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Review Article

Optimal Nitrogen Fertilizer Management for Direct Seeding Rice: A Review

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Abstract

Direct seeding rice (DSR) is an alternative cropping system that requires less labor and water than traditional transplanted rice (TTR). However, nitrogen (N) management in DSR has received very little attention and N management practices in DSR adopted by farmers were the same to that in TTR. Generally, the total N application rate is decided by many factors such as soil indigenous N supply, rice genotype, expected yield, weeds and water management. In this review, we summarized that the total N rate should be 110–180 kg ha^{-1} with 3 or 4 splits considering the grain yield, nitrogen use efficiency, partial factor productivity, labor use, and the environmental effects comprehensively. In addition, basal N was not necessary in DSR because endosperm nutrition may maintain the seedling growth till 4th leaf stage. In DSR, N losses from nitrogenous fertilizers applied on paddy soil were mainly via ammonia volatilization, nitrous oxide emission, N runoff, and N leaching. Furthermore, we discussed the potential ways to reduce the N loss, and to mitigate the negative effects on the environment, such as alternative type of N fertilizer rather than urea, urease inhibitors application, slow or control release fertilizers, less alternate wetting and drying, and exemption of basal N. © 2018 Friends Science Publishers

Keywords: Direct-seeding rice; N management; N loss; Basal N application

Introduction

Direct seeding rice (DSR) is becoming a popular production system (Chauhan *et al*., 2012; Mahajan *et al*., 2013). In recent years, the planting area of DSR has rapidly increased. It has been reported that DSR accounted for 90% of total rice planting area in America, Sri Lanka and Malaysia 28% of total rice planting area in China (Zhang *et al*., 2012). Several superiorities of DSR over traditional transplanted rice (TTR) such as less water and labor requirements (Mahajan *et al*., 2013), lower amount of greenhouse gas emission (Tao *et al*., 2016), and comparable grain yield (Liu *et al*., 2015) may push the shift of cropping systems from TTR to DSR (Fig. 1).

Seeding methods of DSR are divided into wet direct-seeding, dry direct-seeding, and water seeding based on water availability (Table 1). Dry direct seeding rice (DDSR) is traditionally practiced in rainfed upland and low land areas (Rao *et al*., 2007; Wang *et al*., 2017). Planting areas of DDSR is about 20 millions ha, accounting for about 14% in rice production over the world. In Southeast Asia, the total area of wet direct-seeding rice (WDSR) was about 5 millions ha (Pathak *et al*., 2011). The countries with the proportion of DSR area to total rice planting area of over 95% include United states (100%), Sri Lanka (95%), Malaysia (95%) and Brazil (95%) (Kumar and Ladha, 2011; Weerakoon *et al*., 2011; FAO Statistics, 2014).

Nitrogen (N) is the most important nutrient which affects growth and quality in rice systems (De Datta *et al*., 1988; Khan *et al*., 2012). Nis required more consistently than other nutrients, which accounts for 67% of the total agricultural fertilizers (Cassman *et al*., 2002; Mahajan *et al*., 2011). Moderate N could greatly improve the crop yield and quality, however, excessive N application has resulted in serious problems in ecosystem due to soil, atmospheric and water enrichment with reactive N of agricultural origin (Ju *et al*., 2009). Moreover, excessive N rates (Ju *et al*., 2009) or N applications which are not synchronized with crop demand (Peng *et al*., 2010) increase N losses (De Datta, 1987), can pollute surrounding environment and freshwater resources (Foley *et al*., 2011). Appropriate N application in DSR not only reduced the N loss but also meet the demands of crop growth to maximize DSR yield (Schnier *et al*., 1990a). Nevertheless, N Management for DSR is likely to be different from TTR because of different development processes and crop management practices. Unfortunately, N management in DSR has received very little attention and N management practices in DSR adopted by farmers were the same as in TTR.

