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Research Article

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Nitrogen Uptake and Use Efficiency of Irrigated Bread Wheat (*Triticum aestivum* L.) as Influenced by Seed and Nitrogen Fertilizer Rates at Werer, Afar National Regional State, Ethiopia

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Abstract

An offseason field experiment was conducted in 2015-2016 at Werer Agricultural Research Center Middle Awash, Afar regional state to determine N-uptake and use efficiency of irrigated bread wheat (*Triticum aestivum* L.) as influenced by seed and nitrogen fertilizer rates. The experiment was laid down in a randomized complete block design (RCBD) with three replications. The treatments were factorial combination of five nitrogen levels (0, 23, 46, 69, and 92 kgNha^{-1}) with four seed rates (75, 100, 125, and 150 kgha^{-1}). The results of the study showed that both main and interaction effect of nitrogen and seed rates significantly affect N concentrations of the grain and straw, N-uptake, apparent nitrogen recovery, agronomic and physiological efficiencies, nitrogen use efficiency, grain protein content, and N harvest index. The apparent recovery, agronomic and physiological efficiencies and nitrogen use efficiencies decreased with increasing N-rate. Concentration of N and total nitrogen uptake in straw and grain, grain protein and NHI were increased as the N rate increased, while decreased with the increment of seed rate. In conclusion, rate of nitrogen fertilizer applied and seed rate affect the N-uptake and N-use efficiencies.

Keywords: Seed rate; Nitrogen rate; Nitrogen uptake; Nitrogen use efficiency; Wheat

Introduction

Nitrogen is the most important plant nutrient for metabolic process, vegetative growth, plant productivity, protein production, and grain quality [1]. Nitrogen fertilizer rate has a determinant effect on wheat production. Low soil fertility, especially nitrogen (N) deficiency, is one of the major constraints limiting wheat production in Ethiopian highlands and low lands [2].

Nitrogen nutrition affects crop performance through its effects on photosynthetic capacity. In the highland and low land areas N fertilizer application substantially changes yield and yield components of wheat [3]. Seed rate is also an important agronomic parameter, which provides early canopy cover for the maximum interception of the solar radiation and other nutrient.

None of the released lowland bread wheat varieties have known N uptake and N-use efficiency. The introduction of high yielding bread wheat genotype accompanied with improved production technology packages like optimum N fertilization with optimum planting density could significantly increase productivity per a given hectare [4].

Nitrogen deficiency is also the most widespread nutritional problem in irrigated wheat production in lowland areas. At the moment, production of bread wheat is undertaken at Middle Awash; however, the N-uptake and N use efficiency of wheat is not totally understood for the released varieties. This requires an urgent need to understand how seed and N-fertilizer rates influence uptake and use efficiency of low land irrigated wheat in the study area.

Nitrogen use efficiency, grain yield produced per unit of N supplied is complex trait comprising the following factors: N uptake, agronomic and physiologic efficiency of N, crop factor of N and N utilization efficiency from fertilizers [5,6]. Nitrogen uptake (NUPE) reflects the ability of plants to obtain N, while Nitrogen use efficiency (NUE) reflects the efficiency with which the crop utilizes N in the plant for the synthesis of grain yield. Wheat NUPE was lower in the early applications at planting and tillering than application in the later crop growth stage [7].

The amount of economic yield, therefore, increased by increasing NUPE and NUE through efficient N application that decreases N losses from the soil-plant system [8]. The nitrogen harvest index (NHI) of wheat is also depended more on genetically potential to utilize the available N [9]. NHI is usually influenced by environmental condition and high temperature favors more nitrogen utilization [10]. The higher NHI can be achieved by using heavy dose of fertilizer-N through increasing the N utilization duration [11].

Understanding of environmental conditions, agronomic practices, variety characteristics, and the relationship between grain yield and formation of the fertilization efficiency indicators are important issues on wheat production [12]. Therefore, the objectives of the study were to evaluate the effect of seed and nitrogen fertilizer rates on N-uptake, and use efficiency of bread wheat under irrigated agriculture, and to determine the interaction between nitrogen and seed rate for maximum N-uptake and N use efficiency of wheat.

