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論　文
Articles

Comparison of the Effect of Organic and Chemical Fertilizer on Crop Yield in Mongolian Agriculture

By

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Summary：In Mongolia, the rapid increase of extensive cropping areas without fertilization has created a serious need for land conservation technology. This paper describes the field study we conducted in a semi-arid region of Mongolia from 2010 to 2013 in which we used animal composts as a self-support fertilizer for two field experiments. In the first field experiment (Experiment-1), from 2010 to 2012, potato, rye, pea and turnip crops were cultivated in the compost plot with the application of animal compost (3-month matured dung of sheep and goats) of 40 $Mg\,ha^{-1}y^{-1}$, and in the NPK plot with the application of chemical fertilizer (90 $kg\,ha^{-1}y^{-1}$ of N, P_2O_5, and K_2O) under traditional extensive land management without weed control. In the second field experiment (Experiment-2) in 2013, the effects of composts with different application amounts and maturing time were studied under weed control. The composts with a 2-year maturing time (2y-compost) and a 2-month maturing time (2m-compost) were applied in amounts of 20, 40, and 60 $Mg\,ha^{-1}$ for potato and wheat. From the results of Experiment-1, during three years, we saw that the soil available-N values and crop yields tended to be higher for the compost plot and there was no effect from chemical fertilizer on crop yields. The low efficiency of chemical fertilizer might be due to insufficient precipitation and severe weed stress under extensive land management. However, the use of animal compost had an apparent positive effect in Experiment-2 with controlling the weed effect. We observed significantly higher yields for application of the 2y-compost compared to the control. The long maturing time compost was more effective to increase crop yields due to its higher N content. These results showed that the use of both chemical and organic fertilizer was not effective to increase crop production under the extensive cropping system traditionally used in Mongolia. Also it was shown that the compost application increases crop yield under intensive land management.

Key words：Mongolia, Crop yield, Kastanozem, Land degradation, Animal compost

1. Introduction

In Mongolia, from 1961 to 2005, the population increased from 984,000 to 2.6 million : however, during the same period, cereal production decreased from 124 to 75 $Gg\,yr^{-1}$[1]. This decrease was due to the economic transition of the early 1990s which had a profoundly negative effect on agriculture. From 2008 to 2010, the Mongolian government promoted production of arable land, and the production of cereals and wheat increased about 250% in these years ; however, the percent of fertilized areas in the arable land is still only 22%[2]. This indicates that the increased agricultural production in recent decades was achieved mainly by extension of cultivated areas without fertilization. The arable area in Mongolia increased from 282,200 ha in 2008 to 379,800 ha by 2012, and 81% of crops sown were cereals[2]. Furthermore, in Mongolia, soil degradation has appeared as a major limitation to increasing the country's food production. It has been reported that the impact of grazing on vegetation in southern Mongolia was apparent in the effect of high inter-annual variability of precipitation[3,4]. Due to the rapid increase of cropping areas in

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the country, land conservation technology is essential to maintain food production. In the Chinese autonomous region of Inner Mongolia, in search of solutions for land degradation some trials have been made, using such measures as crop rotation and crop residue management[5], animal compost use[6], and nitrogen fertilizer application[7,8]. Intensive use of chemical fertilizer is not recommended for Mongolia : many farmers have never used any mineral fertilizers or pesticides due to insufficient supplies or lack of financial sources and 97% of the fertilizers used have been organic fertilizers[2]. In other semi-arid regions of the world, many studies have evaluated sustainable use of arable land by conservation agriculture, crop rotation, and chemical and organic fertilizer applications. Different results were shown in each case. In Spain, chemical fertilization rarely increased yields due to low precipitation and low effectiveness of weed control[9]. According to Walburger *et al.* (2006)[10], in semiarid lands of Alberta, Canada, crop rotation with wheat and legume crops increased net returns compared to the traditional rotation system with wheat and fallow, but wheat monoculture and fallow wheat rotations with manure treatments were not as profitable as those with chemical fertilizer treatments. For smallholder farming in sub-Saharan Africa, Giller *et al.* (2009) concluded that it was urgent to make a critical assessment of the ecological and socio-economic conditions which were best suited for conservation agriculture[11].

