Growth, yield and phosphorus use efficiency of vegetable cowpea (*Vigna unguiculata*) varieties as influenced by phosphorus levels under rainfed conditions of semi-arid environment

ABSTRACT

Selection of a suitable variety and use of optimum level of phosphorous can significantly increase the productivity and profitability of vegetable cowpea under rainfed conditions in semi-arid tropics. However, application of appropriate level of phosphorus is of prime importance to realize higher yield, economics and phosphorus use efficiency. Hence, a field study was conducted at the Research Farm of Indian Agricultural Research Institute, New Delhi, India to find the effect of different varieties and phosphorus levels on the growth, yield, economics and phosphorus use efficiency in two consecutive rainy seasons of 2018 and 2019 under semi-arid condition. Three varieties of cowpea (Pusa Dharni, Pusa Komal and Kashi Kanchan) and four levels of phosphorus (0, 20, 40 and 60 kg P_2O_5 ha^{-1}) were laid out in split plot design with three replications. The results revealed that Pusa Dharani recorded significantly higher green pod yield (5.12 t ha^{-1}) with net returns of Rs. 40454 $ha^{-1}$and B:C ratio of 1.27. The maximum nodules per plant, nodule weight per plant and nutrient uptake were also recorded with variety Pusa Dharni. Maximum increase in phosphorus use efficiency (33.73 kg pod yield kg^{-1} P applied) and P recovery (18.19%) were noted with Pusa Dharni, whereas the respective values were 29.12 kg pod yield kg^{-1} P applied and 13.23% in variety Kashi Kanchan and 27.79 kg pod yield kg^{-1} P applied and 9.70% with Pusa Sukomal. Phosphorus levels showed significant variation on all the growth and yield attributing parameters, and yield. Application of 60 kg P_2O_5 ha^{-1} resulted in highest green pod yield (5.38 t/ha) but remained statistically comparable with 40 kg P_2O_5 ha^{-1}. However, maximum net return (Rs.41320 ha^{-1}) and B:C ratio (1.28) were obtained with 40 kg P_2O_5 ha^{-1} compared to net returns of Rs. 41120 ha^{-1} and B:C ratio of 1.22 with 60 kg P_2O_5 ha^{-1}. Highest nodules/plant, nodules weight and N, P and K uptake were also recorded with 60 kg P_2O_5 ha^{-1} closely followed by 40 kg P_2O_5 ha^{-1}. Highest P use efficiency (39.72 kg pod yield kg^{-1} P applied) and P recovery (15.05%) was recorded with the application of 20 kg P_2O_5 ha^{-1} followed by 40 kg P_2O_5 ha^{-1}. Application of 40 kg P_2O_5 ha^{-1} fetched highest net returns (Rs. 41345 ha^{-1}), net benefit: cost ratio (1.28), economic efficiency (Rs. 516.81ha^{-1} day^{-1}) and production efficiency (66.25 kg ha^{-1} day^{-1}). Increasing P levels showed positive correlation with nodules/plant, dry weight of nodules, N uptake and pod yield. Hence, the results indicated that growing of cowpea variety Pusa Dharni alongwith application of 40 kg P_2O_5 ha^{-1} registered higher net returns and net benefit:cost ratio under rainfed condition of semi-arid regions.

INTRODUCTION

Cowpea (*Vigna unguiculata* L. Wasp) is one of the most important multipurpose legume crops extensively grown under rainfed conditions in arid and semi-arid ecosystems. It is grown for several purposes like vegetable, pulse, fodder, green manure and as cover crop. Besides many uses of cowpea, it has the ability to improve soil fertility through fixing atmospheric nitrogen and thus can provide around 60–70 kg ha^{-1} nitrogen to the succeeding crops (Aikins and Afuakwa, 2008). Growing of cowpea for vegetable purposes is gaining popularity in the semi-arid regions.

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Many characteristics of cowpea such as its low moisture and nutrient requirements, deep and tap root system, fast growing nature, high profitability (Chatterjee and Bandyopadhyay, 2017), nutritious and delicious vegetable and green fodder quality, enrichment of soil fertility and potentiality of producing higher green pod and fodder yield attracts the farmers to grow it for different purposes even in moisture stress conditions.

