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The Impact of Urea Fertigation on Sugar Beet Performance

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ABSTRACT

The main objective of this research was to determine spatial and temporal variability in a sugar beet filed affected by fertigation by sprinklers to develop a management strategy based on spatial and temporal variability of soil properties and sugar beet performance. The Location of the study area was in Isfahan Province, Iran. To describe the variability of soil and plant status, response to N fertilizer application by sprinklers was studied by analyzing 5 soil elements including N, K, CEC, EC and OM at two times (before and after fertigation) as well as 4 crop properties including tuber moisture content, tuber weight, number of tubers per square meter and tuber sugar content. Results were used to produce spatial and temporal variability maps. Data analysis and map visualization indicate that the higher moisture content causes heavier tuber but the grid which has more number of tubers has the lighter tubers. On the other hand, more tubers with lighter weight have higher sugar content. Matrix correlation of soil and plant properties shows a positive correlation of N in the soil to tuber weight, and tuber moisture while it has a negative correlation to sugar content and number of tubers. Higher sugar content of tubers was achieved compared to previous records of this field and the average of tuber sugar content for the Isfahan province. Fertigation by sprinkler irrigation is beneficial for the high and uniform tuber sugar content (as the economical elements in sugar beet production) of sugar beet in the irrigated area.

Key Word: Precision farming, Spatial and temporal variability, Soil Properties, Sprinkler irrigation

INTRODUCTION

Sugar beet (*Beta vulgaris Var. Saccharifera L.)* which is a biennial tuber crop is known as industrial and commercial crop due to favorable characteristics namely short cultivation season, moderate water requirement, high sugar content, useful to improve soil conditions as a tuber crop, and suitable for saline and alkali soils [1]. As the fourth commercial crop in Isfahan province of Iran, sugar beet production has a strategic role in agriculture section [2].

Nitrogen, the most requisite nutrient for sugar beet, has the important role in sucrose utilization, plant growth and yield. Managing nitrogen fertilizer to maximize crop yields without negative environmental impacts is challenging. Nitrogen applied in excess of the crop's needs is susceptible to losses from the soil-crop system.

Strategies that strive to improve the efficiency of N use would benefit growers by increasing farm profits and reducing the environmental effects associated with excessive fertilizer use. Increasing the efficient use of N is becoming more important with the increases in N fertilizer costs [3].

Over-fertilizing and under-fertilizing could limit the yield and quality of sugar juice [4]. Draycott [5] described that the excessive use of nitrogen fertilizer not only affects the sugar content but also threatens the environment by leaching nitrate and ammonium. Too little N retards leaf growth [6] and gives pale green foliage due to low chlorophyll concentration [7]. Burcky and Biscoe [8] asserted inadequate N expedites senescence of leaves.

Milford [4] found that too much N causes over-production of dark green leaves and a shift in dry matter distribution at the expense of storage root and sugar yield of sugar beet. Pocock [9] showed surplus N affected the sugar beet yield by increasing the concentrations of amino N compounds within the storage. Moreover Dutton and Huijbregts [10] proved surplus N reduces the proportion of the sugar which can be crystallized.

Despite the high installation expenses of sprinkler systems, modern technology would be able to supply a high degree of flexibility in design and operation, raise water and fertilizer use efficiency and make applicable in undulating topography and marginal soils [11]. Solid set sprinkler provides sufficient distribution of water and N when appropriately designed and operated [12]. Field average based recommendations have been a common practice for recommending the major crop nutrients nitrogen (N) and phosphorus (P). The problem is crop response will not be the same from year to year with application of the same amount of recommended rate of fertilizer [13] in order to apply precise management strategy it is crucial to have variability maps of soil properties. Suitable temporal and spatial distribution of nutrient application would be a necessity to apply precision amount of fertilizer to avoid surplus. Sugar beet performance maps are important tools for farm managers in precision farming practices. Spatial distribution maps of crop properties can be linked to soil properties map (by GPS coordinates) in order to apply site specific management. Soil and crop spatial variability maps are accurate tools in precision farming to produce a management strategy to improve yield, sugar content and other required outputs. This research has focused on determination of spatial and temporal variability of selected soil properties and crop performance to produce a management strategy based on soil and crop spatial variability.

