anjou284	90		Silking/milk	88.1	24.2	15.3	68.0	19.3	32.3	20.4	81.1	198.0	33.5	349.6	7.3	669.5
Regular sowing of autumn-sown maize																
Solido	78	863.0	Silking/milk	87.3	25.4	17.1	64.1	20.0	26.2	19.9	112.0	327.3	39.5	403.4	5.5	887.7
Anjou284	90		Silking/milk	88.7	21.8	17.0	64.0	19.1	32.7	19.4	92.3	315.3	52.0	406.7	7.8	874.1

*$p<0.05$ among cultivars in the same cropping season and system

Table 3: Digestibility and fiber concentrations of winter barley and spring, summer and autumn-sown maize in the first year of cropping in 2013-2014

		Leaf (DM%)				Stem (DM%)				Ear (DM%)			
Crops and cultivar	Maturity at harvest	IVDMD	NDF	ADF	ADL	IVDMD	NDF	ADF	ADL	IVDMD	NDF	ADF	ADL
Winter barley													
Wasedorinijou	Milk	80.0	42.2	33.4	2.3	60.2	51.4	33.3	4.0	72.1	60.7	26.0	4.3
Early sowing of spring-sown maize													
LG3215	Dough	65.5	55.1	36.6^a	8.2^a	51.3	59.7^b	41.1	5.8^a	82.3	24.6^b	14.9^a	2.5^b
Solido	Dough	71.1	55.9	35.8^a	7.9^a	51.4	62.4^a	42.9	5.6^{ab}	82.3	32.6^a	12.3^b	1.6^b
Anjou284	Dough	63.6	58.6	29.7^b	5.4^b	53.6	57.7^c	40.2	5.2^b	78.2	28.9^{ab}	12.8^b	6.7^a
Early sowing of summer-sown maize													
KD510	Milk/dough	60.9	59.0	35.6*	9.0*	59.6*	52.9	35.6	6.7	86.3*	36.7	13.3	1.4
NS105 Super	Milk/dough	61.6	57.2	29.6	5.0	52.2	59.0*	39.9*	6.4	79.2	33.7	18.7*	2.6*
Early sowing of autumn-sown maize													
LG3215	Blister	71.0	54.1	28.0	5.3	73.2	45.2	25.7	3.6	87.6	39.4	19.3	5.1
Solido	Blister	71.4	50.7	25.2	4.4	67.1	47.0	29.9	4.9	89.2	41.8	23.2	5.7
Anjou284	Blister	71.9	51.8	25.8	6.1	69.2	47.8	27.7	3.9	91.0	39.7	18.5	3.8

$^{a,b}p<0.05$, *$p<0.05$ among cultivars in the same cropping season and system, IVDMD: *In vitro* dry matter digestibility, NDF: Neutral detergent fiber, ADF: Acid detergent fiber, ADL: Acid detergent lignin

Table 4: Digestibility and fiber concentrations of winter barley and spring, summer and autumn-sown maize in the second year of cropping in 2014-2015

		Leaf (DM%)				Stem (DM%)				Ear (DM%)			
Crops and cultivar	Maturity at harvest	IVDMD	NDF	ADF	ADL	IVDMD	NDF	ADF	ADL	IVDMD	NDF	ADF	ADL
Winter barley													
Wasedorinijou	Early heading	93.0	47.3	17.2	3.7	64.5	55.5	35.2	6.1	NS	NS	NS	NS
Extremely early sowing of spring-sown maize													
Solido	Dough	76.2*	52.1*	34.0	7.5	61.0	52.3	36.4	5.3	90.3*	32.9	17.7	2.2*
Anjou284	Dough	66.3	51.2	35.4	9.8	61.1	52.6	35.0	5.4	86.3	38.8*	19.4	0.5
Early sowing of summer-sown maize													
KD510	Milk	67.9	57.6	35.0	10.1	64.3*	54.5	32.9	3.8	81.6	41.0*	30.1*	6.4*
NS105 Super	Milk	67.2	52.7	33.9	8.5	56.7	58.3*	39.8*	5.5*	84.2	31.6	17.7	3.6
Early sowing of autumn-sown maize													
Solido	Silking/milk	63.2	53.7	35.3	13.0	53.9	57.4	40.7*	7.2	84.2	30.3	15.4	2.9
Anjou284	Silking/milk	63.6	54.0	34.6	12.6	59.5*	47.0	37.2	5.8	75.2	37.7	13.3	2.0