Materials and Methods

Description of the study area

The experiment was conducted in Afar Regional state at Zone three, Amibara district, in Werer Agricultural Research Center (WARC) during offseason in 2015-2016 located at 278 km east of Addis Ababa with an altitude of 740 masl and at the coordinates of latitudes 9°16'N and 40°09' E longitude. The dominant soil type is sand clay loam soil with particle size distribution: Sand (53.75%), Silt (20%) and clay (28.4%) with a bulk density of 1.17 [13]. Soil is slightly alkaline and ranges from 8.0-8.4 pH and total rainfall of growing season was 75.3 mm with minimum and maximum temperatures of 11.9 and 35.7°C, respectively.

Experimental design and procedures

The experimental treatments were laid out in a randomized complete block design (RCBD) in three replications. Factorial combination of five nitrogen levels (0, 23, 46, 69 and 92 kgNha^{-1}) and four seed rates (75, 100, 125 and 150 kg seed ha^{-1}) were used as treatment. Variety Fentalle/Moontiji-3, released in 2015 was used for the experiment, and sown by drilling method. Urea (46% N) and triple super phosphate (TSP) (46% P_2O_5) were used as sources of N and P, respectively. Phosphorus at 46 kg P_2O_5 ha^{-1} was applied to all plots uniformly at sowing time, and the N-fertilizer was applied in two splits: at tillering and booting stages. All other agronomic practices were undertaken uniformly as per the crop requirement for all treatments.

Soil sampling and analysis

Surface soil samples were collected from 0-30 cm depth and randomly in a zigzag pattern before sowing, and after harvesting from the entire experimental field of 20 spots. The soil samples were composited, air dried and passed through a 2 mm sieve and analyzed in the laboratory for physico-chemical analysis. The soil was analyzed for total nitrogen, phosphorous, pH, OM, OC, EC, C/N and textural class. Total soil N was analyzed by Micro-Kjeldahl digestion method with sulfuric acid [14]. Soil pH was determined from the filtered suspension of 1:2.5 soils to water ratio using a glass electrode attached to a digital pH meter (potentiometer) [15]. Organic carbon content was determined by the volumetric method [16]. Texture of the soil was determined by the hydrometer method according to FAO [15].

Data collection

Plant nitrogen concentration: The nitrogen contents of the grain and straw were determined by using Micro-Kjeldahl method from grain and straw samples. Total N contents of straw and grain were multiplied by straw and grain yield ha^{-1} to obtain total N-uptake in straw and grain ha^{-1}, respectively. Total N-uptake by above ground biomass was calculated by summing up the N-uptake by grains and straw ha^{-1}. Apparent fertilizer nutrient recovery was also calculated as per the procedure described by Pal [17] i.e., [(Un-Uo)/n] × 100; where Un stands for nutrient uptake at "n" rate of fertilizer nutrient and Uo stands for nutrient uptake in control or no fertilizer treatment. Agronomic and physiological nutrient use efficiency were calculated (Gn-Go)/n for agronomic efficiency and (Gn-Go)/(Un-Uo) for physiological efficiency, respectively; where Gn and Go stand for grain yield of the plots fertilized at "n" rates of fertilizer and grain yield unfertilized, respectively. NUE is a ratio of an output (biological or economical yield) to the input (N supply or fertilizer), based on an incremental or cumulative base [18]. Nitrogen harvest index (NHI%) was calculated by N uptake of the grain divided to total N uptake by the grain and straw × 100 or ((GNU/TNU) × 100) [19,20]. Grain protein content (GPC%) was determined by multiplying grain N percent by 5.75, i.e., Grain Protein (%)=N% × 5.75 [21].

Statistical data analysis

The data were subjected to analysis of variance (ANOVA) as per the design using statistical analysis software, version 9.1 [22], and interpretations were made following the procedure of Gomez et al. [23]. Where significant differences exist among the treatments mean separation was carried out using the DMRT at 5%.

Results and Discussion

Soil Analysis of experimental site before sowing and after harvest

The results of soil particle size distribution analysis of the experimental field indicated that the soil has a composition of sand (53.6%), clay (26.40%) and silt (21.0%), which is categorized as sandy clay loam according to the textural triangle classification. The average electrical conductivity was 7.15 ds/m, which shows saline/salt/soils. Qadir et al. suggested that, if EC is greater than 4 ds/m the soil is classified as saline soil, which affect crop growth and finally reduce crop yield [24].