In addition, it is one of the important legume crops to diversify the traditional less profitable crops and can be adjusted very well to different cropping systems in arid and semi-arid regions of rain-fed conditions. Cowpea being a legume crop is rich in various nutrients and is an important source of nutrients to provide more nutrients especially in the diet of vegetarians. One hundred gram of cowpea matured seeds contain 24.8 grams protein, 63.6 grams carbohydrates, 1.9 grams fat, 6.3 grams fibre, 0.74 mg thiamine, 0.42 mg riboflavin, and 2.281 mg niacin as well as it is rich in calcium and iron (Shaw M, 2007). Green pods of cowpea also contain 3.55 proteins, 2.0% fibre, 8.1% carbohydrates, 0.09% mineral content and 0.50% niacin (Patel and Kumari, 2018). It is also known as one of the important sources of soluble and insoluble dietary fibres, phenolic compounds and B group vitamins (Liyanage *et al*., 2012). Apart from this, it is a very good source of nutritious and high quality of green and dry fodder for livestock. The versatile characteristics of cowpea make it an important component of subsistence agriculture, especially in water deficit areas (Singh *et al.,* 2003).

In India, cowpea is grown in several states including Rajasthan, Karnataka, Kerala, Tamil Nadu, Maharashtra, Gujarat, Punjab, Haryana, Delhi and Uttar Pradesh, with an average productivity of 567 kg/ha. It is cultivated in an area of 3.9 million hectares with a total production of about 2.21 million tonnes (Giridhar *et al*., 2020). However, low yield of cowpea grown for vegetable as well as grain purposes is a major concern for the growers of semi-arid regions. Among several biotic and abiotic factors, use of non-descript low yielding varieties and inadequate supply of nutrients have been reported by many workers as important reasons for low yield of cowpea in semi-arid region (Kan'ankuk'a, 1999; Boukar, *et.al.* 2016; Patel *et.al.,* 2018).

Soils of semi-arid regions suffer from macro and micronutrient deficiencies in general and major nutrients (nitrogen and phosphorus) in particular (Saharawat *et al*., 2007; Saharawat and Wani, 2013). Most of the soils in arid and semi-arid regions are inherently deficient in phosphorus. Out of total 135 pulses growing districts in India, soils of 68 and 62 districts are low and medium in phosphorus, respectively (Sweta and Malik, 2014; Hosmani, *et al*., 2017). Phosphorus has been recognized as one of the most important elements of plant nutrition involved in various functions of growth and metabolism activities of pulses (Sweta and Malik, 2014). It is involved in many physiological and bio-chemical activities of plant like stimulating root growth and development, root hairs, nodulation, symbiotic nitrogen fixation, transfer of energy, sugar, and starch formation and essential for cell division and photosynthesis (Udvardi and Poole, 2013; Haruna, 2011; Nziguheba *et al.*, 2016; Singh *et al.,* 2011). Enhanced nodulation and plant growth provide energy for nitrogen fixation process that directly affects the nitrogenase activity in nodules and photosynthesis (Hogh-Jensen *et al.*, 2002). Apart from this, phosphorus pronounced the flower initiation, seed and fruit development (Ndakemi and Dakora, 2007). Furthermore, growing suitable varieties with optimum supply of nutrients leads to optimum use of soil and environmental factors that produce higher yield components and yields (Khourgamy and Farnia, 2009). Keeping in view the above facts, an attempt was made to study the effect of varieties and phosphorus levels on the growth, productivity, profitability and nutrient use efficiency of cowpea under rainfed conditions of semi-arid region.

MATERIALS AND METHODS

A field experiment was conducted at the Indian Agricultural Research Institute, New Delhi during rainy seasons of 2018 and 2019 to study the effect of different phosphorus levels on the growth, yield and nutrient uptake of cowpea varieties under rainfed conditions of semi-arid regions. The experimental site is situated at 28^0 38' N latitude and 77^0 18' E longitude at the altitude of 228.6 m above the mean sea-level having semi-arid and sub-tropical type of climate. The total rainfall received during the entire crop growth period (July, August, September and October months) was 854 mm in 2018 and 560 mm in 2019. The experimental soil was sandy loam in texture containing 64.8% sand, 12.4% silt and 22.8%

