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Effects of urea and sunn hemp on nitrogen use efficiency and physiological traits related to Japonica rice yield

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Abstract Application of sunn hemp as a sole fertilizer could provide nitrogen use efficiency (NUE), tiller number, leaf area index (LAI), crop growth rate (CGR), biomass and grain yield higher than application of urea as a sole fertilizer. Correlation coefficients (r) among some physiological traits including LAI, CGR, NUE, NUE for grain yield (NUEg) and agronomic traits consisting of tiller number, biomass and grain yield were significantly positive resulted which ranged between 0.65 and 1.00. The results indicated that application of sunn hemp as green manure can promote growth and yield of Japonica rice and tend to be a good choice for supplying nitrogen in Japonica rice production.

Keywords: Leaf area index, Crop growth rate, Organic fertilizer, *Oryza sativa* L.

Introduction

Nitrogen is an important nutrient in rice production because rice needs nitrogen at all stages of growth. The highest nitrogen is required at early stages to enhance growth and tillering which in turn determines potential number of spikelets. Nitrogen plays an important role in spikelet production during early panicle formation stage and determine sink size during the late panicle formation stage. Nitrogen also plays a role in grain filling, improves the photo-synthetic capacity and promotes carbohydrate accumulation in culms and leaf sheaths (Tayefe *et al*., 2014; Lee, 2021).

Farmers use nitrogen fertilizer in the forms of chemical fertilizers (urea and ammonium sulphate) because it is easy to manage. Besides, farmers often use excessive amounts of nitrogen fertilizer to achieve higher yields. The high price of chemical fertilizers incurs high production cost. If fertilizers from organic sources are freely available or available at low cost, using organic

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fertilizers is another option to reduce production cost and it is environmentally friendly (Avery, 2021; Ren *et al*., 2022).

In the current rice production, many organic fertilizers such as farmyard manure, compost, and green manure are used as alternative fertilizer sources. In addition, the application of green manure together with chemical nitrogen fertilizer is a promising approach to improve nitrogen fertilizer management, soil fertility and organic matter and reduce nitrogen lose from the soil, and green manure from legumes can be used as an alternative fertilizer because legumes can incorporate significant nutrients into the soil through decomposition and nutrient release from biomass (Espinal *et al*., 2016; Pereira *et al*., 2016).

Sunn hemp (*Crotalaria juncea* L.) is commonly used as green manure because it is a short life-cycle crop and easy to grow and maintain (Sarkar and Ghoroi, 2007). The farmers can harvest the seeds for the next seasons. Under moisture stress conditions, sunn hemp is a better green manure crop than cowpea, sesbania and cluster bean (Agrawal *et al*., 1993). In addition, application of sunn hemp as green manure resulted in higher nitrogen use efficiency (NUE), growth, and yield of rice than application of green manure from millet (Meng *et al*., 2019; Supsuan, 2019; Espinal *et al*., 2016).

Sunn hemp is a nitrogen fixing legume widely used as a green manure crop in rice production systems. For Japonica rice grown in the tropics, the information on the responses of Japonica rice to the application of sunn hemp is still not conclusive. The objective of this study was to compare the effects of sunn hemp and urea applied as sole nitrogen sources and in combination of two sources on nitrogen use efficiency and physiological traits related to yield of Japonica rice.

Materials and methods

Location and experimental design

The experiment was conducted during April, 2022 to August, 2022 at the Department of Plant Production Technology, School of Agricultural Technology, King Mongkut’s Institute of Technology Ladkrabang (Latitude: 13.7440 Longitude: 100.7920). Pot experiment was set up in a completely randomized design with four replications in a rain shelter with wire screen to protect the rice from animal and insect pests. The treatments consisted of nitrogen sources including unfertilized control, sunn hemp (*Crotalaria juncea* L.) (4,437.81 kg dry matter/ha), urea (46-0-0) (150 kg N/ha) and sunn hemp (2,218.90 kg dry matter/ha) plus urea (75 kg N/ha).

