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Effect of Component Densities on the Performance of Pearl millet - Mung bean Intercropping System Under Different Rainfall Situations in an Arid Environment

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Abstract: A field study on pearl millet and mung bean component densities in intercropping was assessed under three cropping season rainfall situations, viz., above normal (409 mm), normal (301 mm) and below normal (190 mm) having 24, 14 and 8 effective rainy days, respectively. The soil was sandy loam having 10.5 and 2.5% moisture content (w/w) at field capacity and -15 bar tensions, respectively. Decreasing the density of pearl millet (principal crop) from 20 to 13.3 plants m^{-2} increased its yield, but further decrease to 10 plants m^{-2} decreased the yield at all levels of intercrop component densities irrespective of the type of season. The yield of component crops depended more on the effective storage of moisture in the soil profile and availability of moisture at reproductive stage (weeks 8-12) rather than quantum of rainfall during the season. Component density combination of 13.3 plants m^{-2} of pearl millet with 5 plants m^{-2} of mung bean was optimum and resulted in the highest grain yield, LER and WUE in all seasons. Moisture stress in below normal season and the availability of radiation in lower half of the canopy in good rainfall situation was a limiting factor for pearl millet yield. Higher consumptive use (214-254 mm) was recorded in moisture stress free seasons compared to below normal rainfall season (150-157 mm). On an average, harvest index was lower (0.24) in moisture stress season (due to differential influence of terminal drought on grain and total dry matter yield) as compared to normal and above normal rainfall seasons (0.42). High sustainable yield index for pearl millet under optimum component density (0.37) compared to sole cropping (0.23) indicated better stability of pearl millet production due to intercropping in arid environment.

Key words: Intercropping, pearl millet, mung bean, rainfall, crop density, water-use efficiency, sustainable yield index.

Intercropping is a common practice in tropical regions of the world. Recent studies have suggested substantial yield advantages in this practice over sole cropping. Panjab Singh and Joshi (1980) have found pearl millet-mung bean intercropping system more remunerative for arid areas. The biological advantage due to intercropping may result from complementary use of growth resources, or when inter specific competition for growth resources is less than intra-specific competition. Performance of intercropping relative to sole cropping was found to be enhanced under limited moisture availability (Natrajan and Willey, 1986) in semi-arid tropics. Not much has been reported from arid areas.

The rainfall in arid regions is precarious besides being too aberrant having coefficient of variability between 40-60% (Sastri and Ramakrishna, 1980). Different kinds of agricultural droughts and their complexities influence the productivity of crops in rainfed agriculture under arid conditions of Asia and Africa (Spencer and Sivakumar, 1987; Joshi, 1988; Lahiri, 1990). Under conditions of limited and varying moisture supply, the number of plants per unit area should be a guiding factor for yield responses. Osiru and Willey (1972) indicated that where intercropping gives advantage, the total optimum population may be higher than either of sole crops under semi-arid conditions. But, higher plant population may lead to intense competition for limited available moisture in early growth stages and leave no moisture for reproductive stages. On the other hand, sub-optimal crop stands can also reduce the yields as the area of the polygonal space occupied by the plant in a crop influences yield of an individual plant in a non-linear fashion (Willey and Heath, 1969). Bationo *et al*. (1990) found that low plant density did not significantly increase the yield of sole pearl millet in the dry year and did not help in fully realizing the potential in good rainfall years. This investigation, therefore, is aimed to study component density relationship to achieve sustainability of crop production under above normal, normal and below normal rainfall situations of arid zone.

Materials and Methods

Field experiments were conducted at Central Arid Zone Research Institute, Jodhpur, India, latitude 26.30°N and longitude 73.02°E with a strong monsoonal climate, having a mean annual rainfall of 368 mm, most of which is received from June to September. Therefore, only one rainfed crop a year is possible. The average global solar radiation on horizontal surface is 21.03 MJ m^{-2} day^{-1}.

The soil in the field plots had developed from rhyolite modified by alluvial and aeolian activities. The soil was sandy loam having 80.9% sand, 7.08% silt and 11.9% clay. The soil had 0.162% organic carbon (Walklay and Black method), 17 kg ha^{-1} available P (Olsen's method) and 180 kg ha^{-1} available K (ammonium acetate method). The moisture contents at field capacity and -15 bar tensions were equivalent to 10.5 and 2.5% water content (w/w), respectively. The soil has been classified as coarse loamy, mixed, hyperthermic, camborthids.