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Thus, understanding the N regimes specific to DSR is of first importance. In this paper, we analyzed and reviewed the current literature in order to optimize the N management in DSR. The aims of the paper were (1) to compare the differences in N uptake, utilization and loss between DSR with TTR; (2) to explore the effective N management to synergistically increase the nitrogen use efficiency (NUE) and grain yield in DSR.

N Requirement in DSR Differs from TTR

Studies have demonstrated that N requirement for DSR is quite different than TTR (Mahajan *et al*., 2011). Specific N management carried in DSR was mainly contributed by its specific soil saturation, crop growth patterns, root system and seed rates (Mahajan *et al*., 2011, 2012a).

Soil Saturation in DSR

Soil N availability and N transformations are greatly affected by soil saturation (Li *et al*., 2008). Water management in DSR differed from TTR, particularly within 2 weeks after sowing (or transplanting), thus the changes in soil saturation associated with the anaerobic or aerobic system may result in altered plant N uptake patterns and soil N transformation, along with influence on migration and transformation of N fertilizer in soil (Li *et al*., 2003). Tao *et al*. (2016) reported no significant difference in nitrogen use efficiency for grain production (NUEg) between DSR and TTR at the same N rate. However, Liu *et al*. (2015) found that NUEg in DSR increased significantly by19.9%, 10.9% and 47.9% in 2012, 2013, and 2014, respectively, compared with TTR. With optimal water management, DSR can achieve NUE of over 80% (Wilson *et al*., 2000), much higher than in TTR (30–40%) (Zheng *et al*., 2007).

Crop Growth Patterns in DSR

DSR grows without the transplanted process or the turn-green stage, which causes the differences in growth pattern of DSR compared with TTR, particularly in the early stages (Ikeda *et al*., 2008). Differences in crop growth patterns might result in different N requirements, uptake, assimilation and translocation between TTR and DSR (Sreekala *et al*., 2010). It has also been indicated that high yields cultivars usually exhibit vigorous growth before anthesis under DSR condition and perform poorly after anthesis due to N deficiency in the DSR system (Samborski *et al*., 2009). More ineffective tillers were presented in DSR because DSR has bigger crop population than TTR. Although, N is one of mobile elements that transfer from senescence in effective tillers to effective tillers, N accumulation in effective tillers still be limited because of the delay in the process from senescence tillers to effective tillers. Thus, N accumulation in the early stages in DSR was significantly lower than in TTR, but DSR had high crop growth rate to accumulate more N than TTR in the middle stage to offset N deficiency in the early stages (Yin *et al*., 2004; Liu *et al*., 2015). N uptake in plant tissues at seedling stage for DSR was lower than for TTR, more N uptake would be presented in DSR than in TTR during the later stage. Yin *et al*. (2004) indicated that the ratio of N uptake in DSR during panicle initiation stage was 17.8% higher than in TTR.

Root Characteristics in DSR

There are significant differences in rooting systems between DSR and TTR. Kato and Okami (2010) found lower root biomass in DSR than in TTR due to a reduction in root biomass in the surface soil (fewer adventitious roots). Shallow root systems under direct seeding resulted in low N uptake at the seedling stages (Zhang and Wang, 2002). Tao *et al*. (2016) reported that the root length and root tip number in flooded DSR were reduced significantly by 23.5% and 8.5% at the 0–15 cm soil depth, 45.1% and 32.8% at 15–30 cm, and 39.1 and 36.0% at 30–45 cm, respectively, compared with root parameters in TTR. Similar tendencies in root growth between flooded DSR and TTR were also observed by Liu *et al*. (2015), with the exception that no difference was observed between flooded DSR and TTR in the root length and root tip number at the soil depth of 30–45 cm. The root growth in aerobic DSR was much more vigorous than in both flooded DSR and TTR.

