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Development of SPAD Values of Medium- and Long-duration Rice Variety for Site-specific Nitrogen Management

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Abstract: Nitrogen fertilizer application in rice either in excess or deficit dose, causing environmental pollution and yield loss can be avoided through Site-Specific Management using a chlorophyll meter (SPAD 502). A field experiment was conducted with two rice varieties of varying duration at varying N application levels (0, 50, 100 and 150 kg N ha^{-1}) during wets season (June-November) of the year 2006 to 2008 at the Research farm of Agricultural and Food Engineering Department, Indian Institute of Technology Kharagpur to determine the crop growth stage specific optimum SPAD value for higher grain yield. The rice varieties were Lalat of medium duration (120 days) type and Swarna of long duration (150 days) type. Correlation between N application levels and grain yield determined the optimum grain yield of the variety Lalat and Swrana as 5024 and 6427 kg ha^{-1}, respectively, under the corresponding N application levels of 105 and 155 kg N ha^{-1}. A significant and positive correlation was observed between flag leaf N content and SPAD value (R2≈0.80) and SPAD value at different growth stages and grain yield for both the varieties. The average SPAD value for optimum grain yield production was 35.4 and 40.1 for Lalat and Swarna, respectively. The desired SPAD values at critical growth stages were determined for optimum grain yield production of both the varieties.

Key words: Chlorophyll meter, critical growth stages, rice yield, site-specific nitrogen management, SPAD value

INTRODUCTION

Rice (*Oriza sativa* L.) yield trend analysis in many long-term experiments suggests that rice yields in Asia are either stagnant or declining (Duxbury, 2001; Ladha *et al*., 2003; Yadvinder-Singh and Bijay-Singh, 2003; Pathak *et al*., 2003). This has been mainly attributed to decrease in soil organic carbon and reserve of nutrients, non-uniform distribution of rainfall, improper nutrient management approaches (FAO, 1994; Cassman *et al*., 1997; Cakmak, 2002), especially nitrogen (Ladha *et al*., 2003) that resulted in poor nutrient supply capacity of soil and use efficiency of the applied fertilizer. Nitrogen is one of the key nutrients that limits rice growth in many production systems (Tirol-Padre *et al*., 1996) and nitrogen deficiency is one of the most serious nutritional disorders in rice. Nitrogen contributes to carbohydrate accumulation in culms and leaf sheaths during the pre-heading stage and in the grain during the ripening stage of rice. The proportion of applied N accounted for by the above ground N accumulation in rice was 0.2-0.4 (Schnier *et al*., 1990) as estimated by N^{15} tracer technique. In many regions farmers are applying nitrogen at levels that exceed those suggested by government extension services (Rajsic and Weersink, 2008). A major reason why farmers would apparently waste money by applying more fertilizer than a crop can use is a perception that the general recommendations are not appropriate for their individual situations. Also flooded soils have several pathways for nitrogen loss resulting in low N fertilizer recovery efficiency, which remains a problem in rice production in Asia. There is close relationship between amount of applied N to soil and N content of grain, which ultimately determines the yield of crops (Wilson *et al*., 2001). So, the challenge for farmers is to convert the applied N in soil to grain yield with maximum efficiency because N is one of the most costly inputs to rice based cropping system.

Blanket or package fertilizer recommendations over large areas are not efficient because indigenous nutrient supply varies widely among rice fields in Asia (Dobermann and White, 1998). Rice crops thus require different amounts of nutrients in different fields, depending on native nutrient supply and crop demand. Farmers will benefit significantly if they can adjust N inputs to actual crop conditions and nutrient

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requirements. Successful nitrogen management requires better synchronization between crop N demand and N supply from all sources throughout crop growing season (Cui *et al*., 2008). Various on-farm studies suggested large and potentially manageable variability in soil nutrient supply and crop response to nutrients among rice farms. Site-Specific Nutrient Management (SSNM) provides a field-specific approach for dynamically applying nutrients to rice as and when needed (Dobermann *et al*., 2002). This approach advocates optimal use of indigenous nutrients originating from soil, plant residues, manures and irrigation water. The SSNM strives to enable farmers to dynamically adjust fertilizer use to optimally fill the deficit between the nutrient needs of a high yielding crop and the nutrient supply from naturally occurring indigenous sources.

