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RESEARCH

Nitrogen Rates and Sources Affect Yield and Profitability of Maize in Pakistan

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Abstract

Nitrogen is one of the most important factors affecting maize yield and profitability. To investigate the impact of N fertilizer sources (urea, calcium ammonium nitrate [CAN] and ammonium sulfate [AS]) applied in various amounts (0, 50, 100, 150, and 200 kg N ha^{-1}) on grain yield and profitability of maize genotypes, local cultivars (Azam and Jalal) versus hybrid (Pioneer-3025) field experiments were done during summer 2008–09 (Year 1) and 2009–10 (Year 2). The N yielded 41 and 26% more grain than the check in Year 1 and Year 2, respectively. In both years, grain yield increased in response to the increase in N application. Application of CAN and AS resulted in more grain yield than urea in Year 1, while no differences in yield were observed in Year 2. The hybrid (P-3025) yielded 30 and 24% more grain than the average of local cultivars in Years 1 and 2, respectively. In Year 1, the net returns (NR) of PKR16262 ha^{-1} (one US$ = 95 Pakistani Rupees) was obtained with CAN but value cost ratio (VCR) of 3.7 was noticed with urea; in Year 2, both NR (PKR14271 ha^{-1}) and VCR (3.1) was greatest with urea. In both years, the greatest NR was obtained with 100 and 150 kg N ha^{-1}. Application of urea at 150 and 200 kg N ha^{-1}, CAN at 100 and 150 kg N ha^{-1}, and AS at 50 and 100 kg N ha^{-1} was economical in terms of NR in both years.

Growth of maize is sensitive to N. Nitrogen management is considered the one of the most important factors affecting maize growth (Khan et al., 2008), phenology, and grain yield (Amanullah and Khalil, 2009). As increasing human population is resulting in less land for cultivation in Pakistan, increases in crop production must come from more yield per unit area. Increased cropping intensity removes plant nutrients, especially N, from the soil, in addition to natural losses of N. Therefore, application of N at a greater rate and more split applications are key for sustainable maize production and greater net return in the wheat–maize cropping system in northwest Pakistan (Amanullah and Shah, 2010). Maize is the second most important crop after wheat in northwest Pakistan but its yield unit^{-1}

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Table A. Useful conversions.

To convert Column 1 to Column 2, multiply by	Column 1 Suggested Unit	Column 2 SI Unit
0.405	acre	hectare, ha
0.454	pound, lb	kilogram, kg
62.71	56-lb bushel per acre, bu/acre	kilogram per hectare, kg/ha

area is low compared to Punjab and Sind (Amanullah and Shah, 2009). Efficient use of N for maize production is important for increasing grain yield, maximizing economic return, and minimizing NO_3 leaching into ground water (Gehl et al., 2005). Site-specific application of N to maize is a way to maximize yield potential while minimizing fertilizer cost (Kahabka et al., 2004).

Efficient fertilizer use can be defined as maximum returns per unit of fertilizer applied (Mortvedt et al., 2001). For efficient management of N in cropping systems, adequate rate, appropriate source, and timing of application during the crop growth cycle are important (Fageria et al., 2006). Urea, CAN, and AS urea are the three main N fertilizers for crop production in Pakistan. Selection of fertilizers by growers commonly depends on price—the least costly fertilizer per kilogram of nutrient is commonly selected (Plaster, 1992). Existing maize genotypes have high yield potential and soil and climatic conditions of Pakistan are ideal for maize production; however, yield per hectare is low, particularly in northwest Pakistan. Causes of the yield gap include injudicious use of N fertilizer and growing low-yielding maize genotypes. Obtaining maximum profitability lies not only in reducing rate of fertilizer per unit area but also lowering costs per unit crop production by enhancing yield. Therefore, economic analysis is required to demonstrate to farmers the results of agronomic experiments.

Farmers in Pakistan are profit-oriented and are interested in net returns rather than gross returns. In practice, not all farmers aim for the largest net returns because of greater costs involved in relation to other risks associated with farming (Saleem et al., 1986). According to Bhatti (2006), a VCR of 2 is recommended for farmers using new technology in Pakistan. A VCR of 2 represents 100% return on the money invested on N fertilizer. For farmers using traditional technology with no credit or limited capital, a fertilizer rate giving a VCR greater than 2 is recommended. To increase yield and profit, fertilizers and improved farming practices are the best investments farmers can make.