Seed Rates in DSR

The N management was closely related with seed rates, in which are usually much lower in TTR than in DSR (Kumar and Ladha, 2011; Sudhir *et al*., 2011; Sun *et al*., 2015). Higher seed rates in DSR than in TTR cause poor seed germination and early seedling growth under DSR (Qi *et al*., 2012a, b). In addition, high seeding rates could suppress weed growth in DSR system to increase grain yield (Ahmed *et al*., 2016). Compared with TTR, higher plant density and absence of transplanting shock in DSR produced higher tillers and leaf area under favorable growing conditions (Schnier *et al*., 1990a, b). Increased tillering ability of DSR during the vegetative stage decreased the N concentration during their productive stage. Assuming that the same N management was employed in DSR and TTR, sink size in DSR was reduced, which might limit the grain yield of DSR (Xie *et al*., 2008).

N Management in DSR

Current N management used for TTR are not optimal for DSR. Thus, in order to attain the maximum grain yield and increased NUE, optimization of N schemes for DSR system is inevitable (Mahajan *et al*., 2011). For high grain yield, N management should be investigated to fulfill the crop demand before or after anthesis (Mahajan and Timsina, 2011). High NUE in rice can be achieved through appropriate N managements including N sources, application methods, rates, splits and timing (Ali *et al*., 2007).

N Application rate in DSR

The total N application rates is decided by many factors such as soil indigenous supply, rice genotype, expected yield, weeds and water management (Slaton *et al*., 2003). Previous studies recommended moderate N rate for DSR in consideration of crop growth, grain yield, NUE, N uptake and partial factor productivity (Table 2). Seo *et al*. (2005) indicated that 110 kg N ha^{-1} was properly employed in Korea. Ahmed *et al.* (2016) suggested that 180 kg N ha^{-1} was adopted in Bangladesh. Tao *et al*. (2016), Mi *et al*. (2016) recommended that 150 kg N ha^{-1} was appropriate N rates in DSR in Hubei or Zhejiang provinces of China. While in Jiangsu province of China, the optimal N rate was 270 kg ha^{-1} in DSR (Li *et al*., 2010). However, it was reported that the average N application rates in Jiangsu province of China are 50% higher than in the other rice production area due to its higher expected yield and farmer's practices (Wang *et al*., 2011; Hu *et al*., 2015).

Effect of N Rates on Growth and Grain Yield of DSR

Prasad *et al*. (2003) reported that N had significant effect on the number of tiller m^{-2}, plant height, leaf area index and dry matter accumulation in DSR. It was concluded that the concentration of N in flag leaf was positively correlated with the amount of N applied and the grain yield and yield components in DSR increased as N rate increased up to 150 kg ha^{-1} (Jong *et al*., 1999).

Previous studies suggested that DSR required more N application than TTR, Park *et al*. (1990), Yun *et al*. (1993) suggested that 40–50% more N rates should be applied in DSR than in TTR. Similar results that higher N rate is suggested in DSR than TTR were reported by Dingkuhn *et al*. (1991), Gathala *et al*. (2011), Pittelkow *et al*. (2012), Pittelkow *et al*. (2014). Also, Mahajan and Timsina (2011) demonstrated that the highest grain yield of TTR was achieved at the N rate of 120 kg N ha^{-1}; the maximum grain yield of DSR was observed at the rate of 150 kg N ha^{-1}. Linquist *et al*. (2013), Pittelkow *et al*. (2014) suggested that higher N application rate in DSR than TTR due to bigger plant population, lower NUE, higher N loss in DSR. However, some studies argued that same N rate could be applied between DSR and TTR. Peng *et al*. (1996) recommended that the same yield in DSR and TTR was recorded with the application of the same amount of N fertilizer, the proper N rate of DSR was around 160 kg ha^{-1} in Philippines in consideration of grain yield and NUE in DSR and TTR. Also, grain yield of 9.5 t ha^{-1} (Liu *et al*., 2015) and 8.6 t ha^{-1} (Tao *et al*., 2016) in DSR was observed at the N rate of 150 kg ha^{-1} in central China, and similar yield was achieved in TTR at the N rate.