The SSNM approach was developed in Asian rice-producing countries through partnerships of the Irrigated Rice Research Consortium. Several studies have used site-specific nitrogen management to study the impact or sensitivity of nitrogen application on rice yield (Pampoloni *et al*., 2007; Dobermann and White, 1998). On farm research comparing SSNM and the farmer's fertilizer practice showed increased yield with SSNM with reduced fertilizer N rates (Dobermann *et al*., 2002; Cassman *et al*., 1996; Balasubramanian *et al*., 2000; Peng *et al*., 1996). Site-specific N management such as real-time N management and fixed-time adjustable-dose N management improved fertilizer-N use efficiency of irrigated rice (Huang *et al*., 2008).

Use of new technologies started in SSNM as it provides good nitrogen utilization efficiency so as to make it more effective. Chlorophyll meter is a lightweight, portable instrument developed by the Soil-Plant Analyses Development (SPAD) unit of Minolta Camera Company can be used to estimate chlorophyll levels in plants. Chlorophyll, a green pigment present in plants, captures the sunlight that is used in photosynthesis. Nitrogen is a key element in chlorophyll molecules. Chlorophyll meter provides instantaneous on-site information on crop N status as SPAD reading in a nondestructive manner. Turner and Jund (1994) demonstrated that chlorophyll meter measured leaf greenness and could predict the need for N top dressing at pre-panicle initiation and panicle differentiation for rice in Texas. They have recognized that SPAD values are influenced by plant growth stage, cultivar, leaf thickness, plant population and soil or climate factor. As several studies have shown a relationship between chlorophyll and N contents in plant leaves (Takebe and Yoneyama, 1989; Turner and Jund, 1994; Peng *et al*., 1993; Balasubramanian *et al*., 1999), chlorophyll contents can be used as an alternative measure of plant N status. Timely and nondestructive leaf N status detection could allow real time decision and improvement in N management. The chlorophyll meter can be used to monitor plant N status in-situ and to determine the right time of N topdressing in rice (Peng *et al*., 1996; Balasubramanian *et al*., 1999). By using this tool, we can synchronize fertilizer N application with actual crop demand. The linear relationship between leaf N content and SPAD values has led to the adaptation of the SPAD meter to assess crop N status and to determine the plants need for additional N fertilizer (Peng *et al*., 1995; Balasubramanian *et al*., 1999). The present investigation was focused on the use of chlorophyll meter in development of optimal nitrogen management recommendation for rice as a SSNM approach for improvement in yield and nitrogen use efficiency at Kharagpur, India. The objective of the investigation was to determine the crop growth stage specific optimum SPAD values of rice varieties of varying maturity duration for optimum grain yield production.

MATERIALS AND METHODS

Experimental site: A field experiment was conducted during wet season (June-November) of 2006, 2007 and 2008 at the experimental farm of Agricultural and Food Engineering Department, Indian Institute of Technology, Kharagpur (22°19' N latitude and 87°19' E longitude), India. The farm is situated at an altitude of 48 m above the mean sea level. The soil of this region is of red and lateritic type with sandy loam in texture, which is taxonomically grouped under the greatgroup Haplustaff. The soil is rated as low in organic carbon (0.33%) and available N (225 kg ha^{-1}) content, medium in available P (15.75 kg ha^{-1}) content and low in available K (112 kg ha^{-1}) content.

Field experiment: Two high yielding varieties namely, Lalat of medium duration type (110-120 days) and Swarna of long duration type (140-150 days) were selected. These two rice varieties were grown with four N application levels (0, 50, 100, 150 kg N ha^{-1}) in a split-plot design, where varieties were allocated to main plot and N fertilizer levels to sub-plot of the design. Total number of treatments was eight (2×4) and each treatment was replicated thrice. Total number of plots were 24 and dimension of each plot was 6×5 m. Full dose of P_2O_5 and K_2O at 50 kg ha^{-1} each was applied as basal at the time of transplanting. Nitrogen was applied in four equal splits at basal, active tillering, panicle initiation and flowering stages to the individual plots as per the treatment schedule of fertilizer application. Rice seedlings of 21 days old were transplanted on mid week of July in each plot with 2 to 3 seedlings per hill with a spacing of 20×20 cm.