A package of the latest production technology using high-yielding maize hybrids and low-cost N fertilizer in appropriate amounts needs to be used to increase maize productivity and profitability. Research on interactive effects of genotypes and amount and source of N fertilizer on maize is lacking in the various wheat–maize cropping systems in Pakistan. For sustainable maize production, research is needed on the interactive effect of N fertilizer source (G x S), amount of N (G x N), and N source on amount of available N (S x N) on maize genotypes (G). The objective of this experiment was to investigate grain yield and profitability of different N fertilizer sources applied in various amounts to maize hybrid Pioneer-3025 in comparison to high-yielding local cultivars Jalal and Azam as checks.

MATERIALS AND METHODS

Site Description

Field experiments were done at the Agriculture Research Farm of the Khyber Pakhtunkhwa (KP) Agricultural University, Peshawar during summer 2008–2009 (Year 1) and 2009–2010 (Year 2). The experimental farm is at 34.01° N latitude, 71.35° E longitude at 350 m above sea level in Peshawar Valley. Peshawar is about 1600 km north of the Indian Ocean and has a continental kind of climate. The research farm is irrigated by the Warsak Canal from the Kabul River. The soil texture is calcareous clay loam, low in organic matter (0.87%), extractable phosphorus (6.57 mg kg^{-1}), exchangeable potassium (121 mg kg^{-1}), and alkaline (pH 8.2) (Amanullah and Khalil, 2009).

Experiment

Assuming N (nitrogen), S (nitrogen source) and G (genotype), a 4 × 3 × 3 factorial experiment was done in a randomized complete block (RCB) design with split plots using three replications. Factorial experimental treatments were four amounts of N (N_1 = 50 kg ha^{-1}, N_2 = 100 kg ha^{-1}, N_3 = 150 kg ha^{-1}, and N_4 = 200 kg ha^{-1}) and three N fertilizer sources (S_1 = urea [46% N], S_2 = calcium ammonium nitrate [6% N], and S_3 = ammonium sulfate [21% N]) applied to the main plots, while three maize genotypes (G_1 = Jalal, G_2 = Azam and G_3 = Pioneer-3025) were in subplots. One check plot (N not applied) was also used in each replication.

A subplot size of 4.2 by 5 m, with 6 rows 5 m long and 70 cm apart was used. A uniform basal dose of 60 kg P ha^{-1} as single super phosphate and 60 kg K ha^{-1} as sulfate of potash was applied and mixed with the soil during seedbed preparation. Nitrogen in the form of urea was applied in two equal parts, i.e., 50% at sowing and 50% when irrigation water was applied the second time (20 days after emergence). Nitrogen was incorporated in the soil and then irrigation was applied immediately after each application. A uniform seed rate of 35 kg ha^{-1} for each genotype was used. After 1 week of emergence a uniform plant density of 70,000 plants ha^{-1} (7 plants m^{-2}) was maintained in each subplot. No pesticide was applied to the maize crop in both years. The amount of sulfur was maintained constantly in all plots by application of SOP (sulphate of potash) in the urea and CAN applied plots.

Muriate of potash (MOP) was applied to the plots having ammonium sulphate (AS) as N source.

Statistical Analysis

Data were subjected to analysis of variance (ANOVA) according to the methods described by Steel and Torrie (1980), and means between treatments were separated by least significant difference ($P \leq 0.05$).

Economic Analysis

Net Return (the value of the increased yield produced as a result of N fertilizer applied, less the cost of N) and *Value-Cost Ratio* (the ratio between the value of the additional crop yield and cost of N) was determined according to the procedures described by Amanullah et al. (2010) and Amanullah and Almas (2012). The cost of N per kg in PKR (Pak Rupees) was less (43.48 and 55.43 PKR kg N^{-1}) while using urea, followed by CAN (76.92 and 96.92 PKR kg N^{-1}), and was costly for AS (142.86 and 190.48 PKR kg N^{-1}) in Year 1 and Year 2, respectively. The cost of seeds per kg was less for the local varieties (20 and 25 PKR kg^{-1}) and more for the hybrid Pioneer (100 and 125 PKR kg^{-1}) in Year 1 and Year 2, respectively. The price of grain per kilogram was the same for the three genotypes, 15 PKR kg^{-1} in Year 1 and 20 PKR kg^{-1} in Year 2. Except the price of N which varied among the different treatments, all other costs including the cost of phosphorus, potassium, weed control, irrigation, and tillage were constant for all the treatments.