Further, Ali *et al*. (2015a) reported that the optimum N rate was 120–150 kg ha^{-1} to synergistically increase in grain yield and NUE in Ludhiana, India. Mahajan *et al*. (2013) investigated that 320 randomly farmers covering all the major rice production regions of India to discuss the relationship between N rates and grain yield in DSR, which indicated that the N rate of 150 kg ha^{-1} is appropriate for achieving the highest yield. Similar results were also obtained in the previous studies (Lawal and Lawal, 2002; Sharma *et al*., 2007; Singh *et al*., 2007; Huang *et al*., 2008; Mannan *et al*., 2010). It indicated that crop yields of over 8 t ha^{-1} could be achieved with the N rates from 110 kg ha^{-1} to 160 kg ha^{-1} in Korea, Philippines, and most regions of China. While grain yields were around 6 t ha^{-1} when the N rates ranged from 120 kg ha^{-1} to 180 kg ha^{-1} in India and Bangladesh (Table 2). Comprehensively, the proper N rates for DSR were 110 kg ha^{-1} to 180 kg ha^{-1} in most rice planting areas.

Effect of N Rates on NUE of DSR

NUE is defined as the yield produced per unit of N applied, absorbed, or utilized by the crop to produce straw and grain (Cassman *et al*., 2002; Ladha *et al*., 2005). Ali *et al*. (2015b) reported that NUE in DSR was significantly increased when the N rate decreased from 191 kg ha^{-1} to 98 kg ha^{-1}, while no yield reduction was observed. Ahmed *et al.* (2016) suggested that agronomic fertilizer N use efficiency (15–20 kg grain kg^{-1}) and N recovery efficiency (35–40%) in DSR were lower than in TTR. Mahajan and Timsina (2011) also reported that NUE of DSR is 15% lower than in TTR. Katsura *et al.* (2010) documented that NUE in DSR was lower than in TTR because of higher N losses and immobilization, compared with TTR. On the contrary, some studies argued that NUE for grain is higher in DSR than in TTR. Tao *et al.* (2016), Liu *et al*. (2015) reported that NUE in DSR was 10–15% higher than in TTR in two successive years indicating that higher NUE for grain in DSR because of higher N translocation from straw to grain.

N Application Schemes in DSR

N requirement of DSR at different stages differed from TTR. Appropriate N application regimes could improve N uptake and NUE (Ali *et al*., 2007), reduce N losses, synchronize with plant demand and increase grain yield (Wilson *et al*., 1989; Bufogle *et al*., 1997; Farooq *et al*., 2011). N split should be carried according to the crop need under DSR cultivation. Application of N in splits produced earlier tillering, increased root growth and hence more biomass was accumulated at vegetative stage in DSR (Sanoh *et al*., 2004). It was recommended that 2 or 3 splits of N are the economic N application schemes in DSR in consideration of labor use and yield comprehensively (Rehman *et al*., 2013).

Table 1: Major sowing methods conditions in DSR

Sowing methods	[a]Ratio in rice production(%)	[b]Typical area	[b]Seedbed conditions
[b]DDSR	14	Rainfed upland	Dry soil
[c]WDSR	9	Irrigated and favorable lowland	Wet soil
[d]Water-DSR	<1	Irrigated lowland	Standing water

[a]Ratio in rice production area worldwide; [b]DDSR: dry direct-seeding rice; [c]WDSR: wet direct-seeding rice; [d]Water-DSR: water direct-seeding rice
Source: Rao *et al*. (2007), Gathala *et al*. (2011); Ladha *et al*. (2009)

Table 2: Recommend nitrogen application in selected major rice production countries