Materials were sugar beet field and sugar beet tubers. The Sugar beet field properties were determined and given in maps. Sugar beet variety was monogerm seeds which were sown on 9 July 2007. The field was in Fesaran village that is located in central part of Isfahan province, Iran. It exists between latitude 32° 28' N and longitude 51° 43' E with 3.09 hectares area. Average annual temperature of 16.7° C, annual freezing days of 76 days and the annual rainfall of 116.9 mm are climate data of experimental site. According to soil and water analysis, soil texture types are loam (L) and clay loam (CL). Water source for irrigation system is mixture of open channel which is feeding from Zayandeh – Rood River and deep well in the farm. Water analysis is driven from water sample of pool which holds mixture of water from the river and well. Water EC of well and open channel were about 5.08 and less than 1dS/m, respectively and sodium adsorption ratio (SAR) was about 10.6 so infiltration rate in soil would be in good conditions [14]. Water pH, total suspended solids (TSS) and total dissolved solids (TDS) in water source were in allowable ranges. The sprinkler irrigation system, fixed (solid set) with removable sprinklers was implemented in 2004.

Sprinklers mounted on the 120 cm height risers were installed at the corners of each plot. Urea fertilizer was applied through sprinkler irrigation system. Nitrogen fertigation (Urea, 46% N) has been applied on 30 August 2007 with the rate of 200 kg/ha. Pest and diseases control followed the standard practices in this area. A geostatistical sampling design was established in 3.09 ha area. Total of 27 grids of 23 by 23 m cells were marked on the study area. In each cell, 3 soil samples were collected. This arrangement procedure made 81 sampling locations and was flagged and georefrenced, using DGPS (Differential Global Positioning System). The sampling locations were staked before fertigation to mark them for sampling after fertigation. At each flag location, soil samples were obtained 5 days before planting. A total of 162 soil samples were collected from field before fertigation on 4 July 2007 and after fertigation on 3 September 2007. Soil cores were placed in individual plastic bags and on arrival at the lab they were air dried and sieved (2mm). Soil samples were taken to determine soil properties including total N, available K, CEC, EC and organic matter (OM) at two times (before and after fertigation). Each grid was harvested by hand and tubers put in sacks and were weighed with weighbridge on 4 December, 2007. Sugar beet performance was determined by analyzing tuber moisture content, tuber weight, number of tubers in each grid and tuber sugar content. Result of soil and plant were interpolated geostatistically by kriging technique using ArcGIS9.2 through spatial analysis extension based on semivariogram result of geostatistical software (GS+).

RESULTS AND DISCUSSION

Produced maps are given below. Results of semivariogram analysis for 5 soil elements and 4 crop characteristics were applied. They are described by specific model throughout the range of data. Four variogram model types checked include spherical, exponential, gaussian, and linear to find the best fitting one. The fitted curve for relative semivariance gives values of sill, nugget, range and variogram fitting model as shown in Tables 1 and 2.

Table 1. Geostatistical Analysis of Soil Properties

Soil Properties	Unit	Model type	Nugget	Sill	Range	Partial Sill	Proportion C/(C0+C)	R^2	RSS
N - BF	%	Spherical	0.000305	0.00062	141.80	0.00032	0.510	0.944	5.36×10^{-8}
N - AF	%	Spherical	0.000094	0.00137	38.90	0.00128	0.932	0.569	2.1×10^{-7}
K - BF	Ppm	Spherical	8850.00	37110.0	52.50	28260	0.762	0.820	5.8×10^{-7}
K -AF	Ppm	Exponential	9650.00	19310.0	102.30	9660	0.500	0.590	2.43×10^{-7}
CEC - BF	Ppm	Exponential	0.59000	7.5770	39.90	6.987	0.921	0.572	2.86
CEC - AF	Ppm	Exponential	0.830	5.7850	45.30	5.955	0.860	0.423	3.83
EC- BF	dS/m	Spherical	0.01272	0.03144	77.50	0.0187	0.595	0.920	1.3×10^{-5}
EC-AF	dS/m	Spherical	0.01123	0.0353	100.40	0.0241	0.680	0.900	4.7×10^{-5}
OM - BF	%	Spherical	0.0186	0.0922	77.60	0.0736	0.798	0.971	6.41×10^{-5}
OM - AF	%	Spherical	0.0146	0.0840	86.0	0.0694	0.826	0.940	1.6×10^{-4}