Chemical fertilizer and sunn hemp were not applied for unfertilized control. For sunn hemp alone, sunn hemp at the rate of 4,437.81 kg dry matter/ha harvested at 50 days after planting (at flowering) was chopped into small pieces and incubated under soil capacity moisture content for 14 days prior to transplanting of rice crop. The rate of 4,437.81 kg dry matter/ha was equivalent to 150 kg of urea based on nutrient analysis of sunn hemp. The seedling was 25 days old.

For urea alone, urea at the rate of 150 kg N/ha was applied to the crop at two splits one at 20 days after transplanting (DAT) and another at 40 DAT. For sunn hemp plus urea, sunn hemp at the rate of 2,218.90 kg dry matter/ha was incubated for 14 days prior to transplanting of rice crop, and urea at the rate of 75 kg N/ha applied to the crop at two splits one at 20 days after transplanting (DAT) and another at 40 DAT. The rate of 2,218.90 kg dry matter/ha was equivalent to 75 kg of urea.

Preparation of sunn hemp

Sunn hemp was planted in the field on December 10, 2021 and harvested at flowering stage (50 days after planting). Sunn hemp was chopped into small pieces and dried at 60^{o}C for 72 hours. Dry matter of sunn hemp was analyzed for total nitrogen concentration by the CNS analyzer (LECO Corporation, 2016). The analysis result found that dry matter of sunn hemp contained 3.38% of total nitrogen. The result obtained was used for calculation of sunn hemp used in the treatments.

Crop management

Soil was obtained from the field, then dried for a week and crushed into small particles. The dry soil was loaded into rectangle cement pots with 60 cm in width, 100 cm in length and 30 cm in height. Each plot contained 120 kg soil. Soil was also sampled for analysis of the physical and chemical properties before planting.

Soil samples with the same amount in all containers were collected, bulked into a pile and mixed thoroughly. The mixed soil sample was further divided into four piles, and one pile was used for soil analysis.

Japonica rice variety used in this study is DOA1, which was released by the rice department, Thailand. Seeds were germinated by soaking in water for 24 hours and cover with wet cloth for 24 hours. Pre-germinated seeds were planted with 3 seeds per hill in seedling trays for 25 days, and the seedlings were transplanted into the rectangle cement pots on April 16, 2022. The cement containers accommodated 8 hills. Two fertilizer treatments including sunn hemp alone and sunn hemp green manure plus chemical fertilizer were prepared for two weeks before transplanting. As total dry matter of sunn hemp contained 3.38% of total nitrogen. For sunn hemp alone, sunn hemp at a rate of 4,437.81 kg/ha was applied one time prior to transplanting. Sunn hemp at this rate supplied nitrogen of 150 kg N/ha. For sunn hemp plus urea, sunn hemp at the rate of 2,218.90 kg/ha was applied one time prior to transplanting, and urea at the rate of 75 kg N/ha was applied at two splits as mentioned earlier. Sunn hemp at this rate supplied nitrogen of 75 kg N/ha.

Sunn hemp green manure at the predetermined rates according to the treatments was mixed into the soils, and the mixed soils were loaded into the rectangle cement pots. The mixed soils were then incubated under field capacity condition for 14 days before transplanting. After incubation, the mixed soils in all pots were randomly sampled at the depth of 0-15 cm and analysed for ammonium ion (NH_4^+) by the Kjeldahl method (Bryson and Mills, 2015). Ammonium ion in the soil with sunn hemp alone was about 848.59 mg/kg, and with sunn hemp plus urea was about 211.13 mg/kg (Data not shown).

For urea alone, urea at a rate of 150 kg N/ha was applied at two splits at 20 and 40 days after transplanting. For sunn hemp plus urea, sunn hemp at the rate of 2,218.90 kg/ha was applied to the crop at 14 days before transplanting, and urea at the rate of 75 kg N/ha was applied to the crop at two splits at 20 and 40 days after transplanting. Irrigation water was monitored and supplied at the controlled level at 10 mm above the soil surface throughout the experimental period, and the application of irrigated water was terminated at one week before harvest.