*$p<0.05$ among cultivars in the same cropping season and system, IVDMD: *In vitro* dry matter digestibility, NDF: Neutral detergent fiber, ADF: Aacid detergent fiber, ADL: Acid detergent lignin

Based on these yield data, winter barley yielded around 900-930 g DM m^{-2}, spring maize yielded 1440-1800 g DM m^{-2} with 41-59% ear DM and summer maize yielded 820-1170 g DM m^{-2} with 41-44% ear DM. Averaged across the examined cultivars, annual yield in winter barley with triple maize crops reached around 4000 g DM m^{-2} in the 2013-2014 season, which increased in the following 2014-2015 growing season. Notably, winter barley with early-sown spring maize showed a stable yielding ability of 2500-2800 g DM m^{-2} $year^{-1}$ in both growing seasons due to the minimal influence of climatic disasters such as heavy precipitation and typhoons. However, the autumn maize yield ranged greatly from 120-890 g DM m^{-2} $year^{-1}$ with 0-56% ear DM due to the occurrence of typhoons and cool weather damage.

Forage quality attribute: Forage quality attributes of IVDMD, NDF, ADF and ADL concentrations in each plant fraction for barley and three crops of maize are shown for the 2013-2014 season in Table 3. In barley, IVDMD was highest in leaf blades, followed by ears and stems and was higher than 60% in all fractions. The NDF concentration was higher in ears than in leaf blades due to harvest at the early maturity stage. In contrast, in maize, IVDMD was highest in ears for all of the cropping seasons, above 78%, followed by leaf blades and stems at 51-60%, except for autumn-sown maize, with a range of 67-73% due to harvest at immature stages. The NDF concentration was lower in ears than in leaf blades and stems for every crop, which corresponded with the order of ADF and ADL concentrations among plant fractions. Thus, a negative correlation was obtained between the IVDMD and ADF concentrations among all plant fractions and cultivars ($r = -0.890$, $p<0.01$) in 2014, which partly corresponded with the observed negative correlation of IVDMD and lignin content in several cultivars of maize stover[27]. Significantly lower IVDMD in stems and ears of summer-sown NS105 Super correlated with its significantly higher ADF concentration than that of cultivar KD510.

Forage quality attributes in all plant fractions for both barley and maize are shown for the 2014-2015 season in Table 4. No forage quality attributes of barley ears could be

Table 5: Estimated ADF and TDN yields in the first and second cropping years in 2013-2014 and 2014-2015, respectively

		ADF yield (g m^{-2})								TDN yield (g m^{-2})							
		First year				Second year				First year				Second year			
Crops	Cultivar	LB	ST	E	Whole plant	LB	ST	E	Whole plant	LB	ST	E	Whole plant	LB	ST	E	Whole plant
Winter barley	Wasedorinijou	62.9	342.8	63.4	469.0	137.4	324.8	NS	462.2	93.8	420.3	71.4	585.6	225.1	351.3	NS	576.4
Early sowing of	LG3215	115.4	236.2	213.5	565.1					130.7	233.3	682.8	1046.7				
spring-sown	Solido	115.0	251.3	291.4	657.7	113.4	287.5	211.6	612.5	129.6	232.1	720.8	1082.5	140.0	343.7	492.6	976.2
maize	Anjou284	156.9	313.1	277.5	747.5	140.2	340.6	264.0	744.8	180.9	323.7	770.7	1275.3	173.2	411.6	512.4	1097.3
Early sowing of	KD510	137.8	229.2	174.7	541.7	79.5	160.7	149.8	390.0	147.4	273.5	380.3	801.1	87.8	192.1	245.7	525.6
summer-sown maize	NS105 Super	101.1	213.7	138.8	453.5	77.3	205.2	143.6	426.0	119.5	216.9	312.3	648.7	94.4	211.0	347.9	653.3
Early sowing of	LG3215	28.8	42.0	48.4	119.3					36.7	65.6	92.6	194.9				
autumn-sown	Solido	31.6	68.8	57.7	158.1	51.4	127.5	136.7	315.6	44.2	98.6	100.0	242.9	60.7	131.7	353.3	545.6
maize	Anjou284	31.1	63.3	43.7	138.1	43.8	93.1	131.8	268.7	42.3	91.5	83.6	217.4	51.8	122.6	279.3	453.7