clay. The bulk density of the soil was 1.54 mg/m^3 with pH 7.4 and EC 0.48dSm^{-1}. The soil had 0.41% organic carbon, 154 kg ha/ha available nitrogen, 12.8 kg/ ha available phosphorus and 176 kg/ha available potassium. The experiment comprised of three varieties of cowpea (Pusa Dharani, Pusa Sukomal and Kashi Kanchan (Table 1)) which were allotted to main-plots and four levels of phosphorus (0, 20, 40 and 60 kg ha^{-1}) were placed to sub-plots in split plot design with three replications. Out of all the varieties, Pusa Dharani was recently developed by Indian Agricultural Research Institute, New Delhi for vegetable purposes for rainfed conditions during 2019. The characteristics of all the varieties are given in Table 1. Cowpea crop was sown in the second week of July during both the years after obtaining sufficient moisture in the soil profile through rainfall. Seeds were sown in rows, by maintaining a row-to-row distance of 45 cm and plant to plant distance of 15 cm by using a seed rate of 20 kg/ha. Recommended dose of 20 kg N and 40 kg K_2O/ha was applied uniformly in all the plots, whereas different levels of phosphorus (20, 40 and 60 kg P_2O_5 ha^{-1}) were applied as per treatment schedule. Full amount of all nutrients was applied as basal dose at the time of sowing of the crop. N, P and K nutrients were supplied through urea, single super phosphate and muriate of potash, respectively.

The first picking of marketable green pods was done at 54 days after sowing and a total of four picking were done up to 80 days after sowing the crop. Observations on plant height and yield traits (number of pods per plant, fresh weight of green pods per plant, pod length, fodder yield) were recorded from the selected tagged plants. The yields of green pods of all four picking were summed up according to the treatments to obtain the yield of green pods per plot and per hectare as well. ~~Observation on nodules per plant were~~Observation on nodules per plant was recorded at 60 days after sowing. Determination of N content in pod and stover of cowpea was made by using modified Kjeldahl method (Jackson, 1973), phosphorus by ammonium vanado-molybdate yellow colour method with spectrophotometer (Jackson,1973) and potassium content in pod and stover (biological yield) by flame photometer method (Jackson, 1973). The nutrient uptake, agronomic phosphorus use efficiency, phosphorus recovery efficiency, economic efficiency and production efficiency were worked out by using the different formula given below. Economics of different treatments were worked out considering the prevailing market prices of inputs and outputs. The data were statistically analysed using standard procedures of ANOVA at 5% level of significance using F-test (Gomez and Gomez, 1984).

Table 1. Characteristics of the varieties

Characteristics	**Varieties**		
	Kashi Kanchan	**Pusa Dharni**	**Pusa Sukomal**
Colour of the seed	Reddish, kidney shaped	Kidney shaped bi-colour with white hilum and black spotted	Black and smooth
Flower colour	White purple	Yellow	Cream
Pod	Soft, fleshy, pulpy with less fibrous, lengthy, free from parchment with gap between seeds,	Smooth, slender, round, straight and light green with full of seeds	Round, less fibrous, straight, light green
Plant type	Branched with tendrils and photoperiod insensitive	Semi-erect and branched	Semi-dwarf, bushy

Resistant	Resistant to cowpea golden mosaic virus	Golden yellow mosaic virus	Golden yellow mosaic virus and leaf spot diseases.
Developed by	ICAR-Indian Institute of Vegetable Research, Varanasi, during 2007.	ICAR-Indian Agricultural Research Institute, New Delhi, during 2019.	ICAR-Indian Agricultural Research Institute, New Delhi, during 2005.

The agronomic P use efficiency (AE_P) and fertilizer P recovery efficiency (RE_P) was calculated for different N rates using the following equation as described by Ahmed *et al*. (2016).