Treatments consisted of combinations of three plant to plant spacings (10, 15 and 20 cm) each of pearl millet [*Pennisetum glaucum* (L.) R. Br.] cv. MH179 and mung bean [*Vigna radiata* (L.) Wilczek] cv. S8 in a pearl millet - mung bean intercropping system. Spacing of 10, 15 and 20 cm between plants resulted in densities of 20, 13.3 and 10 plants m^{-2} of pearl millet (principal crop) and 10, 6.6 and 5 plants m^{-2} of mung bean (intercrop). These nine treatments (combination of high, moderate and low densities) were replicated three times in a randomized block design. One row of mung bean was taken in the interpair spaces of paired row planting (30/70 cm) of pearl

Table 1. Grain yield (kg ha^{-1}) of component crops as influenced by their densities (plants m^{-2}) under different rainfall situations

Level*		Density: Pearl millet	Density: Mung bean	Pearl millet: Above normal	Pearl millet: Normal	Pearl millet: Below normal	Mung bean: Above normal	Mung bean: Normal	Mung bean: Below normal
H	H	20.0	10.0	1593	2104	192	179	273	123
H	M	20.0	6.6	2265	2308	283	183	285	100
H	L	20.0	5.0	2265	2500	373	243	319	71
M	H	13.3	10.0	2359	2645	498	128	342	140
M	M	13.3	6.6	2875	2875	588	181	391	100
M	L	13.3	5.0	2992	3083	969	211	404	81
L	H	10.0	10.0	2296	2500	465	290	452	177
L	M	10.0	6.6	2671	2813	525	130	352	142
L	L	10.0	5.0	2781	2946	825	78	352	119
Sole crop				2859	2852	620	518	950	480
CD 5%				627	295	82	NS**	NS	39

* H = High, M = Moderate, L = Low; ** Not significant.

millet (2 rows of pearl millet 30 cm apart, 2 such pairs being 70 cm apart). Each net plot had 8 such pairs. Sole crops of pearl millet and mung bean were also taken for computing land equivalent ratio (LER). These were grown separately as suggested by Oyejola and Mead (1982). Side dressing of 30 kg N and 13.3 kg P ha^{-1} was done at sowing and 30 kg N ha^{-1} was top dressed to pearl millet rows about a month after sowing.

The experiment was assessed under three seasonal rainfall situations, viz., above normal rainfall (409 mm), normal (301 mm) and below normal (190 mm). The mean seasonal rainfall (80 years) of experiment station is 305 mm. The mean index of moisture adequacy (I_{MA}) was computed as described by Joshi (1988). Drought was considered to be initiated whenever I_{MA} decreased to less than 0.50. The I_{MA} values between 0.50-0.25 indicated moderate drought and those below 0.25 indicated a severe drought. Sustainability of the intercropping treatments was assessed by a Sustainable Yield Index (SYI) as given below:

$$SYI = y - \sigma/Y_{max}$$

Where, y is the mean yield of crops over years, σ is standard deviation and Y_{max} is the maximum yield obtained.

Pearl millet yield equivalents for intercrop yield were computed by considering price function, and were added with pearl millet yield for uniform assessment of water-use efficiency.

Results and Discussion

Seasonal rainfall and moisture adequacy

The above normal, normal and below normal rainfall seasons had 24, 14 and 8 effective rainy days, respectively. In above normal rainfall season, the I_{MA} was 0.51 during seedling stage, 0.88 during vegetative