Plant fraction: LB: Leaf blade, ST: Stem inclusive of sheath, E: Ear, TDN concentration (winter barley) = 87.57-0.737×ADF concentration[23]. The TDN concentration (maize) = 89.89-0.752×ADF concentration (Committee for the Nutritive Value of Grass and Forage Crops[24])

determined since harvest was at the beginning of heading. Showing the same trend as in the 2013-2014 season, IVDMD was higher in leaf blades than other fractions for barley, in contrast to higher IVDMD in ears than leaf blades and stems for each crop of maize. In maize, NDF and ADF concentrations were lower in ears, followed by leaf blades and stems. Thus, a negative correlation was obtained between the IVDMD and ADF concentrations among all plant fractions and cultivars ($r = -0.857$, $p<0.01$), reflecting the significantly lower NDF and ADF concentrations, with significantly higher IVDMD in stems and ears across the summer-sown maize cultivars in 2015. For several maize hybrids, the TDN concentration was positively correlated with IVDMD[28].

TDN yield estimation: The ADF yield and TDN yield for barley and three crops of maize are shown for both the first and second years (Table 5). Estimation of barley TDN concentration from the ADF concentration was also conducted in Turkey[18]. In barley, TDN yield of leaf blades was much lower in the first year than in the second year due to senescence of the leaf blades during maturation of the grains in the first year. In maize, TDN yield of ears was the largest component, ranging from 38-67% of TDM yield of whole plants, followed by stems and leaf blades, which was consistent with research showing that the TDN concentration of silage maize was closely correlated with ear characteristics (number of rows per ear) in Brazil[29]. The TDN yield of maize increased with nitrogen fertilization and legume green manure incorporation before maize cropping[30]. Since fertilization of maize and barley followed the regional standards in this study, plant growth might not be impaired by limited fertilizer supply.

The recent trend of global warming should increase the potential maize double-cropping area[31] and productivity of winter forage crops[32]. In the cropping system examined in this study, DM and TDN yield increased by 39 and 36%, respectively, over those of the conventional maize and Italian ryegrass cropping system[11,33] in Southern Kyushu. A higher TDN concentration of oat silage compared with maize silage led to a higher average daily gain when fed to crossbred growing calves[34]. It is still necessary to assess the nutritional effects in silage obtained from forage crops produced in this cropping system, which could be conserved under polyethylene film[35] and fed to dairy[36] and beef cows[37].

CONCLUSION

The TDN yield was 2750-2870 g DM m^{-2} year^{-1} in a triple maize with winter barley cropping system in Southern Kyushu, Japan, based on estimating TDN concentration from ADF concentration by regression. Therefore, triple maize with winter barley cropping can produce 4090-4330 g DM m^{-2} year^{-1} with 66-67% TDN concentration, which is recommended as a potential cropping system in the intensive ley farming system in the region.

SIGNIFICANCE STATEMENTS

Under the progression of global warming, intensive cropping is required to produce increased amounts of self-sufficient herbage in Kyushu, Japan. Quadruple cropping of triple maize crops with winter barley was assessed in a 2 years trial to check the suitability of this approach for yield and quality attributes in the region. Since quality herbage production with high yield was achievable, as assessed by TDN yield, it is recommended to adopt this intensive cropping system in the region.