Irrigation and plant protection measures were followed uniformly in all the plots as per the requirement.

Plant sampling and growth observations: Plant samples were collected at different growth stages from all treatments till harvesting. For this purpose, nondestructive observations on tiller number of 10 hills in each side (total 20 hills) of a plot, leaving two border rows, were recorded and the average number of tillers of a representative hill was established (Thyagarajan *et al*., 1995). From these 20 hills, five representative hills were considered as sample hills. After collection, the plant samples were cleaned and washed in water to remove surface contamination and separated into stems (leaf sheath+stem), leaves. Thereafter the plant parts were kept for oven drying till constant biomass. Dry biomass of leaves and stems are noted down. The dried plant parts were powdered in a porcelain basin to homogenate for N analysis (Yoshida and Parao, 1976).

Grain yield: The crop was harvested at grain moisture content of 18-20%. In each plot, a one m^2 area, where plant sampling was not done earlier was selected for grain yield determination. The grain yield was converted to 12% moisture content. The average yield of past three years was used for determining optimum N application dose from quadratic relationship between N application levels and grain yield.

SPAD value measurement: The chlorophyll meter developed by the Soil-Plant Analyses Development (SPAD) unit of Minolta Camera Company (SPAD 502) was used for SPAD measurement. The SPAD measurement was started from transplanting and was continued up to the first flowering at every 10 days interval for all treatments and replications. The youngest fully expanded leaf of a plant was used for the SPAD measurement. Readings were taken on one side of the midrib of the leaf blade, midway between the leaf base and tip. A mean of 15 readings per plot was taken as the measured SPAD value.

Correlation graph between SPAD value at different crop growth stages and grain yield was made for both the varieties. The SPAD value corresponding to optimum grain yield was determined from the correlation equation, which was considered as optimum SPAD value at particular growth stage. The SPAD value corresponding to 80% of optimum yield was considered as critical SPAD value for N management.

Statistical analysis: The correlations between N application level and grain yield, SPAD value and grain yield and leaf N content and SPAD value were tested at 5% level of significance (Gomez and Gomez, 1984).

RESULTS

Total above ground biomass of both the varieties Lalat and Swarna increased with increasing N application level up to 150 kg N ha^{-1}. The total biomass of long duration variety Swarna was significantly higher than the medium duration variety Lalat. Maximum total biomass recorded for variety Lalat was 10543 kg ha^{-1} while for variety Swarna was 12711 kg ha^{-1} at the time of harvesting. There was a significant difference (p = 0.05) in the total biomass for different N application levels as well as for the varieties (Table 1).

The results averaged from three years of field experiments indicated an increase in grain yield with increasing N application levels up to 100 kg N ha^{-1} for the variety Lalat and 150 kg N ha^{-1} for the variety Swarna. The grain yield was significantly correlated with N application level (R^2 = 0.99) for the variety Lalat ($Y = -0.0904 X^2 + 30.833 X + 2783.5$) and Swarna ($Y = -0.092 X^2 + 35.199 X + 3181.2$) as shown in Fig. 1. From the

Table 1: Effect of varying N levels on total biomass of rice varieties Lalat and Swarna at harvesting

	Total biomass (kg ha^{-1})				
Variety (V)	N_0	N_{50}	N_{100}	N_{150}	Mean
Lalat	5245	7230	8949	10543	7992
Swarna	6854	9298	10889	12711	9938
Mean	6050	8264	9919	11627	
	V	N	V×N		
SE(m)±	105.04	73.27	103.62		
LSD (p = 0.05)	639	226	319		

N_0, N_{50}, N_{100} and N_{150} represents the application of N fertilizer at 0, 50, 100 and 150 kg N ha^{-1}

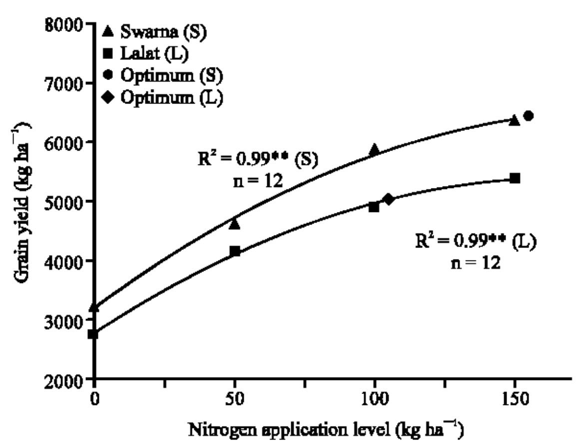

Fig. 1: Relationship between N application levels and grain yield for rice varieties Lalat and Swarna at Kharagpur, India (**significant at p = 0.01)

correlation, the optimum grain yield Lalat was 5024 kg ha^{-1} at 105 kg N ha^{-1} and of Swarna was 6427 kg ha^{-1} at 155 kg N ha^{-1} application level.