Data collection

The crop was harvested at 116 days after transplanting on August 9, 2022. Data were recorded for tiller number, leaf area (LA), biomass, percentage of filled grains, percentage of un-filled grains, 1,000-grain weight and grain yield. The samples were oven-dried at 60-65^{o}C for 48 hours or until dry weights were constant, and the dry weights of the samples were recorded. The data were derived for leaf area index (LAI), specific leaf area (SLA), crop growth rate (CGR), harvest index (HI), nitrogen use efficiency (NUE) and nitrogen use efficiency for grain yield (NUEg) were calculated as follows;

$$LAI = LA/GA$$

where, LA is the leaf area and GA is the land area.

Specific leaf area was calculated as follows:SLA = LA/LW where, LA is the leaf area and LW is the leaf dry weight.

Crop growth rate was calculated as follows: CGR = 1/GA × [(W2- W1)/(T2-T1)], where, GA is the land area, W2 and W1 are dry weights of plant at time T2 and T1, respectively.

Harvest index was calculated as follows:HI = Economic yield/ Biological yield, where, economic yield is seed yield in g/plant and biological yield is seed yield + dry stover yield in g/plant.

Nitrogen use efficiency was calculated as follows: NUE = Biomass (kg/ha)/ N applied (kg/ha), NUEg = Grain yield (kg/ha)/ N applied (kg/ha).

Data analysis

The data were analyzed statistically according to a completely randomized design. The differences among treatment means were compared by least significant difference (LSD) at 0.01 probability level. All statistical analyses were accomplished using M-STATC program from Michigan State University (Bricker, 1989). Correlation coefficients among traits were calculated in Microsoft Excel.

Results

Nitrogen use efficiency (NUE) and nitrogen use efficiency for grain yield (NUEg)

Different types of nitrogen fertilizers were significantly different ($P \leq 0.01$) for NUE of Japonica rice at harvest (Table 1). Sunn hemp alone had the highest NUE with the value of 25.08 kg biomass/kg N applied. However, it was not significantly different from sunn hemp plus urea (19.25 kg biomass/kg N applied), whereas urea alone had the lowest NUE value of 18.17 kg biomass/kg N applied, which was significantly lower than sunn hemp alone.

It is interesting to note here that nitrogen use efficiency for biomass was about three times higher than nitrogen use efficiency for grain yield. The fertilizer treatments were not significantly different for nitrogen use efficiency for grain yield (NUEg). NUEg values ranged between 5.26 kg yield/kg N applied and 7.78 kg yield/kg N applied. Sunn hemp alone was highest (7.78 kg yield/kg N applied) followed by urea alone (6.00 kg yield/kg N applied), whereas sunn hemp plus urea was lowest (5.26 kg yield/kg N applied).

Table 1. Means for nitrogen use efficiency (NUE) for biomass and NUE for grain yield (NUEg) of Japonica rice at harvest as affected by different types of nitrogen fertilizer

Treatment	NUE (kg biomass/kg N applied)	NUEg (kg yield/kg N applied)
Unfertilized control	-	-
Sunn hemp (150 kg N/ha)	25.08[a]	7.78
Urea (150 kg N/ha)	18.17[b]	6.00
Sunn hemp (75 kg N/ha) plus urea (75 kg N/ha)	19.25[ab]	5.26
F-test	**	ns
C.V. (%)	12.31	20.03

ns = non significant
** = significantly different at $P \leq 0.01$
Means within the same column followed by the same letter are not significantly different by LSD

Physiological traits

Different types of nitrogen fertilizer treatments were significantly different ($P \leq 0.01$) for tiller number per plant, leaf area index (LAI) and crop growth rate (CGR) of Japonica rice at harvest (Table 2). Sunn hemp alone had the highest tiller number of 12.75 tillers/plant followed by sunn hemp plus urea, urea alone and unfertilized control with tiller number of 9.00, 6.50 and 5.25 tillers/plant, respectively.