Seeding	N rates (kg/ha)	N splits	RE (%)	UE (%)	AE (kg/kg)	Yield (t/ha)	Location	Source
WDSR	160	MT:PI:FL =3:3:2	--	--	26.0	8.7	Philippines	Peng *et al*. (1996)
	220	BS: MT:PI:FL =3:3:3:2	--	--	16.0	8.1		
WDSR	150	BS : MT: PI =1:1:1	49.8	--	--	9.5	Hubei, China	Tao *et al*. (2016)
WDSR	150	BS: MT:BT =4:3:3	72.5	--	--	9.0	Zhejiang, China	Mi *et al*. (2016)
WDSR	270	BS : 16 D : 31 D :45 D:77 D=1:1:1:1:1	78.7	40.0	--	8.5	Jiangsu, China	Li *et al*. (2010)
WDSR	110	25D : MT : PI =1:1:1	52.7	--	--	9.4	Korea	Seo *et al*. (2005)
DDSR	120	14 D:35 D:63 D =1：1：1	67.7	45.5	--	6.4	Ludhiana, India	Ali *et al*. (2015)
	150	14 D:35 D:63 D =1：1：1	66.5	39.6	--	6.6		
DDSR	40	10 D: 30 D:45D=1:1:1	49.4	-	--	3.9	Himalayas, India	Bhattacharyya and Singh (1992)
	80	10 D: 30 D:45D=1:1:1	43.4	-	--	4.3		
DDSR	150	BS : MT: PI =2:1:1	52.3	--	--	3.8	Varanasi, India	Bazaya *et al*. (2009)
DDSR	180	14 D:30 D:45 D:68 D=1:1:1:1	--	37.5		5.2	Bangladesh	Sharif *et al*. (2016)
DDSR	150	BS : MT: PI =1:1:1	55.5	-	--	8.9	Hubei, China	Tao *et al*. (2016)

(1) D: days after sowing; (2) BS: Basal before sowing; MT: Mid-tillering; PI: Panicle initiation; BT: Booting stage; FL: Flowering stage ;(3) UE: Uptake efficiency: kg grain yield over total N uptake; RE: Recovery efficiency: the percentage of fertilizer-N recovered in aboveground plant biomass at the end of the cropping season; AE: Agronomic efficiency: kg grain yield increase per kg N applied

Table 3: Effects of exempting basal N dose on NUE and yield of DSR

Source	Crop establishment	N rates (kg/ha)	N splits	Yield (t/ha)	RE (%)	AE (kg/kg)
Peng *et al*. (1996)	WDSR	160	MT:PI:FL=3:3:2	8.7 a	--	26.0 a
		220	BS:MT:PI:FL=3:3:3:2	8.1 a	--	16.0 b
Ali *et al*. (2015)	DDSR	120	equal splits 0, 35 and 63 DAS	6.07 a	38.0 b	30.0 a
			equal splits 14, 35 and 63 DAS	6.36 a	45.5 a	32.4 a
		150	equal splits 0, 35 and 63 DAS	6.36 a	37.6 a	25.9 a
			equal splits 14, 35 and 63 DAS	6.56 a	39.6 a	27.2 a
Mahajan *et al*. (2011a)	DDSR	120	equal splits 0, 21, 42, and 63 DAS	7.11 a	35.2 a	--
			equal splits 15, 30, 45, and 60 DAS	7.18 a	38.1 a	--
		150	equal splits 0, 21, 42, and 63 DAS	7.52 a	48.2 a	--
			equal splits 15, 30, 45, and 60 DAS	7.76 a	50.5 a	--
		180	equal splits 0, 21, 42, and 63 DAS	7.34 a	43.8 a	--
			equal splits 15, 30, 45, and 60 DAS	7.43 a	44.9 a	--

(1) DAS: days after seeding; (2) BS: Basal before sowing; MT: Mid-tillering; PI: Panicle initiation; BT: Booting stage; FL: Flowering stage

Rehman *et al*. (2013) concluded that 3 N equal splits applied at sowing, tillering and anthesis increased growth attributes and crop yield because of better crop nutrition and less N losses in DSR. Similarly, these studies in several major rice production countries (Table 3), N was consistently recommended to apply in both mid-tillering (MT) and panicle initiation (PI) stages, however, there is controversy on the first N fertilizer application. It was suggested that first N fertilizer should be applied in few days after sowing or later (Bhattacharyya and Singh, 1992; Peng *et al*., 1996; Seo *et al*., 2005; Ahmed *et al*., 2016).