From 2010 to 2013, we carried out a field study in Mongolia to determine the effects of both chemical and organic fertilizers to maintain crop productivity and sustainable management for soil. We used composts made from sheep and goat dung because these animals are the most common livestock in the country. In the winter, dung was accumulated and naturally matured, and then used for fertilization. Experiment-1 was carried out from 2010 to 2012, and in it we determined the effects of continuous use of compost and chemical fertilizer on rye, potato, and turnip yields. Experiment-2 was carried out in 2013 to acquire clear evidence for the effect of compost on crop yield, and in it we determined the effects of fertilization rate of composts and their quality on wheat and potato yields under more intensive land management than Experiment-1. From the results, we evaluated the effectiveness of both organic and chemical fertilizers and the possibility of animal compost use to maintain productivity of land as a self-support fertilizer.

2. Materials and Methods

Field study area

The field study was conducted on the Nart Experimental Farm (48°36'42.3" North, 106°29'20, 7" East) of the Mongolian State University of Agriculture. The regional climate is semiarid and cold with a short summer. Most of

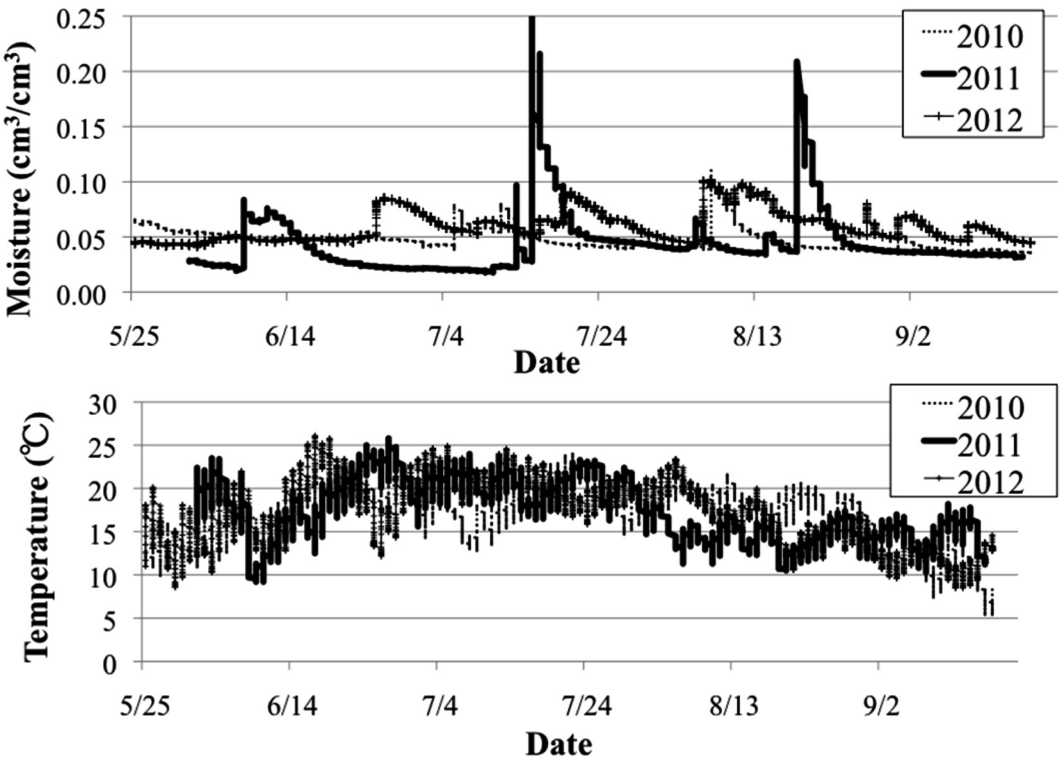

Fig. 1 Changes of soil moisture content at the Nart experimental farm measured during the cropping season in 2010–2012 (measured for the soil depth of 10 cm).