Sunn hemp alone had the highest LAI value of 1.82, and it was significantly different from sunn hemp plus urea (1.22), urea alone (1.06) and unfertilized control (0.79). Although the treatments were not significantly different for specific leaf area (SLA), sunn hemp plus urea seemed to be highest (138.49 cm^2/g) followed by sunn hemp alone (133.49 cm^2/g), unfertilized control (120.78 cm^2/g) and urea alone (115.83 cm^2/g), respectively. Significantly different ($P \leq 0.01$) among types of nitrogen fertilizers were found for crop growth rate (CGR) evaluated during planting to harvest. Sunn hemp alone had the highest CGR value of 2.67 $g/m^2/d$ followed by sunn hemp plus urea (2.05 $g/m^2/d$), urea alone (1.93 $g/m^2/d$) and unfertilized control (1.02 $g/m^2/d$), respectively.

Table 2. Means for tiller number, leaf area index (LAI), specific leaf area (SLA) and crop growth rate (CGR) of Japonica rice at harvest as affected by different types of nitrogen fertilizer

Treatment	Tiller No./plant	LAI	SLA (cm^2/g)	CGR ($g/m^2/d$)[1/]
Unfertilized control	5.25[b]	0.79[b]	120.78	1.02[c]
Sunn hemp (150 kg N/ha)	12.75[a]	1.82[a]	133.49	2.67[a]
Urea (150 kg N/ha)	6.50[b]	1.06[b]	115.83	1.93[b]
Sunn hemp (75 kg N/ha) plus urea (75 kg N/ha)	9.00[ab]	1.22[b]	138.49	2.05[b]
F-test	**	**	ns	**
C.V. (%)	24.49	19.54	20.62	14.82

ns = non significant
** = significantly different at $P \leq 0.01$
Means within the same column followed by the same letter are not significantly different by LSD
[1/] CGR during planting to harvest

Yield and yield components

The different types of nitrogen fertilizers were significantly different ($P \leq 0.01$) for biomass and grain yield, but they were not significantly different for 1,000-grain weight, filled grain, unfilled grain and harvest index (HI) of Japonica rice at harvest stage (Table 3). Sunn hemp alone had the highest biomass (3,762.7 kg/ha), and it was significantly higher than sunn hemp plus urea (2,887.3 kg/ha), urea alone (2,725.0 kg/ha) and unfertilized control (1,443.3 kg/ha).

Sunn hemp alone had grain yield of 1,167.3 kg/ha, which was not significantly different from 900.3 kg/ha of urea alone. However, sunn hemp alone was significantly higher than sunn hemp plus urea (789.0 kg/ha), whereas urea alone was similar to sunn hemp plus urea. Sunn hemp alone and urea alone were significantly higher than unfertilized control (435.3 kg/ha), sunn hemp plus urea was similar to unfertilized control.

All types of nitrogen fertilizers did not have significant effects on 1,000-grain weight, filled grain, unfilled grain and harvest index. However, the treatments associated with sunn hemp (sunn hemp alone and sunn hemp plus urea) seemed to have slightly higher percentage of filled grain and lower of unfilled grain than urea alone and unfertilized control, but they seemed to slightly reduce higher harvest index.