It was recommended that less N application before anthesis and more N application after anthesis should be carried in DSR, compared with TTR (Zhang *et al*., 2009; Sreekala *et al*., 2010). Yin *et al*. (2004) reported that the N uptake in DSR was 17.8% lower than in TTR before anthesis. DSR has more ineffective tillers than TTR, and N is one of mobile elements which was transferred from ineffective tillers to effective ones (Yin *et al*., 2004; Sreekala *et al*., 2010).

N Losses Pathways in DSR

N losses are becoming one of the serious problem in ecosystems (Erisman *et al*., 2007). These are the important processes of N losses from N fertilizers applied on rice field including ammonia volatilization (AV), N runoff, leaching and nitrous oxide (N_2O) emission from N fertilizers applied on paddy soil. These are the important processes of N losses from nitrogenous fertilizers applied on paddy soil. N loss was mainly related to crop establishment method, irrigation and rainfall conditions, and N rates (Singh and Singh, 1988;

Gheysari *et al*., 2009). N losses through AV, surface runoff or leaching, and N uptakes of crop would alter definitely when TTR was replaced by DSR (Farooq *et al*., 2011).

N Loss through AV in DSR

AV is major N loss when urea fertilizer is used in paddy soil, hydrolyzed by urease enzymes to NH_3 and CO_2 resulting in higher pH and NH_4^+ around the fertilizer granule (Francis *et al*., 2008). AV is released from soils and plant tissues in rice and results in a decrease in NUE and an increase in NH_3 concentration in the atmosphere (Norman *et al*., 1992). Previous measurements have shown that the percentages of N losses through AV were about 10–60% of total applied N in rice fields (Tian *et al*., 2001; Liang *et al*., 2007). AV results in many environmental problems such as changes in biodiversity, water eutrophication and rain acidification (Steinfeld *et al*., 2006). Watanabe *et al*. (2009) found N loss through AV (17.7%) was higher in DSR fields than in TTR fields (5.5–17.4%). Xu *et al*. (2013) reported that N input in DSR was lower (60 kg N ha^{-1}) than in TTR, hence, N losses through AV in DSR was higher in TTR. Watanabe *et al*. (2009), Xu *et al*. (2013) concluded the reason why higher AV in DSR than in TTR that AV losses in DSR in gemmiparous and early seedling stages were much higher than in TTR.

The absence of canopy roof and crop uptake, aerobic condition soils favored the N loss through AV in the early growth stages of DSR (Xu *et al*., 2013). In addition, soil AV may result in the toxicity when urea fertilizer is applied at se in DDSR. This was one of the main reason that poor seed germination and reduced early-seedling growth in DDSR (Fan and Mackenzie, 1995; Qi *et al*., 2012a, b). Effective N management could be carried to reduce AV emissions include application of urease inhibitors, split application of urea, and using ammonium sulfate (Bremner, 1995; Qi *et al*., 2012a, b). Along with urease inhibitors, controlled-release urea (CRU) were considered as efficient measures to reduce AV emission from paddy soils (Wang *et al*., 2007; Scivittaro *et al*., 2010). When urea was replaced by CRU at sowing, it has the potential to mitigate poor crop establishment of DSR and decrease AV emissions.