the annual precipitation falls in summer (May–September), and mean annual precipitation is about 270 mm. The measurement and collection of the soil moisture contents and temperature during the cropping season in 2010 to 2012 were done with the 5TM soil moisture and temperature sensor and the Em50 digital data logger (Decagon Devices, Inc., Pullman, WA). The values are summarized in Fig. 1. Mongolian arable soils are typically light and silty, are present to a depth of around 30 cm, have high organic matter content of 3 to 4%, are moderately acidic to neutral with pH of 6.0 to 7.0, and are rich in calcium, but deficient in phosphate[12]. The soil of our field study had such properties, and was classified according to the FAO-UNESCO classification system[13] as a Kastanozem soil, and with the USDA classification system[14], as Typic Calcicryolls.

Experiment-1 : Field experiment to determine the effects of both chemical and organic fertilizers on crop productivity under extensive land management.

During 2010 to 2012, we determined the effects of both chemical and organic fertilizers in a field experiment, Experiment-1. The field was managed without irrigation or weed control like large-scale and extensive land management traditionally used in Mongolia.

In Experiment-1, three fertilization methods were used : i) no fertilization (control 1 and control 2 land plots ; for control 1, a goat pasturage area was used for cultivation and goat dung was distributed for one year in the year before the experiment started, for control 2, nothing was done.) ; ii) application of animal compost at 40 Mg ha^{-1} y^{-1} (668 kg N ha^{-1} y^{-1}, 424 kg P_2O_5 ha^{-1} y^{-1} and 216 kg K_2O ha^{-1} y^{-1}) (compost plot) ; and iii) application of chemical fertilizer at 90 kg N ha^{-1} y^{-1}, 90 kg P_2O_5 ha^{-1} y^{-1} and 90 kg K_2O ha^{-1} y^{-1} (NPK plot). In the compost plot, we used compost made from dung of sheep and goats collected in the winter in Nart area around the Nart Experimental Farm and naturally fermented for three month. Nutrients contained in the compost and the chemical fertilizer used for Experiment-1 are shown in Table 1. The experimental field was separated into three areas, and three crop rotation sequences were made for each area as shown in Fig. 2. Crops grown were potato (*Solanum tuberosum* L.), rye (*Secale cereale* L.), turnip (*Brassica rapa* L. *var. glabra*) and pea (*Pisum sativum* L.). The turnip crop was used for animal feed, and the pea crop was used as green manure. In Experiment-1, crop yields were measured in the first week of every September from 2010 to 2012. Crop yields were calculated from the fresh weight of edible parts of sampled plants from four selected sites (3.3 m^2) in the experimental field.

Experiment-2 : Field experiment to determine the appropriate compost application level under intensive land management.

In 2013, we carried out another field experiment, Experiment-2, on the appropriate use of animal compost that determined the effects of compost maturing time and the applied amount of compost under more intensive land management. The field was small scale and weeds

Table 1 Major nutrient contents in the composts used and the applied nutrient amounts in the two field experiments.

	Major nutrient contents in the composts						
	T-C (%)	T-N (%)	C/N	P_2O_5 (%)	K_2O (%)	CaO (%)	MgO (%)
Compost in Experiment-1	-	1.67	-	1.06	0.54	2.7	0.89
Composts in Experiment-2							
2m-compost	28.9	1.52	19.0	0.62	1.1	2.9	0.9
2y-compost	30.9	2.45	12.6	0.70	1.4	4.2	1.4
	Applied nutrient amounts in chemical fertilizer or composts (kg ha^{-1} $year^{-1}$)						
		N		P_2O_5	K_2O	CaO	MgO
Experiment-1							
Control		0		0	0	0	0
Compost (40 Mg ha^{-1})		668		184	180		
NPK chemical fertilizer		90		90	90	0	0
Experiment-2							
2m-compost, 20 Mg ha^{-1}		304		124	220	578	180
2m-compost, 40 Mg ha^{-1}		608		248	440	1156	360
2m-compost, 60 Mg ha^{-1}		912		372	660	1734	540
2y-compost, 20 Mg ha^{-1}		490		140	286	838	286
2y-compost, 40 Mg ha^{-1}		980		280	572	1676	572
2y-compost, 60 Mg ha^{-1}		1470		420	858	2514	858