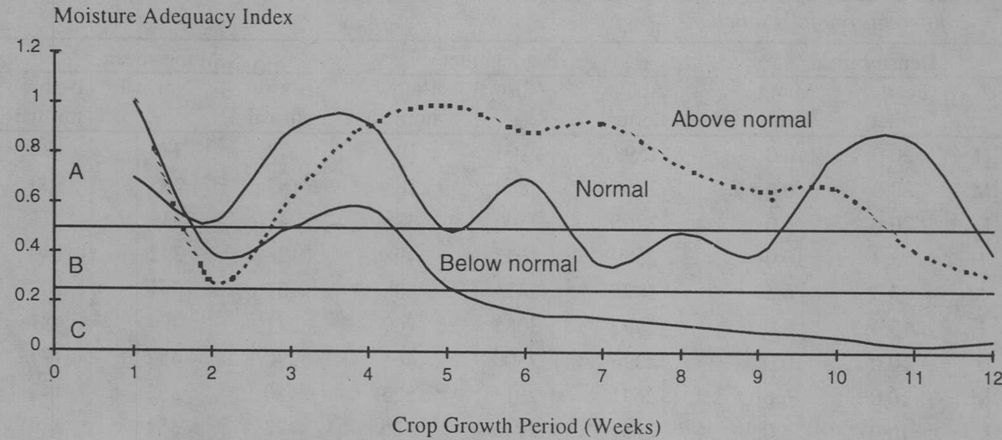

Fig. 1. Variation in index of moisture adequacy (A, Enough moisture; B, Moderate drought; C, Severe drought) during crop growth in different rainfall seasons.

stage and 0.56 during reproductive stage, which indicated sufficient moisture for crop growth (Fig. 1). In normal rainfall season also, enough moisture availability was indicated during seedling (0.50 mean I_{MA}), vegetative (0.66 mean I_{MA}) and reproductive (0.58 mean I_{MA}) stages. However, in below normal rainfall season, enough moisture was available for the crop during initial stage only (0.69 mean I_{MA}). The crop faced mild drought during vegetative stage (0.38 mean I_{MA}) and severe drought (0.09 mean I_{MA}) during reproductive stage.

Grain yield

Yield levels, in general, were higher in normal rainfall season than above normal rainfall season (Table 1). Detailed analyses of rainfall and soil moisture storage indicated that in above normal season, because of continuous rain in the week 4 after sowing, 102 mm of rain water was lost through deep drainage, thus reducing total soil moisture storage to a level similar to the normal rainfall season. Further, I_{MA} indicated relatively better moisture conditions during reproductive stage, especially in weeks 10 and 11, of normal season as compared to above normal season (Fig. 1). Singh and Ramakrishna (1992) found a strong relationship between predicted yield of pearl millet and moisture adequacy between 7 to 11 weeks of crop growth in sole cropping system of pearl millet. Mahender Singh and Joshi (1994) reported availability of moisture during weeks 8 to 12 as crucial factor for final yields in pearl millet based intercropping system. Thus, it is not the quantum of rainfall but the effective soil moisture storage during the season and availability of moisture during reproductive stage (weeks 8 to 12) that played important role in manifestation of final yield of above normal rainfall season.

Pearl millet yield increased as density decreased from 20 to 13.3 plants m^{-2} at all levels of mung been densities in all seasons. Further decrease in pearl millet density to 10 plants m^{-2} resulted in reduced pearl millet yield at all mung bean densities in every season (Table 1). The reductions were, however, nonsignificant except at low mung been density (5 plants m^{-2}) in below normal rainfall season. Plant population responses can be considered, both in terms of number of plants per unit land area (i.e., planting density) and spatial arrangement of plants, in relation to each other (i.e., planting rectangularity) besides component rectangularity of intercropping system. At lower plant density, the per plant yields were higher and remained so upto certain increase in density, because pearl millet has a capacity to compensate for lower density through increased effective tillering and crop plasticity (Joshi, 1987; Youngquist, 1989). This initial constant slope relation between grain yield and increasing population declined when individual plants began to compete for resources like light, water and nutrients. For intercrop component, if a non-tillering crop (as in the present case), the yield per plant would start decreasing with its increasing population. Thus, the yield compensation effect remains to still lesser extent for combined densities and lead to a population optima. The curvilinear response to density in the present study was indicated by positive linear term and negative quadratic term of pearl millet component (Eqs. 1 and 2). As a consequence, the optimum plant density was 13.3 plants of pearl millet in combination with 5 plants m^{-2} of mung bean, irrespective of type of season. This combination of densities of principal crop and intercrop gave pearl millet yield of 2992 kg ha^{-1} in above normal rainfall season, 3083 kg ha^{-1} in normal season and 969 kg ha^{-1} in below normal season. Intercrop component resulted in additional yield of 211, 404 and 81 kg ha^{-1}, respectively.