REFERENCES

1. Khan, Z.R., C.A. Midega, J.O. Pittchar, A.W. Murage, M.A. Birkett, T.J. Bruce and J.A. Pickett, 2014. Achieving food security for one million sub-Saharan African poor through push-pull innovation by 2020. Philosophical Trans. Royal Soc. London B: Biol. Sci., Vol. 369. 10.1098/rstb.2012.0284.
2. Zhang, T., X. Lin and G.F. Sassenrath, 2015. Current irrigation practices in the central United States reduce drought and extreme heat impacts for maize and soybean, but not for wheat. Sci. Total Environ., 508: 331-342.
3. Msangi, S., D. Enahoro, M. Herrero, N. Magnan, P. Havlik, A. Notenbaert and S. Nelgen, 2014. Integrating livestock feeds and production systems into agricultural multi-market models: The example of IMPACT. Food Policy, 49: 365-377.
4. Lobell, D.B., M.J. Roberts, W. Schlenker, N. Braun, B.B. Little, R.M. Rejesus and G.L. Hammer, 2014. Greater sensitivity to drought accompanies maize yield increase in the U.S. Midwest. Science, 344: 516-519.
5. Soderlund, S., F.N. Owens and C. Fagan, 2014. Forages and pastures symposium: Development of and field experience with drought-tolerant maize. J. Anim. Sci., 92: 2823-2831.
6. Cox, W.J., J.J. Hanchar, W.A. Knoblauch and J.H. Cherney, 2006. Growth, yield, quality and economics of corn silage under different row spacings. Agron. J., 98: 163-167.
7. Borrelli, L., F. Castelli, E. Ceotto, G. Cabassi and C. Tomasoni, 2014. Maize grain and silage yield and yield stability in a long-term cropping system experiment in Northern Italy. Eur. J. Agron., 55: 12-19.
8. Huang, C., Q. Liu, N. Heerink, T. Stomph and B. Li *et al*., 2015. Economic performance and sustainability of a novel intercropping system on the north China plain. PloS One, Vol. 10. 10.1371/journal.pone.0135518.
9. Yang, X., F. Chen, X. Lin, Z. Liu and H. Zhang *et al*., 2015. Potential benefits of climate change for crop productivity in China. Agric. For. Meteorol., 208: 76-84.
10. Chauhan, B.S. and J.L. Opena, 2013. Effect of plant geometry on growth and yield of corn in the rice-corn cropping system. Am. J. Plant Sci., 4: 1928-1931.
11. Kato, N., 2011. Corn no-till cultivation in Kyushu region of Japan. J. Jap. Soc. Grassland Sci., 57: 172-175.
12. Kanno, T., S. Morita, H. Sasaki and K. Nishimura, 2014. Recent situation and future prediction for areas suitable for double cropping of corn (*Zea mays* L.) production in Japan's Kanto region. Japan. J. Grassl. Sci., 60: 161-166.
13. Kanno, T., S. Morita, S. Sato, S. Kurokawa and H. Sazarashi *et al*., 2012. Determination of the effective cumulative temperature required for second cropping of corn (*Zea mays* L.) at the Northern boundary for the double-cropping system. Proceedings of the 4th Japan-China-Korea Joint Symposium on Grassland Agriculture and Livestock Production, March 30-April 1, 2012, Aichi, Japan, pp: 64-65.
14. Bonhomme, R., 2000. Bases and limits to using degree.day units. Eur. J. Agron., 13: 1-10.
15. Tamaki, M., H. Sato, H. Mitsuhashi and T. Kikawada, 2015. A study on genomewide selection for maize (*Zea mays* L.) breeding in Japanese public sectors: Heritability of maturity- and yield-related traits in the training populations. Japan Agric. Res. Quart., 49: 255-260.
16. Yoshida, H. and M. Kamio, 1985. Differences in characteristics of earliness partitioned by developmental stage between wheat and barley cultivars. Japan. J. Breed., 35: 323-331.
17. Kato, N., I. Hattori, Y. Kiyomura, M. Katsura and R. Kobayashi, 2014. Waterlogging tolerance in different growth stages among barley, Italian ryegrass and oat. J. Warm Region. Soc. Anim. Sci. Japan, 57: 97-104.
18. Kocer, A. and S. Albayrak, 2012. Determination of forage yield and quality of pea (*Pisum sativum* L.) mixtures with oat and barley. Turk. J. Field Crops, 17: 96-99.
19. Yang, Y., Y. Ishii and S. Idota, 2016. Year-round forage yield stability through a system combining triple-maize crops with winter barley in Kyushu, Japan. Am. J. Agric. Biol. Sci., 11: 19-28.
20. Japan Meteorological Agency, 2015. Meteorological statistical data for Miyazaki, Miyazaki prefecture. URL: http// www.jma.go.jp/jma/menu/report.html
21. Van Soest, P.J., J.B. Robertson and B.A. Lewis, 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci., 74: 3583-3597.
22. Goto, I. and D.J. Minson, 1977. Prediction of the dry matter digestibility of tropical grasses using a pepsin-cellulase assay. Anim. Feed Sci. Technol., 2: 247-253.
23. Tsurusaki, M., K. Munekado and R. Abe, 1990. Estimation of TDN concentration common to grass hay and silages. Grassl. Sci., 36: 139-140.
24. Committee for the Nutritive Value of Grass and Forage Crops, 1991. The Guidebook of Nutritive Values of Herbage and Forage Crop. Hokunoukai, Sapporo, Japan, pp: 41-45.
25. Khan, S.H., A.G. Khan, M. Sarwar and A. Atiya, 2007. Effect of maturity on production efficiency, nutritive value and in situ nutrients digestibility of three cereal fodders. Int. J. Agric. Res., 2: 900-909.
26. Araujo, K.G., S.D.J. Villela, F.P. Leonel, P.M. Costa, L.O. Fernades, W.P. Tamy and V.R. Andrade, 2012. Yield and quality of silage of maize hybrids. R. Rras. Zootec., 41: 1539-1544.
27. Vattikonda, M.R. and R.B. Hunter, 1983. Comparison of grain yield and whole-plant silage production of recommended corn hybrids. Can. J. Plant Sci., 63: 601-609.
28. Garcia-Castillo, R.F., Z.J. Castillo-Sanchez, J.R. Kawas-Garza, J. Salinas-Chavira, F. Ruiz-Zarate and R. Lopez-Trujillo, 2013. Production, chemical evaluation, energy content, structural and non-structural carbohydrates and *in vitro* digestibility in forage maize. Rev. Fac. Agron., 30: 573-590.