Table 3. Means for biomass, grain yield, 1,000-grain weight, filled grain, unfilled grain and harvest index (HI) of Japonica rice at harvest as affected by different types of nitrogen fertilizer

Treatment	Biomass (kg/ha)	Grain yield (kg/ha)	1,000-grain weight (g)	Filled grain (%)	Unfilled grain (%)	HI
Unfertilized control	1,443.3[c]	435.3[c]	28.35	79.56	20.44	0.29
Sunn hemp (150 kg N/ha)	3,762.7[a]	1,167.3[a]	29.00	86.78	13.22	0.27
Urea (150 kg N/ha)	2,725.0[b]	900.3[ab]	29.61	79.84	20.16	0.31
Sunn hemp (75 kg N/ha) plus urea (75 kg N/ha)	2,887.3[b]	789.0[bc]	28.30	86.32	13.68	0.25
F-test	**	**	ns	ns	ns	ns
C.V. (%)	14.82	20.71	5.74	6.02	29.64	16.72

ns = non significant
** = and significantly different at $P \leq 0.01$
Means within the same column followed by the same letter are not significantly different by LSD

Correlation

Leaf area index was positively correlated with number of tillers (r = 0.73**), and they were positively correlated with crop growth rate, nitrogen use efficiency, nitrogen use efficiency for grain yield (NUEg) and biomass with r values ranging between 0.65** and 0.83** for number of tillers and 0.73** and 0.74** for leaf area index. Crop growth rate, nitrogen use efficiency, nitrogen use efficiency for grain yield and biomass were inter correlated, and their correlation coefficients ranged between 0.79** and 1.00**.

Filled grain and unfilled grain were negatively correlated, showing the complete correlation coefficient (r = -1.00**). Significant and positive correlation coefficients were found for grain yield with number of tillers (r = 0.65**), leaf area index (r = 0.73**), crop growth rate (r = 0.79**), nitrogen use efficiency (r = 0.79**), nitrogen use efficiency for grain yield (r = 1.00**) and biomass (r = 0.79**), whereas specific leaf area, 1,000-grain weight and harvest index were not significantly correlated with any trait.

Table 4. Correlation coefficients among traits of Japonica rice at harvest as affected by different types of nitrogen fertilizer

	Correlation coefficient (r)										
	Tiller No.	LAI	SLA	CGR	NUE	NUEg	Biomass	GW	FG	UFG	Yield
LAI	0.73**										
SLA	-0.05^{ns}	0.30^{ns}									
CGR	0.83**	0.74**	-0.12^{ns}								
NUE	0.83**	0.74**	-0.12^{ns}	1.00**							
NUEg	0.65*	0.73**	-0.24^{ns}	0.79**	0.79**						
Biomass	0.83**	0.74**	-0.12^{ns}	1.00**	1.00**	0.79**					
GW	-0.18^{ns}	0.02^{ns}	0.13^{ns}	0.02^{ns}	0.02^{ns}	0.03^{ns}	0.02^{ns}				
FG	0.37^{ns}	0.55^{ns}	0.51^{ns}	0.31^{ns}	0.31^{ns}	0.16^{ns}	0.31^{ns}	0.34^{ns}			
UFG	-0.37^{ns}	-0.55^{ns}	-0.51^{ns}	-0.31^{ns}	-0.31^{ns}	-0.16^{ns}	-0.31^{ns}	-0.34^{ns}	-1.00**		
Yield	0.65*	0.73**	-0.24^{ns}	0.79**	0.79**	1.00**	0.79**	-0.03^{ns}	0.16^{ns}	-0.16^{ns}	
HI	-0.28^{ns}	0.12^{ns}	0.11^{ns}	-0.11^{ns}	-0.11^{ns}	0.43^{ns}	-0.11^{ns}	0.13^{ns}	-0.09^{ns}	0.09^{ns}	0.43^{ns}

ns, *,** = non significantly correlated and significantly correlated at $P < 0.05$ and $P < 0.01$, respectively
n = 12 (Unfertilized control was not included.)
LAI = leaf area index, SLA = specific leaf area, CGR = crop growth rate, NUE = nitrogen use efficiency,
NUEg = nitrogen use efficiency for grain, GW = 1,000-grains weight, FG = % filled grains, UFG = % unfilled grains