BF: Before Fertigation AF: After Fertigation

Table 2. Geostatistical Analysis of Sugar Beet Properties

Plant Properties	Unit	Model type	Nugget	Sill	Range	Partial Sill	Proportion C/(C0+C)	R^2	RSS
Sugar content	%	Exponential	0.167	1.202	32.40	1.035	0.86	0.69	0.03
Tuber numbers	-	Exponential	3.660	9.709	1081.2	6.049	0.62	0.80	0.53
Tuber weight	kg	Spherical	0.0157	0.2584	18.80	0.243	0.94	0.57	9.24×10^{-4}
Moisture content	%	Exponential	3.45	23.93	23.40	20.48	0.86	0.26	15.7

They present the fitting curve of selected model for each soil and plant properties while lag distance in semivariogram analysis assumed at 200 m for N-BF, N-AF, K-BF, K-AF, and EC-AF; 150 m for CEC-BF, CEC-AF and EC-BF; and 135 m for OM-BF and OM-AF in soil properties and 150 m for all crop components.

Figures 1 and 2 show the variability of selected soil and crop properties obtained from kriging technique. Smart quantile divided the whole study area in 5 zones to portray the variability of soil properties and crop performance. Five classes were adjusted in order to generalize the classes to cover both seasons, before and after fertigation. The five classes were defined as very low, low, moderate, high and very high ranges. Table 3 displays the comparison of zonal statistical analysis for two conditions of selected soil elements before and after fertigation.

The map show that 73.22% of the area before fertigation was classified as low N while after fertigation 59.97 % of study area was in the high range of soil N (Table 3 and Figure 1- a, b). CV of soil N before and after fertigation were 12.44% and 14.7% , respectively. It indicates that the soil in study area has low variability of total N [15]. Soil N results are in allowable range of N for sugar beet production (0.03 % to 0.5 %) in Iran [16]. Pearson two-tail test result showed that soil N before fertigation had a positive significant correlation ($P \leq 0.05$) to soil N after fertigation (r= 0.351). Before fertigation the largest part of the field (about 75%) was situated in moderate and high rate of soil available K, whereas 97.4% of the whole field was in low and moderate ranges (Table 3 and Figure. 1- c, d). In both conditions soil available K meets the optimal amount of K for sugar beet cultivated lands of Iran (0.64 cmol $^{(+)}$/kg) which was studied by [17]. High CV of K before (56.27 %) and after (53.26 %) fertigation is an evidence of high variation of K through the study area. Before fertigation 50.24% of whole area had the moderate range of soil CEC but after fertigation 58.31 % of the study area was located in low zone (Table 3 and Figure. 1 - e, f) . Soil EC varied from 0.6 to 1.52 dS/m (Table 3). Highest variation of soil properties was found in soil available K while the least variation was in OM before and after fertigation. The high variation of soil K can be related to non-uniform manual fertilization of pre-plant potash.

Table 3. Comparison of Zone Classification of Soil Elements Before and After Fertigation

ZONE	Classification	Range of N (%)	Area Before Fertigation	Area After Fertigation
1	Very low	<0.173	5.273	0
2	Low	0.173-0.200	73.221	3.869
3	Moderate	0.200-0.230	21.506	21.806
4	High	0.230-0.270	0	59.966
5	Very high	>0.270	0	14.358

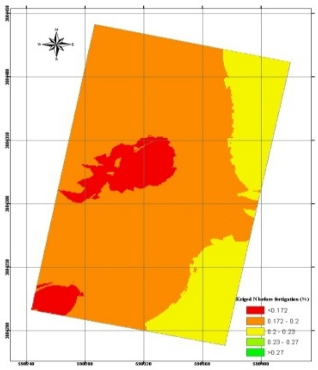
ZONE	Classification	Range of K (cmol $^{(+)}$ kg $^{-1}$)	Area before fertigation	Area after fertigation
1	Very low	<0.34	0	8.466
2	Low	0.34-0.64	21.245	39.848
3	Moderate	0.64-1.08	48.474	49.069
4	High	1.08-1.37	26.093	2.618
5	Very high	>1.37	4.189	0