Grain Yield

All the experimental plots with N yielded 41 and 26% more grain than the check plots (N not applied) in the year 1 and year 2, respectively. In both years, the grain yield increased with the increase in N to 150 kg N ha^{-1} but a further increase in N at 200 kg ha^{-1} did not increase the grain yield (Table 2). Our previously published research indicated that on N-deficient soils of Peshawar, grain yield in maize increased with the application of more N (120 and 180 kg ha^{-1}) over only 60 kg N ha^{-1} because of increase in LAI (Amanullah et al., 2007), light interception (Khan et al., 2008), number of ears 100 $plants^{-1}$, and 1000-grain weight (Amanullah and Shah, 2010), and increase in dry matter partitioning (Amanullah and Shah, 2011).

Application of CAN and AS resulted in more grain yield than did urea in Year 1; however, no significant differences in grain yield were observed while using different N fertilizer sources in Year 2 (Table 2). Chien et al. (2011) reported AS was the best N fertilizer source which contains free sulfur and had many potential agronomic and environmental benefits over urea and ammonium nitrate. In Khyber Pakhtunkhwa (northwest Pakistan) where most soils are calcareous, AS because of its free sulfur could be the best N fertilizer for more growth and yield. However, because of its greater cost (142.86 and 190.48 PKR kg N^{-1}) than CAN (76.92 and 96.92 PKR kg N^{-1}) and urea (43.48 and 55.43 PKR kg N^{-1}) during the 2 years the poor growers in the study area could not afford to buy AS. The higher cost of AS was due to the presence of sulfur (24%) and also having more transportation charges than urea. Lloyd et al. (1997) reported that urea was a less expensive form of N fertilizer than ammonium nitrate. However, urea is considered less effective than other N fertilizers because of N loss by ammonia volatilization, especially when used on soils of high pH or low CEC (Terman, 1979).

Table 1. Differences in grain yield (kg ha^{-1}) of maize with change in N rates, N source, and genotype at Peshawar.

N rates (kg ha^{-1})	Grain yield Year 1	Year 2	Average
	kg ha^{-1}		
50	3228	3736	3482
100	3792	4494	4143
150	4144	4749	4447
200	4146	4801	4474
LSD ($P \leq 0.05$)	148	286	156
N Fertilizer source			
Urea	3593	4353	3973
Calcium ammonium nitrate	3977	4452	4215
Ammonium sulfate	3912	4530	4221
LSD ($P \leq 0.05$)	128	ns	135
Genotypes			
Azam	3284	3908	3596
Jalal	3429	4148	3774
Pioneer-3025	4769	5309	5039
LSD ($P \leq 0.05$)	91	311	227

The maize hybrid (P-3025) yielded 30 and 24% more grain than the average of the two local high-yielding cultivars (Azam and Jalal) in Year 1 and Year 2, respectively (Table 1). The reasons for more grain yield of P-3025 during the 2 years was attributed to greater LAI, greater CGR, greater biomass, heaviest 1000-grain weight, more grains ear^{-1} and fewer barren plants in both years (unpublished data). On the other hand, the local cultivars had less LAI, CGR, biomass and yield, 1000-grain weight, grains ear^{-1}, and more barren plants per 100 plants in both years (unpublished data) as compared to the hybrid. Our 2-year study confirmed the maize hybrid was more efficient in terms of growth, yield, and yield components because it responded better than the local cultivars to all sources and amounts of N. Fageria et al. (2008) suggested that in the 21st century, nutrient-efficient plants will play a major role in increasing crop yield compared to the 20th century, mostly because of limited land and water resources for crop production, more costly inorganic fertilizer input, decreasing crop yield globally, and increasing environmental concerns. Baligar et al. (2001) reported that efficiency of acquisition, transport, and utilization of nutrients varies with crop species and genotype/cultivar within species, and their interactions with the environment. Differences

Table 2. Interaction of nitrogen rate × nitrogen source on grain yield of maize at Peshawar.