Discussion

Fertility of agricultural soil has been reduced because of long term cultivation. Soil fertility can be defined as the capacity of the soil to supply adequate nutrients to support plant growth (Liu *et al*., 2006). The ideal soil consists of 45% minerals, 5% organic matter, 25% air and 25% water (Nathan, 2017). Application of green manure is important to replenish soil fertility as it can improve soil organic matter. The soil in this study was purchased from a farmer's field near the experimental site in the central plain of Thailand. Soil analysis indicated that the soil properties included 4.04 soil pH, 0.41 mS/cm electrical conductivity (EC) and 3.53 % organic matter (OM). Soil elements consisted of 7.77 ppm phosphorus (P), 137.82 ppm potassium (K), 2,029.59 ppm calcium (Ca) and 0.16 % total nitrogen (N). Organic matter was lower than that of ideal soil but it was still higher than the average of the country. Central plain of Thailand was a rice bowl of the country for centuries, and it is expected to have nitrogen deficiency because it has been under cultivation for a long period. However, soil nitrogen was still high, and this should be due to high clay particles that could maintain high organic matter. According to Tahir and Marschner (2016), addition of clayey soil into sandy soil after addition of low C/N ratio biomass increased soil organic matter. What concern about soil properties is that it has too low soil pH (4.04). The suitable soil pH for rice cultivation is at pH 6 (Azman *et al*., 2014).

To level up the soil organic matter, organic matter should be regularly incorporated into the soil, and green manure is most interesting because it has the lowest cost and it is more convenient. In this study, sunn hemp both used as sole fertilizer and in combination with urea was compared with sole urea for nitrogen use efficiency, physiological characters, yield and yield components of Japonica rice. As a legume, sunn helm can fix atmospheric nitrogen, and its residue can increase soil fertility (Fall *et al*., 2020).

Nitrogen use efficiency (NUE) and nitrogen use efficiency for grain yield (NUEg)

In this study, sunn hemp as sole fertilizer was highest for NUE and NUEg followed by sunn hemp with urea as combined fertilizer and urea as sole fertilizer, respectively. The nitrogen use efficiency for biomass was about three times greater than the nitrogen use efficiency for grain yield. However, the ranks of the treatments were different from those for biomass as urea alone was higher than sunn hemp with urea although they were not significantly different.

In previous study in rice, NUE values were in a range between 14.1% and 16.8% (Espinal *et al*., 2016). Application of sunn hemp as green manure significantly increased soil organic carbon, total and available nitrogen, available phosphorus and available potassium and water-holding capacity

(Sharma *et al*., 2000). Both rice grain and straw biomass yields under sunn hemp were greater than that of millet or without the application of green manure (Espinal *et al*., 2016). In India, sum hemp was also used for controlling aerobic weeds in wheat-rice cropping system (Jalali and Falahzadah, 2021).

The increase in NUE would be due to the increase in nitrogen uptake and increase in nitrogen utilization. Urea generally depletes very early after application (about 20 days after application), and more frequent application is required. According to Stallings (2015), nitrogen from sunn hemp under aerobic condition was released quickly, and the rapid decomposition limited the nitrogen contribution to the subsequent wheat crop. In some cases, as much as 65% of nitrogen was lost within the first two weeks of decomposition, leaving little to no available nitrogen for wheat uptake. However, nitrogen loss from green manure is expected to be lower than that from mineral fertilizer. The lower NUEg value in sunn hemp plus urea compared to urea alone would be due to insufficient nitrogen at late growth stages of rice.

Physiological traits

In this study, fertilizer application had significant effects on tiller number, leaf area index and crop growth rate, but it did not have significant effect on specific leaf area. The ranks of the treatments were in a similar pattern for all significant parameters. Sunn hemp alone was highest followed by sunn hemp with urea, urea alone and unfertilized control, respectively.

The results showed better performance of the treatments associated with sunn hemp green manure over urea alone and unfertilized control. The differences among the treatments would be due to rapid nitrogen loss of urea and decomposition of sunn hemp green manure. According to Qi *et al*., (2020), high percentage of nitrogen applied to the rice crop could loss as gas leading to low nitrogen use efficiency. Nitrogen loss from sunn hemp is rapid at the initiation of decomposition, and the decomposition process continues for many years (Lupwayi *et al*., 2005).