In all seasons, high density of both component crops resulted in the lowest pearl millet yield. Yield obtained with this combination was 46.7% lower in above normal rainfall season, 31.7% lower in normal season and 80.1% lower in below normal season than that obtained by keeping moderate density of pearl millet and low density of mung bean. The I_{MA} values of above normal and normal seasons indicated moisture sufficiency even at high density combination of both components. Yield reductions under such situations, indicated deficiency of some factor other than moisture. Reddy and Willey (1981) reported that higher yields from pearl millet/groundnut intercropping was associated with improved light energy conversion. Radiation interception observations recorded at peak crop growth stage during normal season showed that out of 269 Wm^{-2} mean total radiation at the top of canopy, 153 and 91 Wm^{-2} was available at middle and bottom of canopy, respectively, in high component density combination. The corresponding values for optimum density combinations were 198 and 153 Wm^{-2}, respectively. Similar trend of radiation interception was recorded during reproductive stage. McPherson and Slatyer (1973) established light response curve for pearl millet leaves exposed to artificial light and reported linear response of photosynthesis upto 170 Wm^{-2} irradiance. Thus, the lower canopy in high density combination photosynthesized at a low radiation level, suggesting the possibility of radiation as a limiting factor. The better radiation availability in optimum density combination could also be due to improved rectangularity within and between component species besides relatively lower density.

Moisture availability appeared to be a limiting factor in below normal season because, (a) the consumptive use was fairly constant in this season only, and (b) physiological maturity was hastened (65 days in below normal season as against 88 days in normal and above normal seasons) which curtailed the length of grain filling period with a consequent reduction in yield. Forced maturity and lower yields due to moisture stress have also been reported by Kanemasu *et al.* (1984); Reddy *et al.* (1990) and Garg *et al.* (1993).

At any of the density levels of pearl millet, reduction in density of intercrop significantly increased the yield of principal crop in all seasons. But, in below normal season, the intercrop population effects were more pronounced, with significant increase in the yield of the principal crop with every stepping down of mung bean density. Inverse relationship of component yields was also recorded by Ntare (1989) in Sahelian zone of West Africa with cowpea/pearl millet intercropping.

The intercrop yield remained uninfluenced in above normal and normal rainfall seasons. In below normal rainfall season, mung bean yields were significantly influenced by plant densities (Table 1). Reduction in pearl millet density from high to low and increasing plant density of mung bean from low to high significantly increased mung bean yield. Yield of intercrop was maximum at low pearl millet density in combination with high mung bean density.

Yield and component density relationship

Relationship of principal crop yield with density of component crops was developed. The models developed for pearl millet yields regressed on levels of pearl millet and mung bean plant densities under different rainfall situations are as under:

For normal rainfall (moisture stress free season):

$$Y = 1905.40 + 302.26\ X_1 - 199.10\ X_2 - 11.89\ X_1^2 + 6.23\ X_2^2 + 1.31\ X_1X_2$$

$$R^2 = 0.9917 \qquad ...(1)$$

For below normal rainfall (moisture stress) season:

$$Y = 1449.3 + 194.68\ X_1 - 508.64\ X_2 - 8.43\ X_1^2 + 25.95\ X_2^2 + 3.59\ X_1X_2$$

$$R^2 = 0.8862 \qquad ...(2)$$

where,

Y = the expected pearl millet yield,

X_1 = number of pearl millet plants ha^{-1} and

X_2 = number of mung bean plants ha^{-1}.

The adjusted R^2 values indicated that component densities explained up to 99 and 88% variation in pearl millet yields in normal and below normal rainfall seasons, respectively. Amongst significant coefficients, the quadratic term of pearl millet density contributed maximum to the coefficient of determination in both types of situations.