ZONE	Classification	Range of CEC (cmol $^{(+)}$ kg $^{-1}$)	Area before fertigation	Area after fertigation
1	Very low	<0.93	0	6.224
2	Low	0.93-1.11	38.383	58.312
3	Moderate	1.11-1.29	50.240	28.823
4	High	1.29-1.47	11.377	5.584
5	Very high	>1.47	0	1.056

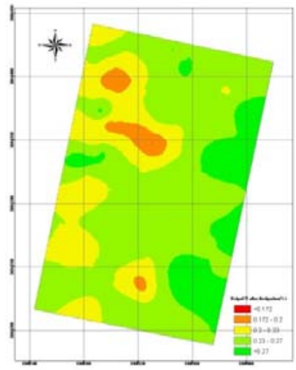
ZONE	Classification	Range of OM (%)	Area before fertigation	Area after fertigation
1	Very low	<8.6	16.455	8.863
2	Low	8.6-8.8	20.886	25.162
3	Moderate	8.8-9	35.429	33.022
4	High	9-9.2	21.781	21.960
5	Very high	>9.2	5.450	10.992

ZONE	Classification	Range of EC (ds/m)	Area before fertigation	Area after fertigation
1	Very low	<0.773	0	20.860
2	Low	0.773-0.890	1.712	28.360
3	Moderate	0.890-1.010	9.537	27.724
4	High	1.010-1.226	63.598	23.056
5	Very high	>1.226	25.153	0

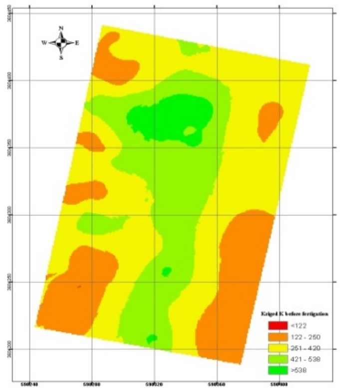
Before fertigation, the biggest part of the field (88.7 %) was situated in high and very high EC zones while after fertigation it decreased to 23% (Table 3 and Figure. 1- g, h). It can be related to different water sources for sprinkler irrigation. Water source in spring was deep well (EC=5.08 dS/m) and during summer was open channel (EC<1 dS/m). Soil OM had the least variation (CV=3%) compared to other soil elements (Figure. 1- i, j). The relationship of OM and sugar beet shows that if a soil has a greater organic matter content, it will likely mineralize more N over the growing season, thus decreasing a crop's responsiveness to applied N fertilizer [18]. Spatial variability maps of sugar beet performance were given in Figure 2. It is apparent that highest sugar content (18.29-19%) belongs to tubers which were harvested from the west part of the study area while the least sugar content (14.54- 15.65 %) was found in the east north of the field (Figure 2-a). Fewer numbers of tubers (5-9) were given in north and east part compared to higher number of tubers (9-14) in the west part (Figure 2-b). Spatial variability map of fresh tuber weight (Figure 2-c) presents the heavier tubers (1.27-1.67 kg) in east-north part and lighter tubers (0.78-0.98 kg) in the west part of the field. The highest moisture content range (79.70 -82.9 %) was seen in the east and some part of south while the least moisture content (75.73-77.7 %) was found in tubers in the west (Figure 2-d).