Measurement of SPAD values was done at every 10 days interval starting from fifteen Days after Transplanting (DAT). The time series data indicated considerable difference in the SPAD values between the two varieties (Lalat and Swarna) at each N application level as well as no N application (control) as shown in Fig. 2. The variety Swarna had higher SPAD value than Lalat throughout the growing period. After each top dressing of N fertilizer, the SPAD value increased up to 10 to 15 days and declined thereafter. Increasing N application level resulted in increasing SPAD value of both the varieties. The relationship between N content of flag leaves and SPAD readings analyzed at flowering stage, was positive and significant ($p = 0.01$) for the variety Lalat as well as Swarna (Fig. 3). The linear relationship is expressed as $Y = 11.61 X + 3.852$ ($R^2 = 0.76$) for Lalat and $Y = 14.83 X-0.447$ ($R^2 = 0.79$) for Swarna. The result shows that the SPAD value is linearly correlated with N content of the leaves. The SPAD values will help in predicting the N status of the crop instantaneously for correction of the N deficiency, if any.

The SPAD values recorded at every 10 days interval were used for estimating the SPAD value for achieving the economically optimum grain yield. The average SPAD value of each N treatment was determined for the whole growing season and its relationship was established with the grain yield for both varieties. The results indicated a significant and positive correlation between the average SPAD value and grain yield for varieties Lalat ($Y = 356.9 X-7614.6$, $R^2 = 0.92$) and Swarna ($Y = 540.6 X-15270$, $R^2 = 0.98$). Based on the relationship, the average SPAD value for varieties Lalat and Swarna was 35.4 and 40.1, respectively for achieving the optimum grain yield.

The growth stage-specific SPAD value was also derived from the relationship between the SPAD value and grain yield at each 10 days interval. The results revealed that for variety Lalat, there was significant and positive relation between SPAD value and grain yield for the observations at 15, 25, 45, 55 and 65 DAT. While, for variety Swarna, the correlation between SPAD value and grain yield was significant throughout the observation period. From the relationship, the optimum SPAD value that should be maintained at different growth stages for achieving the optimum grain yield was calculated for Lalat (Table 2) and Swarna (Table 3). The grain yield i.e. 80% of optimum yield was found to be significantly lower and hence was considered as critical yield level for N management. The SPAD value calculated from the relation for the critical yield was assumed as critical SPAD value,

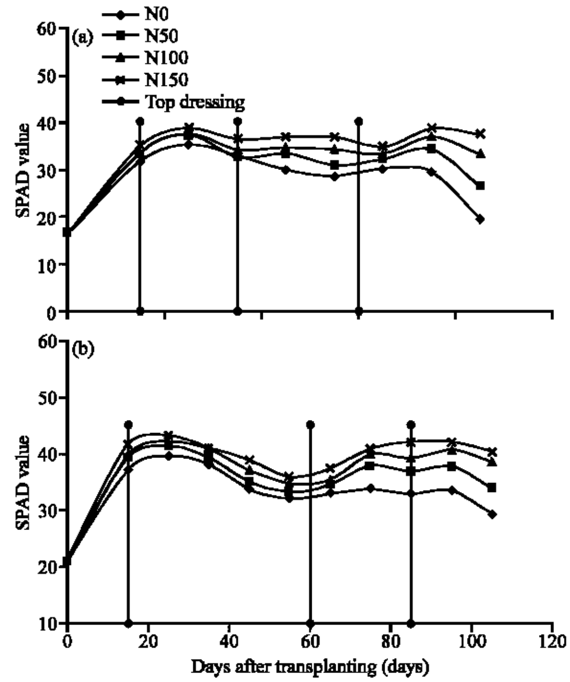

Fig. 2: SPAD readings at every 10 days interval after transplanting for rice varieties (a) Lalat and (b) Swarna at varying N application levels at Kharagpur, India