Tiller number determines number of panicles and rice yield. Tiller numbers of modern rice varieties ranged between 20 and 25 tillers per plant (Pawar *et al*., 2016), while leaf area indexes were in the range between 0 and 6.0 depending on growth stages (He *et al*., 2019), and crop growth rates were in the range between 19.67 and 26.17 g/m^2/d depending on variety and planting date (Garces-Varon and Restrepo-Díaz, 2015). The ranges in this study were lower than those reported in the literature because the plants were rather small. It is common that Japonica rice grown well in the temperate regions but it usually grows badly in the tropics especially under the fluctuated temperatures.

Specific leaf area values in previous study were in the range between 200.0 cm^2/g and 320.0 cm^2/g depending on planting date and day-night temperature (Stuerz and Asch, 2019). Therefore, specific leaf area has been used as a selection criterion for crop response to environment.

Yield and yield components

In this study, fertilizer treatments were significantly different for biomass and grain yield. Sunn hemp alone was highest followed by sunn hemp with urea, urea alone and unfertilized control, respectively. For grain yield, however, the ranks of sunn hemp alone and unfertilized control were similar to those for biomass, but the ranks of sunn hemp with urea and urea alone were alternated.
Biomass and grain yield in this study were rather low ranging from 2,725.0 kg/ha and 3,762.7 kg/ha for biomass and 789.0 kg/ha and 1,167.3 kg/ha for grain yield due mainly to unfavourable growing condition for Japonica rice and fluctuated air temperatures. Sun *et al*. (2020) reported in China that biomass values of rice from diverse sources approximately ranged between 8,000 kg/ha and 25,000 kg/ha and grain yields ranged between 6,000 kg/ha and 13,000 kg/ha depending on variety and nitrogen rate.

The results for grain yield would be explained by the effects of fertilizers on filled grain, unfilled grain and harvest index although the treatments were not significantly different. However, these parameters showed a similar pattern. The treatments associated with sunn hemp seemed to have low harvest index and unfilled grain, but they had high filled grain.

It was assumed that all fertilizer treatments had the equivalent nitrogen of 150 kg/ha, and the variations in yield and yield components should be due to the differences in nitrogen uptake and nitrogen utilization. Unfortunately, this information is not available in this study. Decomposition of green manure and nitrogen loss were lower in heavy soil than medium texture soil (Ambrosano *et al*., 2009). Therefore, sunn hemp in this study might improve nitrogen uptake and nitrogen utilization. As sunn hemp was low in sunn hemp plus urea, it could reduce nitrogen uptake at the late growth stages, and, therefore, it affected yield in sunn hemp plus urea.

Correlation

In this study, the relationships among traits could be divided roughly into three groups. The groups consisted of tiller number, leaf area index, crop growth rate, nitrogen use efficiency for biomass, nitrogen use efficiency for grain yield and biomass. Traits in this group were inter-correlated and closely associated with grain yield.

Group two was the relationship between filled grain and unfilled grain. These traits were negatively associated, but they did not have contribution to grain yield. Group three has low correlation in both positive and negative directions.

The good associations between NUE and NUEg with grain yield and other related traits indicated the contributions of nitrogen to grain yield. NUE is determined by plant seed yield or biomass relative to the amount of N applied.

Using good nitrogen sources and appropriate rates not only increase the efficiency of nitrogen utilization and crop yield, but also can help to reduce production costs and environmental pollution (Fageria *et al*., 2011). According to Mae (1997), the increase in leaf nitrogen could promote growth mainly due to the increase in photosynthesis. Nitrogen fertilizer increased grain zinc concentration and yield simultaneously in low-grain zinc varieties, but depressed grain zinc concentration, while boosting yield, in high-grain zinc varieties (Jaksomsak *et al*., 2017).

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