Land equivalent ratio

The total land equivalent ratio (LER) was greater than unity at all density combinations in above normal and normal rainfall seasons. In below normal rainfall season,

Table 2. Influence of component density (plant m^{-2}) on land equivalent ratio under different rainfall situations

Density				Above normal			Normal			Below normal		
Level*		Pearl millet	Mung bean	Pearl millet	Mung bean	Total	Pearl millet	Mung bean	Total	Pearl millet	Mung bean	Total
H	H	20.0	10.0	0.55	0.34	0.89	0.73	0.28	1.01	0.30	0.25	0.55
H	M	20.0	6.6	0.79	0.35	1.14	0.80	0.30	1.10	0.45	0.20	0.65
H	L	20.0	5.0	0.79	0.46	1.25	0.87	0.33	1.20	0.60	0.14	0.74
M	H	13.3	10.0	0.82	0.24	1.06	0.92	0.36	1.28	0.80	0.29	1.09
M	M	13.3	6.6	1.00	0.34	1.34	1.00	0.41	1.41	0.94	0.20	1.14
M	L	13.3	5.0	1.04	0.40	1.44	1.08	0.42	1.50	1.56	0.16	1.72
L	H	10.0	10.0	0.80	0.55	1.35	0.87	0.47	1.34	0.75	0.36	1.11
L	M	10.0	6.6	0.93	0.25	1.18	0.98	0.37	1.35	0.84	0.29	1.13
L	L	10.0	5.0	0.97	0.15	1.12	1.03	0.34	1.37	1.33	0.24	1.57
Sole crop				1.00	1.00	–	1.00	1.00	–	1.00	1.00	–
CD 5%				–	0.10	–	–	0.11	–	–	0.15	–

* H = High, M = Moderate, L = Low.

at high pearl millet density, the LER was less than unity, but at moderate and low densities, the LER was greater than unity (Table 2). The LER of principal crop increased with decreasing density of mung bean in all seasons. The total LER followed a similar trend except at low pearl millet density in above normal season. Moderate density of pearl millet with low density of mung bean resulted in the highest LER irrespective of the type of rainfall season. The total LER values of this density combination indicated yield advantage of 44% in above normal, 42% in normal and 72% in below normal season over sole pearl millet.

Consumptive use and water-use efficiency

The consumptive use was higher in stress free seasons (214-254 mm) compared to below normal rainfall season (150-157 mm). Seasonal water use by a crop is governed by leaf area index and leaf area duration. Stress free seasons in the present study caused longer (15 days) active leaf growing period as compared to moisture stress season and thus, could be considered as a major factor causing variation in consumptive use. Component density significantly influenced the consumptive use in above normal and normal rainfall seasons only (Table 3). In above normal and normal seasons also, variation in pearl millet density influenced the mean consumptive use (±5 mm) only marginally, but variation in mung bean density influenced the consumptive use significantly. Maximum consumptive use of 242 mm in above normal season, 254 mm in normal season and 157 mm in below normal rainfall season was recorded at high density combination of component crops. Decreasing mung bean density from high to moderate and moderate to low, significantly reduced the consumptive use. Studies of Azam-Ali (1983) indicated that the leaf area was the main determinant of evaporation in sole pearl millet cropping system and it also had a far greater influence on

Table 3. Consumptive use (mm) and water-use efficiency (kg pearl millet grain equivalent mm^{-1} ha^{-1}) of intercropping system as influenced by component densities under different rainfall situations

Density			Consumptive use			Water use efficiency		
Level*	Pearl millet	Mung bean	Above normal	Normal	Below normal	Above normal	Normal	Below normal
H H	20.0	10.0	242	254	157	8.64	11.28	3.40
H M	20.0	6.6	231	239	155	12.01	12.99	3.63
H L	20.0	5.0	220	220	154	13.35	15.44	3.70
M H	13.3	10.0	236	246	153	11.48	14.64	5.80
M M	13.3	6.6	228	235	152	14.79	16.90	5.70
M L	13.3	5.0	216	226	152	16.59	18.62	7.86
L H	10.0	10.0	231	240	154	13.44	15.66	6.23
L M	10.0	6.6	222	231	151	13.63	16.46	6.11
L L	10.0	5.0	214	221	150	14.01	17.44	7.68
CD 5%			7.9	9.3	NS**	1.79	1.70	0.95

* H = High, M = Moderate, L = Low; ** Not significant.

seasonal water use than other physiological factors (e.g., stomatal resistance) or physical factors (e.g., vapour pressure deficit).