were eliminated during the cultivation. The Animal composts prepared with a 2-year fermentation process (2y-compost) and a 2-month fermentation process (2m-compost) were used. Crops grown were wheat (*Triticum aestivum* L.) and potato (*Solanum tuberosum* L.). These composts were applied in amounts of 20 Mg ha^{-1}, 40 Mg ha^{-1} and 60 Mg ha^{-1}. Nutrients contained in the composts and the chemical fertilizer used for Experiment-2 are shown in Table 1. The land plot design and the amounts of composts applied are shown in Fig. 2. For each crop, there were three sets of land plots for the four application amounts and the two composts (24 plots in total per crop). Crop yields were measured in the first week of September 2013 and calculated in the same way as described for Experiment-1.

Chemical analysis of composts and soil

In both Experiment-1 and Experiment-2, soil samples were collected from each of the land plots at the same time as the yield measurements were made ; samples were taken at a depth of 0–20 cm. The soil pH (H_2O), CEC, available-N, available-P (only for Experiment-1), and exchangeable K, Ca, and Mg were measured. Chemical analysis of composts was done as follows. For the composts, nitrogen content was analyzed with a nitrogen content analyzer (Sumigraph NC-220F, Tokyo, Japan) and phosphorus was analyzed by colorimetry using ammonium molybdate as a reagent. The other nutrient amounts of compost were measured by atomic absorption spectrometry (iCE 3000, ThermoFisher Scientific, Kanagawa) following digestion of the sample with $HClO_4$-HNO_3-HF.

Chemical analysis of soil samples was done as follows. Soil available-N amount was measured by 1 mol L^{-1} KCl extraction after a 4-week incubation. The available soil P was extracted by the Truog method (Truog-P) using a pH 4 $(NH_4)_2SO_4$-H_2SO_4 solution[15,16] and by the Olsen method (Olsen-P) using 0.5 mol L^{-1} $NaHCO_3$ (pH 8.5) as extractant[17]. The CEC and exchangeable K, Ca, and Mg amounts were determined by the Schollenberger method[18].

Statistical analysis

For the data treatment, all analysis was replicated three times for both Experiment-1 and Experiment-2 and the differences tested statistically by ANOVA using Bonferroni's method ($p < 0.05$).

3. Results and Discussion

Effects of chemical fertilizer and compost on crop yields, and soil properties in Experiment-1.

The crop yields from 2010 to 2012 are shown in Table 2. They were in wide ranges : 5.1–25.8 Mg ha^{-1} for potato tuber, 1.3–2.2 Mg ha^{-1} for rye grain, and 0.4–18.6 Mg ha^{-1} for turnip root. In this crop rotation system, yields of potato and turnip varied greatly between years while the rye yield was relatively stable. This related to annual variability in precipitation, and the effect of weeds. Pea yield in 2012 was not observed since most of the pea plants did not germinate because of drought stress. Relatively higher yield of potato and rye in 2011 should be due to high soil moisture content in July of each year as shown in Fig. 1. As reported by Wesche *et al.* (2010), the effect of high inter-annual variability in the precipitation of Mongolia is the dominant factor affecting plant growth[4]. Though no significant effect on yield was observed for