Particle size distribution						Chemical properties						
Analysis results	Soil Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Textural Class	EC (ds/m)	pH (H_2O)	OC (%)	OM (%)	Total N%	C/N Ratio	Av.P (ppm)
Before Sowing	0-30	26.4	21.0	53.6	SCL	7.15	8.06	1.3	2.2	0.17	7.7	10.4
After Harvest	0-30	30.4	19.0	53.9	SCL	7.30	8. 40	5.1	8.7	0.6	8.9	11.5

SCL=Sandy Clay Loam; EC=Electrical Conductivity; OC=Organic Carbon; OM=Organic Matter; TN=Total Nitrogen; C/N ratio=Carbon to Nitrogen Ratio; Av.P=Available Phosphorus.

Table 1: Physico-chemical properties of the soil before sowing and after harvest.

The average pH was 8.06, which indicates a moderately basic soil reaction class. FAO reported that the preferable pH ranges for most crops and productive soils are 4 to 8. Thus, the pH of the experimental soil is almost within the range for productive soils. The organic matter and total nitrogen content of the soil, before planting were found to be 2.22% and 0.17%, respectively, which according to Charman et al. can be described as low in nitrogen and OM. The carbon to nitrogen ratio (C/N ratio) value was 7.7, which signify a relatively high rate of mineralization and low rate of N immobilization [25].

The laboratory analysis results of different physicochemical properties of soil, after harvesting shows particle size distribution of the surface layers of the experimental field was dominated by sand (53.9%), clay fraction (30.4%) and 19% silt; and categorized as sand clay loam.

The proportion of soil particle size after harvesting wheat differ from before sowing, clay particle increase from 26.4 to 30.4%, while sand soil had little change 53.6 to 53.9% after harvesting wheat, and silt fraction of the soil decreased (Table 1). Similar to soil analysis before sowing, the average of electrical conductivity (EC) of soil after harvesting was also 7.3 ds/m which shows that the soil is saline.

The average soil pH after harvesting was 8.4 which indicate a moderately basic reaction, which is above the range for productive soils [25]. The average organic matter content and total N percent of the soil after harvest was 8.7 and 0.6, respectively (Table 1). The nitrogen and organic matter contents were improved and described as high accordingly.

The carbon to nitrogen ratio (C/N ratio) values was 8.9%, which signify a relatively high rate of mineralization and low rate of N immobilization. The available phosphorus content of the experimental area after harvest was 11.5 ppm, which indicate an improvement to medium level.

Nitrogen concentration of the soil after harvest

The maximum (0.92%) N concentration after harvest was recorded when 75 kg/ha seed rate and 92 Nkg/ha was used, while the minimum (0.03%) N was recorded when 150 kg/ha seed rate with no nitrogen (0 Nkg/ha) was used (Table 2).

The N concentration in the soil after harvest increased with increased N fertilizer rate, while slightly decreased as seed rate increased. Carter et al. found that most of the applied N was either taken up into the plant or kept in the top 15 cm of the soil profile [26].

Seed rate (kg/ha)	**Applied N rate (kg/ha)**					
	0	**23**	**46**	**69**	**92**	**Mean**
	N% concentration after harvesting					
75	0.035^{b}	0.083^{ba}	0.357^{ba}	0.766^{ba}	0.92^{a}	0.43
100	0.035^{b}	0.047^{b}	0.178^{ba}	0.546^{ba}	0.68^{ba}	0.3
125	0.035^{b}	0.036^{b}	0.141^{ba}	0.39^{ba}	0.489^{ba}	0.22
150	0.033^{b}	0.038^{b}	0.105^{ba}	0.389^{ba}	0.467^{ba}	0.21
Mean	0.03	0.05	0.2	0.52	0.64	--
SE (±)	0.4					
CV (%)	7.0					
Means followed by the same letters are not significantly difference at p<0.05.						

Table 2: The interaction effect of N and seed rates on N concentration after harvest.