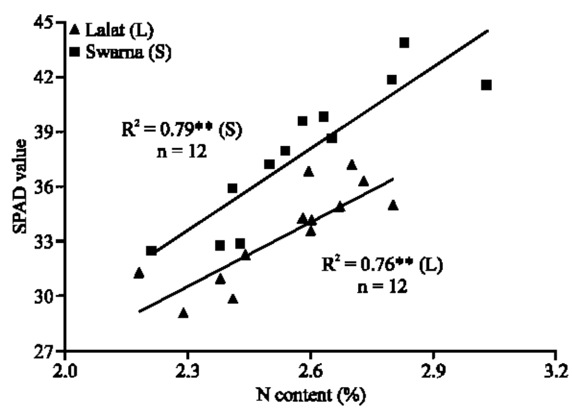

Fig. 3: Relationship between N content and SPAD values of flag leaves of rice varieties Lalat and Swarna at flowering (**, significant at $p = 0.01$)

when quick N management is necessary for correction of the deficiency. For the variety Lalat, the optimum SPAD values were 38.3±0.2, 35.6±0.3 and 34.0±0.8 and the critical SPAD values were 36.7, 32.8 and 32.0 at 25, 45 and 65 DAT, respectively. Similarly, for the variety Swarna, the optimum SPAD values were 43.1±0.7, 36.7±0.2 and 42.4±0.6 and the critical values were 41.3, 34.7 and 37.9 at 25, 65 and 95 DAT, respectively.

Table 2: Optimum- and critical- SPAD value and relationship between SPAD value and grain yield of the rice variety Lalat during the growing season

Crop duration after transplanting (days)	Relationship	R^2 value	Optimum SPAD value†	Critical SPAD value
15	Y = 546.33X-13965 (31.5≤X≤36.2)	0.62**	34.8±0.7	32.9
25	Y = 603.27X-18101 (34.3≤X≤39.2)	0.73**	38.3±0.2	36.7
45	Y = 359.53X - 7778.1 (29.2≤X≤38.1)	0.90**	35.6±0.3	32.8
55	Y = 282.93X-4916 (27.2≤X≤37.7)	0.87**	35.1±0.5	31.6
65	Y = 493.02X-11763 (29.8≤X≤35.1)	0.80**	34.0±0.8	32.0

Y: Grain yield; X: SPAD value; **indicates significance at $p\leq 0.01$; †Values are as Mean±SE

Table 3: Optimum- and critical- SPAD value and relationship between SPAD value and grain yield of the rice variety Swarna during the growing season

Crop duration after transplanting (days)	Relationship	R^2 value	Optimum SPAD value†	Critical SPAD value
15	Y = 667.78X-21289 (36.9≤X≤42.0)	0.81**	41.2±0.3	39.1
25	Y = 777.12X-27221 (39.1≤X≤44.3)	0.81**	43.1±0.7	41.3
35	Y = 550.69X-16841 (35.7≤X≤42.0)	0.54**	41.9±0.5	39.3
45	Y = 498.33X-12986 (33.0≤X≤40.8)	0.77**	38.6±1.0	35.7
55	Y = 798.24X-22090 (31.9≤X≤36.1)	0.92**	35.5±0.1	33.7
65	Y = 694.67X-19279 (32.1≤X≤37.6)	0.86**	36.7±0.2	34.7
75	Y = 427.99X-11269 (33.4≤X≤41.8)	0.92**	40.9±0.6	37.6
85	Y = 348.72X - 8115.6 (31.9≤X≤42.6)	0.94**	41.2±0.5	37.1
95	Y = 360.16X-8828.7 (33.0≤X≤43.0)	0.95**	42.4±0.6	37.9

Y: Grain yield; X: SPAD value; ** indicates significance at $p = 0.01$; †Values are as Mean±SE