Kriged N before fertigation (%)
<0.172
0.172 - 0.2
0.2 - 0.23
0.23 - 0.27
>0.27

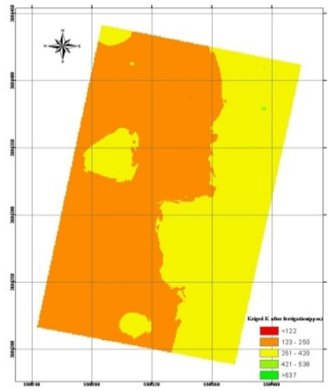
a



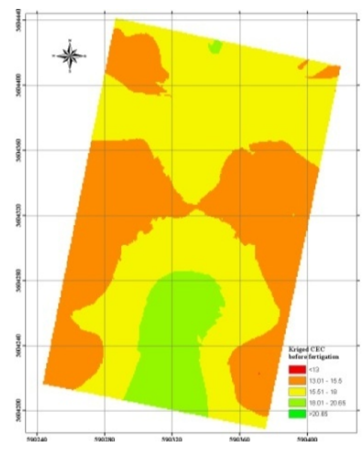
b


Kriged K before fertigation
<122
122 - 250
251 - 420
421 - 538
>538

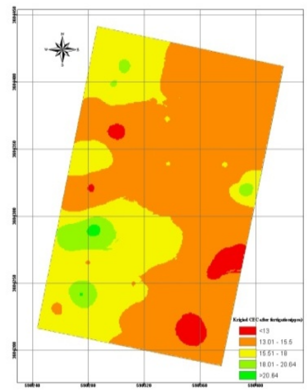
c


Kriged K after fertigation(ppm)
<122
123 - 250
251 - 420
421 - 536
>537

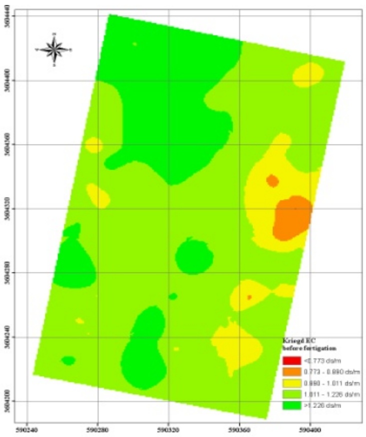
d


Kriged CEC before fertigation
<13
13.01 - 15.5
15.51 - 18
18.01 - 20.65
>20.65
590400

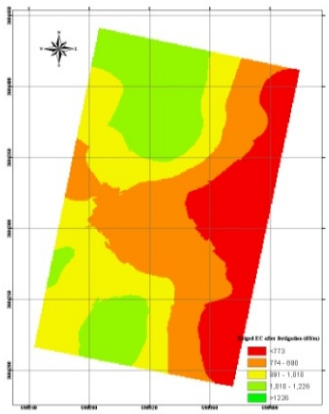
e


Kriged CEC after fertigation(ppm)
<13
13.01 - 15.5
15.51 - 18
18.01 - 20.64
>20.64

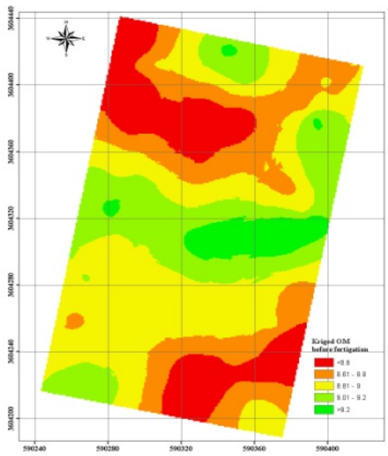
f



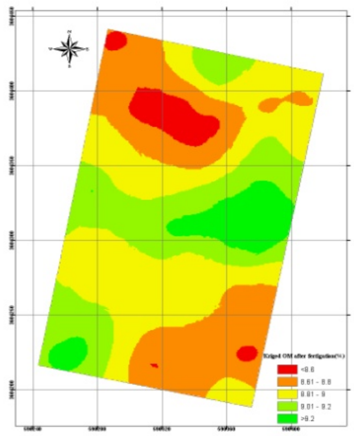
g



h



i



j

Figure 1. Spatial Variability Maps of Soil Nutrients, (a) N- BF, (b) N-AF, (c) K-BF, (d) K-AF, (e) CEC-BF, (f) CEC-AF, (g) EC- BF, (h) EC-AF, (i) OM-BF, (j) OM-AF

Statistical analysis and variability maps of crop properties showed the least variation in tuber sugar content. Result of Pearson's two tail correlation test showed that tuber weight had a negative significant correlation ($P \leq 0.05$) to number of tuber (r=-0.369) , but positive correlation to moisture content of tuber (r=0.303). It indicates that the higher moisture content causes heavier tuber. Moreover, the area with more number of tubers has the lighter tubers. There is a positive correlation of number of tubers and tuber sugar content (r =0.368) that specifies the higher sugar content harvested from places with more number of tubers. On the other hand, the negative correlation of moisture content and sugar content (r=-0.251) means tubers with higher moisture content (heavier) have less sugar content.