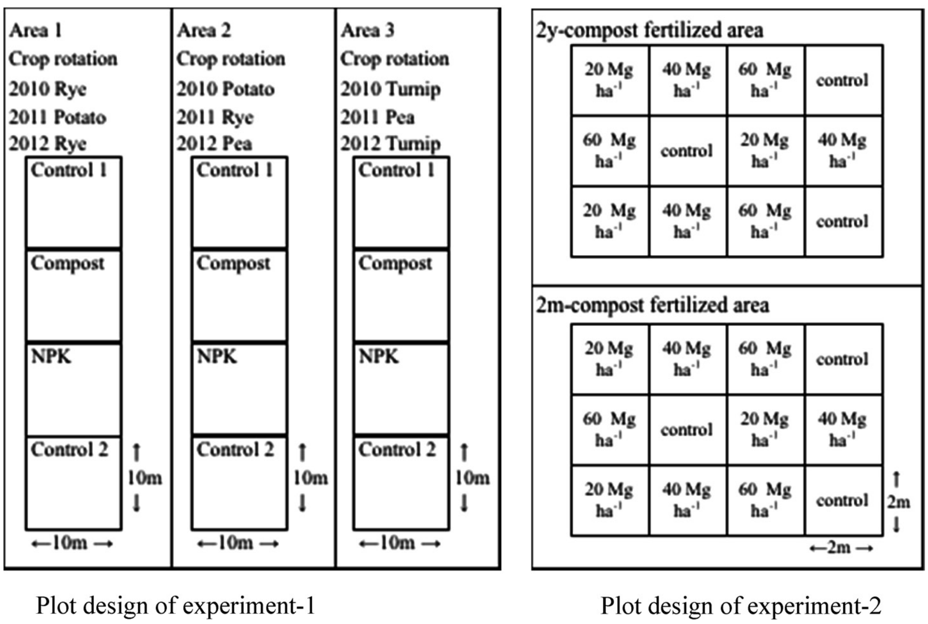

Fig. 2 Land plot design of Experiment-1and Experiment-2.

chemical and organic fertilizer applications, the highest yields of potato (in 2010), pea (in 2011), and turnip (in 2012) were observed for compost application. These results suggested that chemical fertilizer application was less effective than compost. The seasonal variability of precipitation might explain the relatively lower effectiveness of chemical fertilizer as compared to compost because the effect of chemical fertilizer depended on the rainfall events, and soil moisture content was low in the sowing season (late May) during 2010 to 2012 (Fig. 1). However, among the eight crop yields in Table 2 (except the pea yield in 2012), potato yield in 2011 and rye yield in 2010, 2011 and 2012, turnip yield in 2010 was highest in the control plot. This indicated that traditional no fertilization agriculture is still reasonable for farmers under high seasonal variability of precipitation and severe weed effect in Mongolia. In addition to this, the crop yield of control 1 was not superior to control 2, thus the goat pasturage effect of control 1 was not detected. Therefore it was suggested that to detect the effect of organic fertilization in Mongolia, more intensive use of composts was needed. So we examined this factor in Experiment-2. The soil properties after three years of cultivation in Experiment-1 are shown in Table 3. Among measured soil nutrients, no significant effect was observed for both chemical and organic fertilizer applications. The available-N amount tended to be higher for compost plots, but the carbon amount was not increased with organic fertilization. These values were measured after cultivation, thus the effect on soil nutrient amount was obscure due to uptake by the plants or erosion. This result indicated that the three-year field experiment was not long enough to assess the effects of compost on soil nutrients and land conservation.

Effect of composts on crop yields in Experiment-2

The crop yields in Experiment-2 are shown in Table 4. The potato yield increased significantly with the application of 2y-compost, and the average yield of potato was related to the compost application rate. The 2m-compost also increased average yield of potato but the change was not significant. No significant effect was observed for the wheat yield for 2y and 2m-composts. However the wheat yield of compost applied plots tended to be higher than that of control plots. For both crops, the positive effect of compost application was observed but the wheat yield did not increased linearly with applied compost amount like the yield of potato. The reason for this difference between crops was unknown ; it should be recalled that the effect of compost was apparent when potato and cereal

Table 2 Yield data[*1] of Experiment-1 (2010–2012)

	2010			2011			2012		
	Rye grain	Potato tuber	Turnip[*3] root	Potato tuber	Rye grain	Pea[*3] shoot	Rye grain	Pea[*3]	Turnip root
	$Mg\ ha^{-1}$	$Mg\ ha^{-1}$	$Mg\ ha^{-1}$	$Mg\ ha^{-1}$	$Mg\ ha^{-1}$	$Mg\ ha^{-1}$	$Mg\ ha^{-1}$		$Mg\ ha^{-1}$
Control 1	1.69	5.14	No data	17.7	2.18 [a]	No data	1.67	No data	0.24
Control 2	1.83	6.59	18.6 [a]	25.8	1.75 [b]	0.408	1.60	No data	0.49
Compost	1.40	6.96	0.4 [b]	21.4	1.86 [ab]	0.423	1.47	No data	0.81
NPK	1.31	5.97	6.3 [b]	23.6	1.65 [c]	0.373	1.20	No data	0.44
Statistical significance[*2]	NS	NS		NS		NS	NS		NS