29. Martins, C.M.M.R., R.F. Bernudes, W.G. Cerutti, J. Viegas and M.N. Correa *et al*., 2014. Morphological characteristics of maize plants in estimate the silage chemical composition Braz. J. Vet. Res. Anim. Sci., 51: 233-241.
30. Omokanye, A.T., F.M. Kelleher and A. McInnes, 2014. Maize managed on diverse cropping systems and N supply on yield and quality of maize stover silage. Int. J. Agron. Agric. Res., 4: 65-74.
31. Takahashi, S., 2002. A model predicting forage maize growth based on temperature and solar radiation. Jap. J. Grassl. Sci., 48: 43-49.
32. McMaster, G.S. and W.W. Wilhelm, 2003. Phenological responses of wheat and barley to water and temperature: Improving simulation models. J. Agric. Sci., 141: 129-147.
33. Idota, S. and Y. Ishii, 2007. Annual variation in herbage dry matter yield under some forage cropping systems on the heavy soil in Southern Kyushu. Jap. J. Grassl. Sci., 53: 93-101.
34. Medhi, D., A.S. Bhat, J. Hussain and W. Raja, 2010. Comparative study on the nutritive values of oats and maize silages in crossbred growing calves. Indian J. Anim. Res., 44: 58-60.
35. Spadaro, D., M.P. Bustos-Lopez, M.L. Gullino, S. Piano, E. Tabacco and G. Borreani, 2015. Evolution of fungal populations in corn silage conserved under polyethylene or biodegradable films. J. Applied Microbiol., 119: 510-520.
36. Khan, N.Z., P. Yu, M. Ali, J.W. Cone and W.H. Hendriks, 2014. Nutritive value of maize silage in relation to dairy cow performance and milk quality. J. Sci. Food Agric., 95: 238-252.
37. Watson, A.K., J.C. MacDonald, C.E. Erickson, P.J. Kononoff and T.J. Klopfenstein, 2015. Forages and pastures symposium: Optimizing the use of fibrous residues in beef and dairy diets. J. Anim. Sci., 93: 2616-2625.