- Agronomic P use Efficiency (kg ha^{-1} P applied) = $\dfrac{\text{Seed yield in P applied plot- yield in control (kg ha}^{-1}\text{)}}{\text{Applied P in fertilized plot (Kg ha}^{-1}\text{)}}$

- Phosphorus recovery efficiency (%) = $\dfrac{\text{P uptake in treated plot (Kg ha}^{-1}\text{)} - \text{P uptake in control plot (Kg ha}^{-1}\text{)}}{\text{Phosphorus applied to the test treatment (kg ha}^{-1}\text{)}}$

- Production Efficiency (kg pod yield/day/ha) = $\dfrac{\text{Green pod yield (kg/ha)}}{\text{Total duration taken by crop (days)}}$

- Economic efficiency (Rs. /day/ha) = $\dfrac{\text{Net return (Rs./day/ha)}}{\text{Total duration taken crop (days)}}$

RESULTS AND DISCUSSION

Effect of varieties

Perusal of data presented in Table 2 indicated that varieties significantly influenced all the growth and yield attributing parameters. Among all three varieties, Pusa Dharni recorded tallest plant (68.17 cm) followed by Kashi Kanchan (64.83 cm) and registered significantly superior over Pusa Sukomal (39.75 cm). Significantly higher pods plant^{-1} (31.08) were also recorded with Pusa Dharni which were 91.26 and 18.81% higher than Pusa Sukomal and Kashi Kanchan, respectively. However, pod length and pod weight were recorded maximum with Kashi Kanchan, but remained statistically at par with Pusa Dharni and significantly higher over variety Pusa Sukomal. Significant variation in the plant height and yield attributing parameters could be attributed to the genetic makeup of the individual varieties and differences in their performance due to environmental adaptability (Shilpa *et al*., 2015; Das *et al*., 2019; Samant, 2014).

Among the different cowpea varieties, Pusa Dharni recorded significantly higher green pod yield (5.12 t ha^{-1}) increasing by 7.34 and 6.22% higher over Pusa Sukomal and Kashi Kanchan, respectively. Variety Kashi Kanchan produced statistically higher green pod yield (4.82 t ha^{-1}) than Pusa Sukomal; thus lowest green pod yield (4.77 t ha^{-1}) was obtained with variety Pusa Sukomal. The increase in pod yield indicates that the genetic characteristics and adaptability to moisture deficient conditions were better in Pusa Dharani variety as compared to rest of the varieties. Srinivas *et al*. (2017) also reported significant variability for yields and yield attributing parameters in cowpea due to genetic makeup of the genotypes and climate diversity. The results further showed that variety Pusa Dharni found to be superior variety in terms of producing significantly higher green fodder yield (21.03 t ha^{-1}) compared to Pusa Sukomal (16.87 t ha^{-1}) and Kashi Kanchan (19.48 t ha^{-1}).

The maximum N, P and K uptake was observed with variety Pusa Dharni, Increase of N, P and K was 32.98, 36.79 and 38.78%, and 12.61, 17.0 and 11.33% higher than Pusa Sukomal and Kashi Kanchan, respectively. Maximum increase of NPK uptake might be attributed to the increased higher pod and fodder yield, higher root growth, and root hair formation in Pusa Dharni variety than the rest of the variety. Sathyaseelan *et al.* (2014) reported that increased uptake of NPK largely depends on yield potentiality of a variety.

The maximum agronomical P use efficiency (33.73 kg pod yield/kg P applied) was registered in variety Pusa Dharni, which was 21.37 and 15.83% higher over Pusa Sukomal and Kashi Kanchan, respectively. The lowest agronomical P use efficiency (27.79 kg pod yield/kg P applied) was noted in case of variety Pusa Sukomal. Variety Pusa Dharni also recorded maximum phosphorus recovery (18.19%) followed by Kashi Kanchan (13.23%). The lowest phosphorus recovery (9.70%) was registered by the variety Pusa Sukomal. Variety Pusa Dharni fetched highest net returns (Rs. 40454 ha^{-1}) with net Benefit: cost ratio of 1.27 and economic efficiency of Rs.505.7 day^{-1} ha^{-1} (Table 3). The variety also resulted in maximum production efficiency (63.9 kg day^{-1} ha^{-1}). The lowest net returns, net B: C ratio, economic efficiency and production efficiency were registered with variety Pusa Sukomal. Production of higher green pod and fodder yield. The higher net returns, net B: C ratio, economic efficiency and production efficiency might be attributed to the production of higher green pod and fodder yield by variety Pusa Dharni.