N Rates	N Source	Grain yield Year 1	Year 2	Average
kg ha^{-1}		——— kg ha^{-1} ———		
50	Urea	2773	3600	3186
	CAN	3337	3452	3394
	AS	3735	4155	3865
100	Urea	3399	4364	3881
	CAN	4094	4585	4340
	AS	3882	4533	4208
150	Urea	4077	4641	4359
	CAN	4224	4937	4580
	AS	4131	4670	4401
200	Urea	4124	4806	4465
	CAN	4253	4835	4544
	AS	4062	4761	4411
LSD ($P \leq 0.05$		256	ns	271

Table 3. Interaction of nitrogen rate × genotype on grain yield of maize at Peshawar.

N Rates	Genotypes	Grain yield Year 1	Year 2	Average
kg ha^{-1}		——— kg ha^{-1} ———		
50	Azam	2775	3107	2941
	Jalal	2906	3652	3279
	P-3025	4003	4448	4226
100	Azam	3383	4067	3725
	Jalal	3450	4116	3783
	P-3025	4543	5300	4921
150	Azam	3499	4170	3835
	Jalal	3836	4444	4140
	P-3025	5097	5633	5365
200	Azam	3481	4288	3884
	Jalal	3526	4259	3892
	P-3025	5432	5856	5644
LSD ($P \leq 0.05$		191	ns	472

in N use efficiency, harvest index, economic yield, and net returns in different maize genotypes also were reported by Mkhabela et al. (2001).

Interaction of N sources with N rate affected grain yield of maize in the first year but had no significant effect on grain yield in the second year (Table 2). Grain yield was more with AS than CAN and urea when applied at the lowest N rate (50 kg ha^{-1}). The CAN resulted in more grain yield when applied at the three higher rates (100, 150, and 200 kg N ha^{-1}) than urea or AS. Urea produced more grain yield than AS at the two higher N rates (150 and 200 kg N ha^{-1}), but AS yielded more grain than did urea at the two lower N rates (50 and 100 kg N ha^{-1}). However, economic analysis of the data indicated that urea at the two higher N rates was most economical in terms of NR than that applied at the two lower N rates. But application of CAN at the two intermediate N rates and AS at the two lower N rates was more profitable. In contrast to our study, in research on rice, Fageria et al. (2011) found that the higher and lower N rate of AS produced more grain yield and most of the plant growth and yield components, while the intermediate N rates (125 to 275 mg N kg^{-1}) of urea were slightly better compared to AS for grain production. The discrepancies in our results and that of Fageria et al. (2011) were caused by differences in crop species, amounts of N sources, and weather conditions.

Interaction of amounts of N with maize genotypes (N x G) affected the grain yield of maize during the first year and when combined over the 2 years, but had no effect on grain yield of maize in the second year (Table 3). Application of any four amounts of N to the maize hybrid resulted in more grain yield than from the two local cultivars. Increase in amounts of N increased grain yield of the maize hybrid in ascending order from 4003 to 5432 kg ha^{-1} in the first year, 4448 to 5856 kg ha^{-1} in the second year, and 4226 to 5644 kg ha^{-1} when combined for the 2 years. In contrast, the grain yield of the two local cultivars increased with increase in N rate to 150 kg ha^{-1}, but a further increase in N of 200 kg ha^{-1} did not increase the grain yield of the two local cultivars. Amanullah and Almas (2012) reported that the greater average yield in Punjab Province than Khyber Pakhtunkhwa Province in Pakistan was caused by the hybrid maize and efficient fertilizer use by the farmers. Interaction of N sources on maize genotypes had no effect ($P \leq 0.05$) on grain yield in the first year, second year, and 2-year average. However, application of any three N sources resulted in more grain yield when applied to the maize hybrid compared with the two local cultivars. With the hybrid, applications of CAN and AS were relatively better than urea in the first year, but in the second year, urea and AS yielded more grain than CAN. In both years, application of urea to the two local cultivars resulted in less grain yield as compared with CAN or AS.