[*1] Data were the arithmetic mean of four replicated values from four sites.
[*2] Values followed by letters were found to be statistically different between plots, NS means not significant. (ANOVA; $P < 0.05$).
[*3] In control 1, turnip yield data of 2010 and pea yield data of 2011 were not measured because of low germination due to weeds. In 2012, pea yield data were not measured because most pea plants did not germinate due to drought stress.

Table 3 Changes of soil properties[*1] with 3 years of fertilization in Experiment-1.

	pH	EC	Total-C	N ($mg\ N\ kg^{-1}$)		Available-P ($mg\ P\ kg^{-1}$)		Exchangeable cations ($mg\ kg^{-1}$)		
	(H_2O)	($mS\ cm^{-1}$)	(C%)	Total-N	Available–N	Truog method	Olsen method	K	Ca	Mg
Control 1	8.04	0.097	1.56	1522	168	111	13.1	171	920	219
Control 2	8.14	0.097	1.59	1561	208	114	17.3	184	1118	206
Compost	7.93	0.105	1.69	1574	219	115	16.6	210	1236	230
NPK	8.05	0.105	1.97	1811	177	119	18.7	189	1321	230
Statistical significance[*2]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[*1] Data were the arithmetic mean of 3 areas (areas 1-3).
[*2] Statistical significance of difference between plots was tested (ANOVA; $P < 0.05$), NS means not statistically significant.

Table 4 Yield data[*1] of Experiment-2 (2013).

	Potato tuber yield (Mg ha^{-1})	Wheat grain yield (Mg ha^{-1})
Control	29.5^{a}	0.084
2m-compost 20 Mg ha^{-1}	29.8^{a}	0.158
2m-compost 40 Mg ha^{-1}	38.4^{ab}	0.100
2m-compost 60 Mg ha^{-1}	37.1^{ab}	0.106
2y-compost 20 Mg ha^{-1}	39.7^{ab}	0.095
2y-compost 40 Mg ha^{-1}	40.1^{ab}	0.144
2y-compost 60 Mg ha^{-1}	43.2^{b}	0.134
Statistical significance[*1]		NS

[*1] Values are the mean of three replicated values. Values followed by letters were found to be statistically different between plots, NS means not statistically significant. (ANOVA; P < 0.05)

Table 5 Changes of soil properties[*1] with the application of composts in Experiment-2.

		pH (H_2O)	EC (mS cm^{-1})	Available N (mg N kg^{-1})	Exchangeable cations: Exch. K (mg K kg^{-1})	Exch. Ca (mg Ca kg^{-1})	Exch. Mg (mg Mg kg^{-1})
Potato							
Control		7.86	0.117 ^{a}	10.3	134 ^{a}	2958	294 ^{a}
2m-compost	20Mg ha^{-1}	7.77	0.141 ^{ab}	13.1	212 ^{ab}	2998	343 ^{ab}
	40Mg ha^{-1}	7.66	0.153 ^{ab}	10.3	258 ^{ab}	2728	365 ^{ab}
	60Mg ha^{-1}	7.74	0.228 ^{b}	10.6	189 ^{ab}	3436	414 ^{ab}
2y-compost	20Mg ha^{-1}	7.89	0.128 ^{a}	10.1	196 ^{ab}	2979	370 ^{ab}
	40Mg ha^{-1}	7.86	0.162 ^{ab}	13.5	252 ^{ab}	3532	466 ^{b}
	60Mg ha^{-1}	7.90	0.163 ^{ab}	11.0	374 ^{b}	3268	557 ^{c}
Statistical significance[*1]		NS		NS		NS	
Wheat							
Control		7.88	0.108	8.2	158	3261	351
2m-compost	20Mg ha^{-1}	8.02	0.118	8.6	150	3189	305
	40Mg ha^{-1}	7.82	0.128	6.9	178	3463	331
	60Mg ha^{-1}	7.73	0.121	9.4	205	3050	403
2y-compost	20Mg ha^{-1}	8.19	0.124	7.7	122	3912	277
	40Mg ha^{-1}	8.14	0.129	7.5	149	3490	301
	60Mg ha^{-1}	8.00	0.130	7.2	174	3935	359
Statistical significance[*1]		NS	NS	NS	NS	NS	NS