Effect of phosphorus levels

Various growth and yield attributing parameters viz. plant height, pod ~~length,~~length; pod weight and pods per plant of cowpea were significantly influenced by the application of different phosphorus levels compared to no phosphorus application (Table 2). Highest plant height (63.44 cm), pods per plant (27.89), pod length (26.91 cm) and weight per pod (7.22 g) were recorded in 60 kg P_2O_5 ha^{-1} and found significantly superior over control and 20 kg P_2O_5 ha^{-1}. However, no significant difference was observed between the growth and yield attributing parameters obtained with of that 60 kg P_2O_5 ha^{-1} and 40 kg P_2O_5 ha^{-1}. The lowest plant height, pods $plant^{-1}$, pod length and pod weight were observed in control. The green pod and fodder yield increased significantly with the application of all the levels of phosphorus over control. The highest green pod yield (5.38 t ha^{-1}) and green fodder yield (21.02 t ha^{-1}) were recorded with the application of 60 kg P_2O_5 ha^{-1} closely followed by 40 kg P_2O_5 ha^{-1} (5.30 t/ha and 20.75 t/ha). Thus, the lowest green pod yield (4.11 t/ha) and green fodder yield (16.82 t/ha) were obtained under control. This might be owing to the fact that phosphorus application significantly influenced root development and stimulation of several biochemical activities such as photosynthesis, respiration, cell division and other processes, leading to better sink translocation, consequently increased growth, yield attributing parameters and yields over control (Nkaa *et al*., 2014; Kumar *et al*., 2012). The increase in phosphorous level from control to 20 kg ha^{-1} resulted in an increase of 19.22% in green pod yield, whereas the application of 40 kg and 60 kg P_2O_5 ha^{-1} did not exhibit much difference (28.95 and 30.90%) in the increased pod yield over control, indicating significant response of phosphorus up to 40 kg ha^{-1} on increasing yield of cowpea under rainfed condition. Magani and Kuchinda (2009) also reported 40 kg P_2O_5 ha^{-1} as optimum phosphorus dose for cowpea.

Increasing phosphorus levels significantly increased N, P and K uptake by cowpea crop over control (Table 3). Application of 60 kg P_2O_5 ha^{-1} showed maximum N (94.84 kg ha^{-1}), P (16.42 kg ha^{-1}) and K (60.65 kg ha^{-1}) uptake followed by 40 kg P_2O_5 ha^{-1} recording by the 91.71, 15.93 and 59.09 kg ha^{-1} uptake of NPK. However lowest uptake of N (63.91kg ha^{-1}), P (9.93 kg ha^{-1}) and K (39.58 kg ha^{-1}) was registered under control. Higher N, P and K uptake by cowpea crop might be attributed to availability of phosphorus, that caused better root development and root hairs growth, nodulation and nutrient translocation in plants, leading to higher biological activities for N_2 fixation, P-solubilization and mineralization, resulting in increased NPK uptake by the crop plants (Vikrant *et al.*, 2005; Singh *et al*., 2016; Singh and Prasad, 2008; Rudreshappa and Halikatti, 2002). The agronomical phosphorus use efficiency and phosphorus recovery was significantly influenced due to the application of increased phosphorus levels compared to control.

The highest agronomical phosphorus use efficiency (39.75 kg pod yield/kg nutrient applied) and phosphorus recovery (15.05%) were observed with lowest level of phosphorus (20 kg ha^{-1}). Further, application of 40 kg P_2O_5 ha^{-1} found superior for providing higher agronomical phosphorus use efficiency (29.67 Kg pod yield/kg nutrient applied) and phosphorus recovery (14.86%) compared to 60 kg P_2O_5 ha^{-1}. Increased values of agronomical phosphorus use efficiency and phosphorus recovery with lower doses of phosphorus showed an inverse relationship between agronomical phosphorus use efficiency, phosphorus recovery, and phosphorus levels (Devi *et al*., 2012; Ahirwar *et al*., 2016). The number of nodules $plant^{-1}$ and dry weight of nodules $plant^{-1}$ increased significantly with the increase of phosphorus levels compared to control. The maximum number of nodules $plant^{-1}$ (16.67) and dry weight of nodules $plant^{-1}$ (251.67 mg $plant^{-1}$) were recorded with the application of 60 kg P_2O_5 ha^{-1}, which was at par with 40 kg P_2O_5 ha^{-1}. However, the lowest nodules $plant^{-1}$ (11.20) and nodules dry weight (153 mg $plant^{-1}$) were recorded in control). The increase in nodules and their dry weight might be attributed to enhanced root growth and root hairs due to phosphorus nutrition (Nziguheba *et al*., 2016).