Profitability

Among the N sources, the greatest NR of PKR 16262 ha^{-1} (*1 USD = 95 PKR*) was obtained from plots to which CAN was applied, followed by urea (PKR 14687 ha^{-1}), while the minimum NR (PKR 7051 ha^{-1}) was obtained after application of AS in the first year. On the other hand, the greatest VCR of 3.7 was calculated for urea, followed by CAN (2.7), while the minimum VCR (1.4) was obtained after application of AS (Table 4). Similarly, in the second year, the greatest NR (PKR 14271 ha^{-1}) was obtained for plots to which urea was applied, followed by CAN (PKR 11065 ha^{-1}), while the minimum NR (PKR 930 ha^{-1}) was calculated for AS. Likewise, the greatest VCR (3.1) was noted for urea, followed by CAN (1.9), while the minimum VCR (1.0) was obtained with AS (Table 5). The low profitability of AS was attributed to its higher price kg^{-1} N than urea or CAN (AS [142.86 and 190.48 PKR kg N^{-1}] > CAN [76.92 and 96.92 PKR kg N^{-1}] > urea [43.48 and 55.43 PKR kg N^{-1}] in 2008 and 2010, respectively).

Table 4. Comparison of economic analysis of maize genotypes as affected by N fertilizer source and amount in Year 1 at Peshawar.

	Grain yield (kg ha^{-1})	Value in Pak. Rupees	Increase in values over control	Cost of N fertilizers applied	Net returns	Value cost ratio
Urea	3593	53899	20122	5435	14687	3.7
CAN	3977	59655	25877	9615	16262	2.7
AS	3912	58685	24908	17857	7051	1.4
N (kg ha^{-1})						
50	3228	48423	14645	4388	10258	3.3
100	3792	56877	23100	8775	14325	2.6
150	4144	62160	28382	13163	15219	2.2
200	4146	62193	28415	17551	10864	1.6
Genotypes						
Azam	3284	49266	19026	10969	8057	1.7
Jalal	3429	51441	20384	10969	9415	1.9
P-3025	4769	71531	31496	10969	20527	2.9

Table 5. Comparison of economic analysis of maize genotypes as affected by N fertilizer source and amount in Year 2 at Peshawar.

N Source	Grain yield (kg ha^{-1})	Value in Pak. Rupees	Increase in values over control	Cost of N fertilizers applied	Net returns	Value cost ratio
Urea	4353	87060	21200	6929	14271	3.1
CAN	4452	89040	23180	12115	11065	1.9
AS	4530	90600	24740	23810	930	1.0
N applied (kg ha^{-1})						
50	3736	74720	8860	5714	3146	1.6
100	4494	89880	24020	11428	12592	2.1
150	4749	94980	29120	17142	11978	1.7
200	4801	96020	30160	22856	7304	1.3
Genotypes						
Azam	3908	78160	19340	14228	5112	1.4
Jalal	4148	82960	20516	14228	6288	1.4
P-3025	5309	106180	29849	14228	15621	2.1

Moreover, because of its (AS) low N content (21% N) its transportation charges were also more than for urea (46% N) or CAN (26% N). The profitability of urea and CAN was because of the lower price of N kg^{-1} of both fertilizers than AS. Lloyd et al. (1997) reported that urea was a less expensive form of N fertilizer than ammonium nitrate.

In this study, profitability was generally greater in the second year than in the first year. The variation in profitability in both years may be attributed to fluctuation in rainfall during the maize-growing periods in the 2 years as well as differences in grain yield. In the first year, less rainfall during the early growth stage of maize (July 2008) decreased emergence per unit area and CGR (data not published) adversely affected grain yield and profitability. Lloyd et al. (1997) noted increase in grain yield with N application at all sites. However, at three sites (B6, B8, and C7), yield was greater with ammonium nitrate, while at two sites (B9 and C13) yield was greater with application of urea.