Nitrogen concentration and uptake in grain and straw

Nitrogen concentration of grain and straw were significantly (p<0.05) affected by both main and their interaction effect of N and seed rates (Table 3). The highest N concentration of grain (3.05%) and straw (0.75%), and the lowest concentration of grain (2.45%) and straw (0.52%) were recorded with the combination of 92 N kg/ha and 75 kg/ha seed rate and the treatment of control N and 150 kg/ha seed rates, respectively (Table 3).

Seed rate (kg/ha)	**Applied N rate (kg/ha)**											
	0	**23**	**46**	**69**	**92**	**Mean**	**0**	**23**	**46**	**69**	**92**	**Mean**
	N Concentration of Grain (%)						**N Concentration of Straw (%)**					
75	2.65^{a-c}	2.74^{a-c}	2.75^{a-c}	2.8^{a-c}	3.05^{a}	9.4	0.54^{c}	0.57^{a-c}	0.61^{a-c}	0.6^{a-c}	0.75^{a}	0.62
100	2.59^{bc}	2.71^{a-c}	2.77^{a-c}	2.82^{a-c}	2.93^{ba}	11.6	0.53^{c}	0.57^{a-c}	0.6^{a-c}	0.66^{a-c}	0.71^{a-c}	0.61
125	2.55^{bc}	2.69^{a-c}	2.75^{a-c}	2.8^{a-c}	2.84^{a-c}	13.8	0.53^{c}	0.56^{bc}	0.59^{a-c}	0.64^{a-c}	0.73^{ba}	0.61
150	2.45^{c}	2.65^{a-c}	2.74^{a-c}	2.77^{a-c}	2.83^{a-c}	16.1	0.52^{c}	0.55^{bc}	0.59^{a-c}	0.63^{a-c}	0.68^{a-c}	0.59
Mean	2.6	2.7	2.8	2.8	2.9	--	0.5	0.6	0.6	0.6	0.7	--
SE (+)	0.22						0.1					
CV (%)	8.0						12					
Means followed by the same letters are not significantly different at p<0.05.												

Table 3: The interaction effect of N and seed rates on N concentration of grain and straw.

Uptake of N by grain and straw were also significantly (p<0.05) affected by the main and interactions of N and seed rate (Table 4). The highest N uptake of grain (89.0 kg/ha) and straw (73.0 kg/ha), and the lowest N uptake of grain (34.4 kg/ha) and straw (23.7 kg/ha) were

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obtained with the treatment of 92 kg/ha N and 75 kg/ha seed rates; and with control treatment of N and 150 kg/ha seed rate, respectively (Table 4).

The percentage of N in the straw and grain increased in line with the increase in grain yield, which means that more N was required per unit of dry weight as yield increases, which in turn was responsible for the increase in the grain and straw N uptake from the increasing levels of N. Generally, increasing applied N fertilizer rate and decreasing seed rate increased the N concentration and uptake in both grain and straw, whereas decreasing N level with increasing seed rate decreased the N concentration and uptake of both grain and straw. The N-uptake by grain and straw increased as N level increased, these results agreed with the findings of Fowler [27] and Gibson et al. [28].

Seed rate (kg/ha)	Applied N rate (kg/ha)											
	0	23	46	69	92	Mean	0	23	46	69	92	Mean
	N uptake of grain (kg/ha)						N uptake of straw (kg/ha)					
75	53.0^{c}	73.2^{bc}	75.3^{bc}	83.2^{a-c}	89.0^{a}	74.7	31.6^{bc}	38.5^{bc}	41.5^{a-c}	50.8^{a-c}	73.0^{a}	47.1
100	50.5^{c}	72.3^{bc}	75.1^{bc}	82.3^{a-c}	88.7^{a}	73.8	31.4^{bc}	37.4^{bc}	40.7^{a-c}	50.6^{a-c}	57.6^{ba}	43.5
125	45.1^{cd}	66.7^{bc}	74.7^{bc}	80.0^{a-c}	88.0^{a-c}	70.9	30.9^{bc}	35.3^{bc}	38.7^{bc}	44.4^{a-c}	54.5^{a-c}	40.8
150	34.4^{d}	60.3^{bc}	74.1^{bc}	77.1^{bc}	85.0^{a-c}	66.2	23.7^{c}	33.1^{bc}	38.6^{bc}	42.1^{a-c}	53.7^{a-c}	38.3
Mean	45.8	68.1	74.8	80.7	87.7	--	29.4	36.1	39.9	47	59.7	--
SE (±)	0.2						0.05					
CV (%)	7.1						7.4					
Means followed by the same letters are not significantly different at p<0.05.												