N Loss through Surface Runoff in DSR

Fertilizer N surface runoff accounts for 1–13% of the total applied N (Blevins *et al*., 1996), which resulted in water eutrophication (Buckley and Carney, 2013). DSR significantly increased N runoff losses during the early growth period by increasing runoff volumes and decreasing N uptake compared to TTR, thus increased the seasonal total N runoff losses (Bhushan *et al*., 2007; Kumar and Ladha, 2011). It is common practice to drain the remaining water from the field before sowing to ensure a good crop stand in DSR (Kumar and Ladha, 2011; Huang *et al*., 2012), through which lots of N would be lost along with drained water. During a single rice growing season, the total N runoff in WDSR fields ranged from 2.65 to 21.8 kg N ha^{-1} (Zhao *et al*., 2012), whereas, it ranged from 0.12 to 110 kg N ha^{-1}in TTR，depending on the year and amount of N fertilizer applied (Tian *et al*., 2007; Qiao *et al*., 2012; Xue *et al*., 2014; Zhao *et al*., 2015).

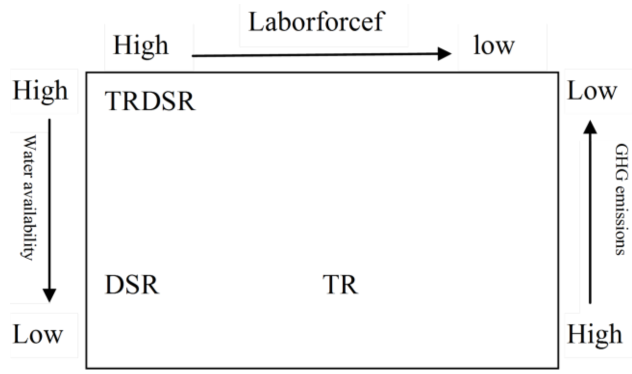

Fig. 1: Factors affecting the choice of rice establishment methods

N Loss through Leaching in DSR

For N loss through leaching in DSR.N loss through leaching was mainly influenced by irrigation and precipitation (Yahdjian and Sala, 2010). Li *et al*. (2010) reported that N leaching occurred mainly at the seedling stage, and the abilities of N absorption and utilization are weak at the early stage in DSR. The first flood irrigation is generally employed at 15 DAS or later in DSR. AWD promoted the nitrification and denitrification processes, particularly more N would be nitrate in the 0–40 cm soil layer, which caused more N leaching (Zhang *et al*., 2011). Moreover, Li *et al*. (2010) documented that significant higher N leaching happened during alternate wetting and drying. AV losses were low as the urea is transported below the soil surface when urea is applied before irrigation of non-flooded soils (As N leaching was greatly affected by irrigation regimes, delaying the first flood irrigation and reducing irrigation times may decrease the N leaching (Power and Schepers, 1989). It was suggested that the timing of starting flood irrigation can be postponed to 45 DAS with precipitation levels higher than160 mm under DSR in central China (Jiang *et al*., 2016). Less irrigation may greatly reduce the risks of N leaching in DSR.

N Loss through N_2O Emission in DSR

N_2O emission is one of the pathways to cause N losses. IPCC (2007) estimated that the percentage of N loss as N_2O was about 1.25% regardless of N sources. N_2O emission is emerged through denitrification and nitrification by soil bacteria. After irrigation, soils have specific soil characteristic that brings about the development of oxidizing and reduced layers in the shallow layer (Xing *et al*., 2009). It was reported that N_2O emission was greatly affected by crop establishment (Hussain *et al*., 2015). And DSR production increased N_2O emissions compared with TTR cultivation practice (Shang *et al*., 2011). Liu *et al*. (2014) demonstrated that seasonal N_2O emissions from DSR cropping systems increased by 49% and 46% with or without N application compared to TTR, respectively. However, Pathak *et al*. (2013) found that emissions of N_2O were similar in the DSR and TPR fields. N_2O emissions are mainly affected by N and water management practices, high N_2O emissions have been measured in DSR fields with midseason drainage or intermittent irrigation (Zou *et al*., 2005) or excessive N application (Cai *et al*., 1997; Van *et al*., 2010) were similar to the result from Ma *et al*. (2007) also found that excessive N rates resulting in increased N_2O emissions and recommended that N application based on crop demand to achieve environmental and economic benefits without comprising yield.

Is Basal Fertilizer-N Essential to DSR?