Among the amounts of N, the greatest NR (PKR 15219 ha^{-1}) was obtained from plots to which 150 kg N ha^{-1} was applied, followed by PKR 14325 ha^{-1} with 100 kg N ha^{-1}, while the minimum NR (PKR 10258 ha^{-1}) was obtained when 50 kg N ha^{-1} was applied in the first year (Table 4). In contrast, the greatest VCR (3.3) was noted for plots to which the least rate of 50 kg N ha^{-1}, followed by 100 kg N ha^{-1} (2.6) was applied, while the minimum VCR (1.6) was obtained with 200 kg N ha^{-1} (Table 5). Similarly, in the second year, the greatest NR (PKR 12592 ha^{-1}) was calculated for 100 kg N ha^{-1}, followed by PKR 11978 ha^{-1} with 150 kg N ha^{-1}, while the minimum NR (PKR 3146 ha^{-1}) was obtained when 50 kg N ha^{-1} was applied (Table 5). The greatest VCR (2.1) was obtained with 100 kg N ha^{-1}, followed by 150 kg N ha^{-1} (1.7); while the minimum VCR (1.3) was obtained with an application of 200 kg N ha^{-1} (Table 5). In an earlier study (Amanullah and Shah, 2010), we found that an increase in amount of N significantly and positively impacted grain and stover yields as well as net returns. The NR was increased by 39% (12,383 PKR ha^{-1}) when 50% (180 kg N ha^{-1}) more than the recommended rate of 120 kg N ha^{-1}

was applied. Each PKR spent on N resulted in 11.6 PKR ha^{-1} when N was increased from the conventional rate of 60 kg N ha^{-1} to 120 kg N ha^{-1}. A further increase in N to 180 kg ha^{-1} gave 7.4 PKR per one PKR spent on N compared with the recommended N (120 kg ha^{-1}). The increase in NR and VCR with application of 100 and 150 kg N ha^{-1} was attributed to faster CGR, improvement in grain yield and yield components (unpublished data).

Similarly, in the previous research, an increase in NR with more N (120 and 180 kg N ha^{-1}) than 60 kg N ha^{-1} was attributed to an increase in LAI, CGR, number of grains ear^{-1}, ears 100 $plants^{-1}$, and grain yield (Amanullah et al., 2007; Amanullah and Khalil, 2009; Amanullah and Shah, 2010; Khan et al., 2008). Greater NR of 32 and 85 USD ha^{-1} with application of greater N rates of 112 and 224 kg N ha^{-1}, respectively, was obtained as compared with the check (N applied) and the lower rate of 56 kg N ha^{-1} (Stanger et al., 2008).

Among the maize genotypes, the greatest NR (PKR 20527 ha^{-1}) and VCR (2.9) were from plots sown with the maize hybrid Pioneer-3025 in the first year. The local cultivar, Jalal ranked second in terms of NR (PKR 9415 ha^{-1}) and VCR (1.9), but Azam ranked at the bottom in terms of NR (PKR 8057 ha^{-1}) and VCR (1.7) in the first year (Table 5). Similarly, in the second year, the greatest NR (PKR 15621 ha^{-1}) and VCR (2.1) were obtained from plots sown with the maize hybrid Pioneer-3025 (Table 5). The local cultivar Jalal ranked second (PKR 6288 ha^{-1}) and Azam ranked at the bottom in terms of NR (PKR 5112 ha^{-1}), but no difference was found in the VCR of the two local cultivars (Table 5). It was a function of yield and better agronomy. This study confirmed the maize hybrid was more efficient in terms of growth, yield, and yield components as well as profitability because it responded better to all three N sources and amounts than did the local cultivars. Difference in N use efficiency, harvest index, economic yield and net returns in different maize genotypes was earlier reported by Mkhabela et al. (2001).

CONCLUSIONS

The recent higher N fertilizer prices and the lower income of growers have had negative impacts on crop productivity and profitability in northwest Pakistan. Results of this study indicated that maize productivity and profitability changes while using different maize genotypes, N fertilizer sources and amounts. The likely reason for the disparity in cost of the various nitrogen fertilizer sources is differences in their cost of production and cost of transportation. From this study it is concluded that there is a need to formulate prices of N fertilizers on the basis of the amount of N in a bag rather than the entire bag. It is unjust to expect farmers to buy a bag of AS (21% N) or CAN (26% N) for more than urea which contains 46% N. There is huge disparity in price of one kg N in different N fertilizers. A decrease in the current prices of AS and CAN will not only decrease the cost of production but also could increase crop productivity and profitability for farmers. Growing hybrids could increase maize productivity and income for farmers. The greater yield of the hybrid was attributed to better agronomy and other factors that improve yield. The profitability of N fertilizers varies among different areas of the world because of fluctuation in the prices of N fertilizers, differences in weather conditions, and soil characteristics.

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