Table 4: The interaction effect of N and seed rates on N uptake of grain and straw.

The interaction effect of N and seed rates on agronomic and physiological efficiencies

The results of the study showed that both main and interaction effects of nitrogen and seed rates significantly ($p<0.05$) affect agronomic and physiological efficiencies (Table 5). Agronomic and physiological efficiencies decreased with increased in N rate. The highest AE (57.1) and PE (26.5) recorded with the treatment of 23 kgN/ha and 75 kg/ha seed rate; and 92 kgN/ha and 100 kg/ha seed rate, respectively. While the lowest AE (15.20) and PE (12.7) were obtained with the treatment of 92 kgN/ha with 150 kg/ha seed rate; and above 125 kg N/ha with 23 kg/ha seed rate, respectively.

Seed rate (kg/ha)	Applied N rate (kg/ha)											
	0	23	46	69	92	Mean	0	23	46	69	92	Mean
	Agronomic efficiency						Physiological efficiency					
75	-	57.1^{a}	32.2^{a-c}	22.6^{bc}	18.90^{bc}	29.1	-	13.9^{a-c}	20.4^{a-c}	23.10^{a-c}	23.3^{ba}	18.6
100	-	41.2^{ba}	30.6^{a-c}	22.27^{bc}	16.8^{bc}	25.1	-	12.8^{a-c}	19.2^{a-c}	22.4^{a-c}	26.5^{a}	18.6
125	-	35.93^{a-c}	30.23^{a-c}	22.13^{bc}	15.60^{bc}	23.1	-	12.7^{a-c}	17.0^{a-c}	21.8^{a-c}	26.1^{a}	16.9
150	-	33.6^{a-c}	24.0^{a-c}	21.9^{bc}	15.20^{bc}	19.4	-	12.7^{a-c}	14.3^{a-c}	21.5^{a-c}	24.2^{ba}	15.4
Mean		42	29.3	22.2	16.6	--	-	13	17.7	22.2	25	--
SE (±)	2							3.4				
CV (%)	7							9.3				
Means followed by the same letters are not significantly different at p<0.05.												

Table 5: The interaction effect of N and seed rates on agronomic and physiological efficiencies.

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Interaction effect of N and seed rates on nitrogen use efficiency and apparent nitrogen recovery

The interaction of N and seed rates significantly ($p<0.05$) affect nitrogen use efficiency (NUE), and apparent nitrogen recovery (ANR) (Table 6). The lowest (28.27) and highest (98.79) NUE obtained with the treatment of 23 kgN/ha and 125 kg/ha; and 92 kgN/ha and 150 kg/ha seed rate, respectively (Table 6). According to Gaju et al. wheat with 18-38 NUE is considered high, while low at 41-101 NUE [29]. Lopez-Bellido indicated that decreased in NUE with increasing fertilizer rates is because grain yield rises less than the N supply in soil and fertilizer [30]. Similarly, ANR decreased with increasing N rate (Table 6). The highest ANR (224.17%), was recorded with the treatment of 23 kgN/ha and 75 kg/ha seed rate, while the lowest (78.5%) is recorded on treatment 92 kgN/ha with 150 kg/ha seed rate (Table 6).