Basal N fertilizer has been applied before sowing or transplantation to improve the soil fertility and provide nutrients for crop growth in rice production systems (Peng *et al*., 2010; Ma *et al*., 2013), however, the soil fertility in many areas was significantly improved with the wide use of chemical fertilizer. Furthermore, the growth patterns was different in DSR than in TTR, it's worth that considering basal N fertilizer is essential in DSR. Some previous studies have claimed that basal N was not necessary in DSR through elucidating the role of basal N fertilizer in DSR (Table 3). Mahajan and Timsina (2011) concluded that basal N is not necessary in DSR after a survey of 320 randomly selected farmers in India. In this survey, higher yields were achieved in the fields without basal N application. Similarly, Ali *et al*. (2015a) found that the grain yield, total N uptake, recovery efficiency of N, and agronomic efficiency of N without basal N application were not lower or even higher than with basal N application. It was suggested that the application of N at sowing time may not be used immediately by rice plants (Mahajan *et al*., 2012b).

At initial stages of seedling, the growth of coleoptiles and subsequent leaves are largely dependent on the seed reserve i.e., nutrients accumulated in the endosperm. When a seed germinates and grows in the dark, it continues to grow until the tip of the 4^{th} leaf emerges (Yoshida, 1981).

N uptake for rice growth and yield is highly associated with leaf area and root development, spikelet formation and biomass accumulation (Stitt and Krapp, 1999; Yoshida and Horie, 2010). Roots of rice were not fully developed and were inactive at the seedling stage, the N absorption ability was weak and the N necessity was less. Less N application could be employed at the early stage to reduce N loss (Weerakoon *et al*., 2011).

The basal N fertilizer is usually prior applied before seeding to promote seedling emergence in DSR fields. But there are a period that seedling could not absorb N after basal fertilizer when paddy fields was aerobic. The low flooding water depth aerobic condition during the gemmiparous and early seedling stages of DSR fields prompted the AV emissions, thus higher AV losses in DSR than in TTR (Xu *et al*., 2013). Evidence has been presented to illustrate that basal N fertilizer is not essential to DSR, whereas few studies were designed to clarify the roles of basal N fertilizer. Whether the basal N fertilizer in DSR can be exempted and the performances of NUE and crop yield would be addressed in the near future.

Conclusion

N uptake and utilization greatly differs between DSR and TTR because of different development processes and crop management practices. However, N management in DSR has received very little attention and N management practices in DSR adopted by farmers were the same as in TTR. Generally, the total N application rate is decided by many factors such as soil indigenous N supply, rice genotype, and expected yield, weed and water management. In this review, we summarized that the total N rate should not exceed 200 kg ha^{-1} with 3 or 4 splits, considering grain yield, NUE, labor use, and the environmental effects comprehensively. In addition, basal N was not necessary in DSR because endosperm nutrition may maintain the seedling growth till 4^{th} leaf stage. In DSR, N losses from fertilizer-N applied on paddy soil were mainly via NH_3 volatilization, N runoff, and N leaching. Proper measures should be taken to reduce the N loss potentials for instance, alternative type of N fertilizer rather than urea, slow or control release fertilizers, urease inhibitors application, less AWD, and exemption of basal N.

Currently, DSR is gaining popularity because of less water consumption, reduced labor intensity, facilitating mechanization during crop establishment, and less methane emissions. However, constraints that include lodging, weak root development, weed and weedy rice infestations and poor crop establishment under drought, water logging, or chilling stresses might limit wide-scalead option of DSR (Wang *et al*., 2016). Varieties selected and improved nutrition, water, and weed and weedy rice management practices for DSR must be developed. Previous studies investigated that grain yield and NUE were affected by N management in DSR. But lodging resistance, weed and weedy rice suppression, root system, poor crop establishment were also high related to N management in DSR. Thus, further studies should be draw their attention on the interaction between those potential risks and N management in DSR comprehensively.

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