DISCUSSION

The results had shown that the variety Swarna had significantly higher total biomass accumulation and grain yield than Lalat; this was due to the longer duration of the growing season of Swarna. This observation is consistent with the findings of the other researchers who reported the higher biomass accumulation and grain yield in long-duration rice varieties than that for medium-duration varieties (Singh *et al*., 1998; Peng *et al*., 1996). Swain *et al*. (2006) also observed that the biomass of variety Swarna was significantly higher than that for variety Lalat. The grain yield of Lalat was increased significantly with increasing N application up to 100 kg N ha^{-1}. Whereas for Swarna, the grain yield was increased with increasing N application all the way up to 150 kg N ha^{-1}. The long duration varieties had higher N uptake (Vergara *et al*., 1966) because of well developed root system and longer vegetative growth period than medium duration varieties. In our experiment, high N application increased N uptake and grain number per panicle of the long duration variety Swarna (data not shown) and hence the grain yield. The medium duration varieties are of panicle number type, which absorb more surface N because of their shallow root system and have limited vegetative period. Large N uptake with high N application of medium duration varieties resulted in very high leaf area index, which enhanced carbohydrate loss via dark respiration (Shi and Akita, 1993).

The SPAD value was linearly correlated with leaf N content for both the varieties (Fig. 3). The SPAD values also responded well to the N application levels in both the varieties. Similar observation was noted by other researchers, where the SPAD value increased with the N top-dressing (Huang *et al*., 2008; Balasubramanian *et al*., 2000; Peng *et al*., 1996). The variety Swarna had a higher SPAD value than Lalat at the same N input. Hence, for precise N management optimal SPAD threshold value will be higher for Swarna than that for Lalat. This observation is consistent with the other researcher's findings, who reported that rice varieties with different characteristics have different optimum or threshold SPAD values (Balasubramanian *et al*., 2000; Huang *et al*., 2008). The average SPAD value for the varieties Lalat and Swarna were found to be 35.4 and 40.1, respectively for attaining optimum yield. This was estimated from the relationship between the average SPAD value from 15 days after transplanting to heading and rice grain yield of both the varieties. Huang *et al*. (2008) estimated different SPAD threshold values for two hybrid varieties using the same relationship for efficient N management. The SPAD threshold for optimizing N management was 35 for indica varieties grown under tropical condition (Peng *et al*., 1996).

In this experiment, the growth stage-specific SPAD value was derived from the relationship between the SPAD value at each 10 days interval and grain yield. The SPAD value at different growth stages resulting in optimum grain yield is considered as the optimum SPAD value. The growth stage-specific optimum values should be maintained to attain the target yield. The results revealed that for variety Lalat and Swarna there was significant and positive relation between SPAD value and grain yield for most of the observation period. There has been similar study for estimating the SPAD value corresponding to optimum gain yield (Scharf *et al*., 2006). They reported that there was significant relationship between SPAD values at different stages with grain yield. In our experiment, the grain yield i.e.,80% of optimum grain yield (significantly low) was considered as the critical grain yield and the SPAD value corresponding to critical grain yield was considered as critical SPAD value.

If the SPAD value reaches the critical level, immediate N application is necessary to avoid the yield reduction due to the N deficiency. The critical SPAD value of the Swarna was higher than Lalat at different crop growth stages. There had been different studies where the critical or optimal SPAD value was used as the desired SPAD value for target yield (Balasubramanian *et al.*, 2000; Wang *et al.*, 2001).

The three most important critical growth stages of rice are active tillering, panicle initiation and flowering stages where the crop should not suffer from any stress for achieving the target yield. The optimum SPAD values must be observed during these critical growth stages for yield maximization. To maintain optimum SPAD value at the critical growth stages, the N fertilizer needs to be applied about 10 days before appearance of the critical stages as seen in our experiment. The critical period of N management was observed to be 15, 25 and 55 days after transplanting for Lalat and 15, 55 and 85 days after transplanting for Swarna to maintain the optimum SPAD values at the critical growth stages i.e., active tillering, panicle initiation and flowering, respectively.

CONCLUSIONS

The varieties Lalat and Swarna differing in maturity duration had different optimum N requirement for attaining the optimum grain yield. The optimum N application level for Lalat was 105 kg N ha^{-1} and for Swarna was 155 kg N ha^{-1}. As Site-Specific N Management, growth stage-specific SPAD values are developed for both the varieties to attain their yield potential. The average SPAD values of Lalat and Swarna were 35.4 and 40.1, respectively for achieving the optimum yield.

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