Seed rate (kg/ha)	Applied N rate (kg/ha)											
	0	23	46	69	92	Mean	0	23	46	69	92	Mean
	Nitrogen Use Efficiency						Apparent Nitrogen Recovery (%)					
75	-	82.16^{a-c}	64.05^{a-c}	52.65^{a-c}	37.17^{a-c}	59	-	224.17^{a}	127.63^{ba}	106.87^{ba}	82.53^{ba}	122.2
100	-	70.75^{a-c}	62.00^{a-c}	50.44^{a-c}	34.07^{a-c}	54.3	-	166.5^{ba}	126.03^{ba}	104.37^{ba}	81.73^{ba}	108.3
125	-	98.79^{a}	54.66^{a-c}	44.84^{a-c}	31.26^{a-c}	57.4	-	160.6^{ba}	123.3^{ba}	90.4^{ba}	81.40^{ba}	103.3
150	-	87.37^{a}	53.20^{a-c}	38.21^{a-c}	28.27^{bc}	51.8	-	158.03^{ba}	112.23^{ba}	85.83^{ba}	78.50^{ba}	90.6
Mean	-	84.8	58.5	46.5	32.7	--	-	177.3	122.3	96.9	81	--
SE (±)	3.0						1.6					
CV (%)	11.0						5.0					
Means followed by the same letters are not significantly different at p<0.05.												

Table 6: Interaction effect of N and Seed rates on N-use efficiency and apparent N-Recovery.

Grain protein content and nitrogen harvest index

The main and interaction of both N and seed rates significantly ($p<0.05$) affected grain protein content and N harvest index of bread wheat (Table 7). Grain protein percentage and N harvest index (NHI) increased with increasing N rate (Table 7). The highest grain protein content (17.1%; 17.0%) and N harvest index (71.8; 70.95%) obtained on treatments 92 kgN/ha with 75 kg/ha and 100 kg/ha seed rates, respectively. The lowest grain protein content (14.2%) and NHI (55.3%) obtained from the treatment of control N with 150 kg/ha seed rate. Halvorson et al. indicated that grain protein content in wheat generally increased with increased N rate [31,32].

Seed rate (kg/ha)	Applied N rate (kg/ha)											
	0	23	46	69	92	Mean	0	23	46	69	92	Mean
	Grain protein percent						Nitrogen Harvest Index (%)					
75	14.8^{bc}	15.6^{a-c}	16.0^{a-c}	16.2^{a-c}	17.1^{a}	15.9	62.8^{a-c}	65.8^{ba}	68.4^{ba}	68.97^{ba}	70.95^{a}	67.4
100	14.7^{bc}	15.6^{a-c}	15.9^{a-c}	16.1^{a-c}	17.0^{a}	15.9	62.6^{a-c}	65.5^{ba}	68.1^{ba}	68.97^{ba}	71.8^{a}	67.4
125	14.5^{bc}	15.6^{a-c}	15.8^{a-c}	16.1^{a-c}	16.6^{ba}	15.7	60.2^{bc}	64.9^{a-c}	66.1^{ba}	68.80^{ba}	69.9^{ba}	66
150	14.2^{c}	15.4^{a-c}	15.7^{a-c}	16.0^{a-c}	16.5^{ba}	15.6	55.3^{bc}	64.3^{a-c}	65.9^{ba}	68.4^{ba}	69.7^{ba}	64.7
Mean	14.6	15.6	15.9	16.1	16.8	60.2	65.1	67.1	68.8	--	--	70.6
SE (±)	0.5						4.4					
CV (%)	3.2						6.7					
Means followed by the same letters are not significantly different at p<0.05.												

Table 7: The interaction effect of N and seed rates on grain protein content and N harvest index.

Conclusion and Recommendation

Based on this study maximum N uptake by grain and straw of bread wheat was recorded at 92 kg/ha N and 75 kg/ha seed rates. Agronomic and physiological efficiencies of irrigated wheat decreased with increased in N and seed rates of bread wheat. The highest agronomic and physiological efficiencies of irrigated wheat 57.1 and 26.5 percent were recorded with the treatment of 23 kgN/ha and 75 kg/ha seed rate; and 92 kgN/ha and 100 kg/ha seed rate, respectively. The highest Nitrogen Use Efficiency (98.79%) and lowest (28.27%) was recorded with treatment 23 kgN/ha and 125 kg/ha seed rate; and 92 kgN/ha and 150 kg/ha seed rate, respectively. Therefore, high N uptake by wheat crop is achieved with optimal N rate and low seed rate; in addition, the uses of optimal seed rate increase the N use efficiency of wheat. In general, rate of nitrogen fertilizer applied, and seed rate affect the N-uptake and N-use efficiencies in wheat. However, the uptake and nitrogen use efficiency of crops vary with varieties and soil environment, hence further research is recommended for different wheat genotypes in the study area.

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