Economic analysis revealed that the highest net returns (Rs.41345 ha^{-1}) and B: C ratio (1.28) was realized with the application of 40 kg P_2O_5 ha^{-1} (Table 4). Application of 60 kg P_2O_5 ha^{-1} fetched lower net return by Rs.225 ha^{-1} compared to 40 kg P_2O_5 ha^{-1}, which was owing to involvement of higher cost of cultivation with 60 kg P_2O_5 ha^{-1} than 40 kg P_2O_5 ha^{-1}. Further, application of 40 kg P_2O_5 ha^{-1} showed 47.42 and 11.07 % higher net returns over control and 20 kg P_2O_5 ha^{-1}, respectively which indicates the importance of optimum supply of phosphorus for realizing higher net returns. Jat *et al*. (2013) also reported higher net returns and B: C ratio with the application of 40 P_2O_5 ha^{-1} from cowpea crop under rainfed conditions.

Conclusion

On the basis of the results obtained from the study, it is concluded that productivity and profitability of cowpea can be enhanced with the application of 40 kg P_2O_5 ha^{-1} in newly evolved variety Pusa Dharni under rainfed conditions of semi-arid regions.

Table 2: Yield and yield attributes of cowpea varieties as influenced by phosphorus levels

Treatments	Plant height (cm)	Pods plant^{-1}	Pod length (cm)	Weight pod^{-1} (g)	Green Pod yield (ton/ha)	Green fodder yield (t ha^{-1})	Harvest index (%)
Variety							
Pusa Dharni	68.17	31.08	25.40	6.74	5.12	21.03	19.58
Pusa Sukomal	39.75	16.25	23.10	6.14	4.77	16.87	22.04
Kashi Kanchan	64.83	26.16	26.71	7.07	4.82	19.48	19.00
CD (P=0.05)	4.52	2.20	1.82	0.62	0.13	1.26	-
Phosphorus levels (kg ha^{-1})							
0	49.78	19.67	23.10	5.77	4.11	16.82	19.64
20	56.00	23.33	24.52	6.58	4.90	19.35	20.21
40	61.10	27.11	25.70	7.05	5.30	20.75	20.34
60	63.44	27.89	26.91	7.22	5.38	21.02	20.38
CD (P=0.05)	2.76	1.19	1.26	0.17	0.17	0.64	-

Table 3: Effect of varieties and phosphorus levels on economics and production efficiency

Treatments	N	P	K	Nodules/ Plant	Nodule weight (mg/plant)	Agronomical P use efficiency (Kg pod yield/kg P applied)	P recovery (%)
Variety							
Pusa Dharni	92.42	16.10	60.54	15.50	221.90	33.73	18.19
Pusa Sukomal	69.50	11.77	43.75	13.00	208.62	27.79	9.70
Kashi Kanchan	82.07	13.76	53.68	14.75	194.51	29.12	13.23
CD (P=0.05)	8.01	1.26	5.28	1.51	16.48	2.49	1.01
Phosphorus levels (kg/ha)							
0	63.91	9.93	39.58	11.20	153.32	0	0
20	77.21	12.93	52.73	13.48	173.40	39.72	15.05
40	91.71	15.93	59.09	16.33	245.00	29.67	14.86
60	94.84	16.42	60.65	16.67	251.61	21.24	11.22
CD (P=0.05)	7.15	1.09	4.28	1..23	18.61	2.71	1.24

Table 4: Effect of varieties and phosphorus levels on economics and production efficiency

Treatments	Cost of cultivation (Rs. ha^{-1})	Gross returns (Rs. ha^{-1})	Net returns (Rs ha^{-1})	Net B:C ratio	Economic efficiency (Rs. ha^{-1} day^{-1})	Production efficiency (kg ha day/ha)
Variety						
Pusa Dharni	31776	72230	40454	1.27	505.67	63.9
Pusa Sukomal	31776	64570	32794	1.03	409.92	59.62
Kashi Kanchan	31776	68740	36964	1.16	462.05	60.25
Phosphorus levels (kg ha^{-1})						
0	29875	57920	28045	0.94	350.56	51.37
20	31125	68350	37225	1.20	465.31	61.25
40	32405	73750	41345	1.28	516.81	66.25
60	33700	74820	41120	1.22	514.00	67.25

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