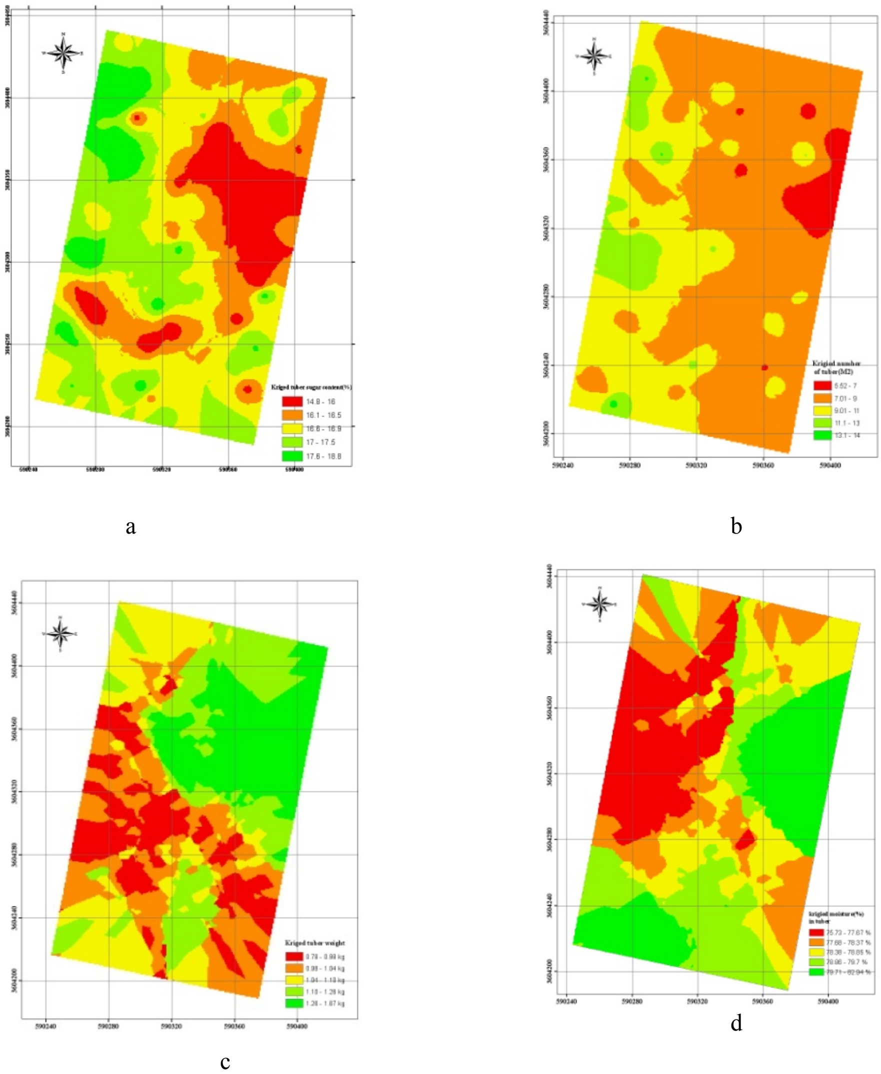


Figure 2. Spatial Variability Maps of Selected Crop Properties After Fertigation, (a) Tuber Sugar Content, (b) Tuber Numbers, (c) Tuber Weight and (d) Tuber Moisture Content

CONCLUSION

Application of precision farming in Iran is an appropriate technique for efficient and economic fertilization method in sustainable agriculture. It requires time and long term investment to apply suitable management strategy based on precision farming concept to prevent unconscious and unnecessary fertilization which causes environmental pollution and economic losses. It should be reminded that technical application of N fertilizers protect accumulation and leaching of N. Fertilizer application based on spatial variability maps of soil and crop properties makes uniformity in required crop output and also prevent excessive use of fertilizers.

Nitrogen fertigation by sprinklers in this experimental site produced a more uniform tuber sugar content, Tuber moisture content and number of sugar beet tubers. The application of Urea through fertigation increased N soil content while the enhancement of soil N decreased tuber sugar content so excessive use of fertilizers should be stopped.

Results of N fertigation through sprinkler irrigation show the low variability of leaf N content and sugar content through and across the study area and achievement of higher yield and sugar content compared to previous records of this field and average of the Isfahan Province records. Therefore, farmers should be encouraged to apply N fertigation by sprinklers instead of the current methods.

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