[*1]Data were the arithmetic mean of 3 replicated areas. Values followed by letters were found to be statistically different between plots, NS means not statistically significant. (ANOVA; P < 0.05).

crops were compared for Experiment-1. These results showed that the effect of compost depended on the quality of the compost, such as maturing time, and crop species. The 2y-compost was more effective to increase crop yield than 2m-compost due to the higher N content of the former. Also, it was shown that increasing the application of 2y-compost from 20 Mg ha^{-1} to 60 Mg ha^{-1} did not increase potato yield significantly. Optimization of the compost application rate by balancing its benefits and the cost for preparing and transporting the animal compost should be examined.

Further, the potato yields of Experiment-2 were about 2 times higher than that of the compost plot in Experiment-1 even in the same 40 Mg ha^{-1} of fertilization. The N content of compost used in experiment-1 and 2m-compost in Experiment-2 was almost the same level, so the difference was due to the higher weed stress in the field used in Experiment-1. The weeds of field in Experiment-2 were eliminated during the experiment, and it was suggested that the weed effect was also a strong factor to be controlled in Mongolian agriculture.

Effects of applied nutrients in composts on soil properties and crop yield in Experiment-2

The soil properties measured after Experiment-2 are shown in Table 5. The compost application increased electric conductivity (EC) and exchangeable K, Ca, and Mg, especially for 2y-compost. The increase of available-N by compost application was not observed : this might be due to N uptake by potato and wheat. The relationship between applied nutrient and potato yield is shown in Fig. 3. For wheat, no significant relationship was observed between applied N and crop yield. Only applied N and potato yield had a significant relationship. No significant relationship was observed for applied N, P, and K amounts in the compost and wheat yield (data not shown). From these results, it was considered that the increase of potato yield was due to the applied N in the compost,

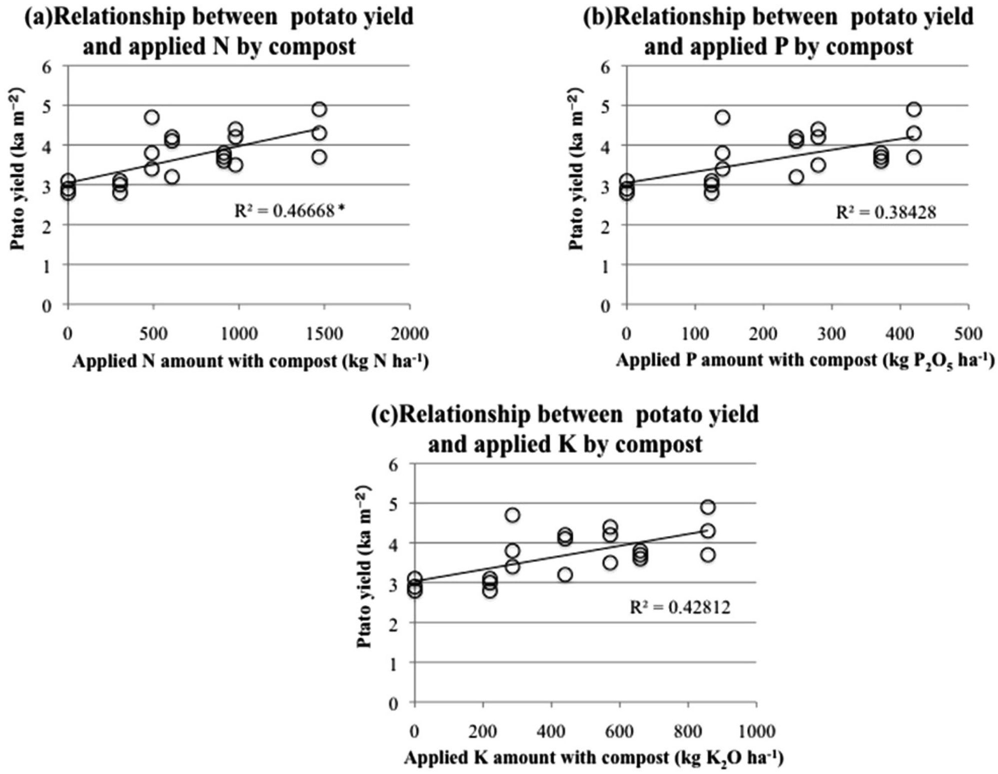

Fig. 3 Relationships between yield and amounts of applied N (a), P (b), K (c) by compost for potato. (The * indicates statistical significance at the 5% level.)

and the apparent effect of 2y-compost was due to its higher N content as shown in Table 1.

4. Conclusion

From the results of our field study, it was suggested that the use of chemical fertilizer was not effective to maintain soil productivity as shown in Experiment-1. The crop yield was highly affected by the high inter-annual variability in precipitation and weed stress, and it made the effect of both organic and chemical fertilizer obscure. Also the three-year field experiment was not long enough to assess the effects of compost on soil nutrients and land conservation. However, the use of animal compost had an apparent positive effect in Experiment-2 under intensive land management with control of the weed effect. These results showed that the use of both chemical and organic fertilizer was not effective under extensive cropping system traditionally used in Mongolia. Also it was shown that compost application increased crop yield under intensive land management. The effect of manure had an upper limit, and manure application of more than 20 $Mg\,ha^{-1}$ was not effective. Furthermore, not only the amount, but also the compost quality was important, and our field study showed the 2y-compost was more effective to increase crop yield than 2m-compost due to the higher N content of the former.

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モンゴル農業における有機肥料と化学肥料の収量への効果の比較

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要約：モンゴルにおいて，施肥を行わない粗放的農地の拡大から土壌保全のための技術が求められている。そこでモンゴルの半乾燥地において，2010年から2013年にわたり行った，家畜糞を自給可能な肥料として使用する圃場試験について報告する。最初の圃場試験（Experiment-1）では，モンゴルで伝統的な粗放的農地管理下において，2010年から2012年にわたり，バレイショ，ライ麦，飼料用カブを家畜糞堆肥（ヤギおよび羊の糞）40 Mg $ha^{-1}y^{-1}$ または化学肥料（90 kg $ha^{-1}y^{-1}$ of N, P_2O_5, and K_2O）を使用して3年間栽培した。次の圃場試験（Experiment-2）では，より集約的に雑草除去を行う条件下で2013年に家畜糞堆肥を2ヶ月熟成したもの（2m-compost）および2年間熟成した堆肥（2y-compost）をそれぞれ20, 40, 60 Mg ha^{-1} 施用し，バレイショを栽培した。Experiment-1の結果，3年間の栽培において，土壌中可給態窒素量および収量は，ともに家畜糞堆肥において多く，化学肥料の施与効果は全く認められなかった。化学肥料の効果が認められなかった理由として，生育期間中の降水量の不足及び粗放的管理下における雑草によるストレスが考えられる。しかしながらExperiment-2の結果として，雑草除去を行う条件下では2y-compost施用下において無施肥区に比べ有意な収量増加が認められた。これは2y-compostの熟成期間が長くそれにより窒素含量も高かったことによると見られた。これらの結果から，モンゴルにおいて伝統的な粗放的農地管理下では，化学肥料，有機肥料の使用はともに収量向上に効果的でなく，一方で堆肥施肥は集約的な農地管理下で有効に収量を向上させうることが示された。

キーワード：モンゴル，作物収量，カスタノーゼム，土壌劣化，家畜糞コンポスト

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