The water-use efficiency (WUE) was computed in terms of pearl millet yield equivalents to facilitate better comparison of intercropping system treatments. The WUE significantly increased by reducing pearl millet density from high to medium at every level of mung bean density in all seasons (Table 3). Further reduction in pearl millet density did not significantly influence the WUE. High density combination of both the components led to the lowest WUE irrespective of type of rainfall season. This could be attributed to higher water use by high density of component crops but lower yields due to various limiting factors (radiation or moisture) in different seasons. The WUEs obtained in the present study are higher than those reported by Kanemasu *et al.* (1984) for sole cropping. This was because of the added equivalent yields for mung bean component which caused better resource utilization as indicated by LER (Table 2). Maximum WUE of 16.59, 18.62 and 7.86 kg grain mm^{-1} ha^{-1} (pearl millet equivalent) in above normal, normal and below normal season, respectively, was achieved by keeping moderate density of pearl millet in combination with low density of mung bean and was significantly higher than any other density combination.

Harvest index and yield sustainability

The harvest index (HI) was much lower (0.24) in below normal rainfall situation as against normal and above normal rainfall season (0.42).

Current evidence indicates, that the assimilate distribution pathway is highly resistant to water deficits. Nevertheless, the overall translocation of assimilates is affected by water deficit (Turner and Burch, 1983). Many workers have reported relatively higher reduction in grain yield than total dry matter yield due to stress at re-

Table 4. Influence of component density (plant m^{-2}) on harvest index under different rainfall situations and sustainable yield index in arid environment

Density				Harvest index			Sustainable yield index	
Level*		Pearl millet	Mung bean	Above normal	Normal	Below normal	Pearl millet	Mung bean
H	H	20.0	10.0	0.30	0.34	0.09	0.10	0.26
H	M	20.0	6.6	0.41	0.37	0.15	0.15	0.21
H	L	20.0	5.0	0.42	0.42	0.20	0.18	0.19
M	H	13.3	10.0	0.40	0.42	0.23	0.22	0.19
M	M	13.3	6.6	0.43	0.43	0.28	0.26	0.17
M	L	13.3	5.0	0.45	0.46	0.40	0.37	0.15
L	H	10.0	10.0	0.44	0.44	0.25	0.21	0.38
L	M	10.0	6.6	0.45	0.44	0.26	0.23	0.19
L	L	10.0	5.0	0.45	0.45	0.30	0.33	0.08
Sole crop				0.40	0.42	0.29	0.23	0.86
CD 5%				NS**	NS	0.03	0.03	0.04

* H = High, M = Moderate, L = Low.

productive phase (Begg and Turner, 1976). This differential reduction, as might be in the present case of below normal rainfall season, where crop faced severe drought during reproductive phase (Fig. 1), grain yield and total dry matter yield would result in lower harvest index. Component densities of intercropping system did not influence the HI in normal and above normal seasons but had significant influence in below normal season (Table 4). At high density combination of both components, the HI was the least (0.09). Maximum HI of 0.40, which was significantly higher than all density combinations, was achieved by keeping moderate density of pearl millet and low density of mung bean in below normal rainfall season. The very low HI under high density combinations confirm that under low rainfall season, high density caused severe stress resulting in drastic reduction in grain yield (80%), but relatively lower reduction in total dry biomass (8% only). This could be attributed to the product of interacting factors such as radiation interception (Azam-Ali *et al.*, 1984), moisture use (Garg *et al.*, 1993), influence on yield components (Bidinger *et al.*, 1987) and tiller mortality (Ong and Monteith, 1984).

The sustainable yield index (SYI) calculated in the present study (Table 4) helped to identify the treatment giving maximum sustainable yield under arid environment. The SYI of pearl millet increased with decreasing density of mung bean at all pearl millet densities. This showed that component crops had competition for limiting factors, but the better LER indicated that in some way the component crops were not competing for exactly the same overall resources. The negative linear term of mung bean component (X_2) in response equations 1 and 2 also suggests that low population of this component would be appropriate. The SYI at moderate and low pearl millet densities in combination with low mung bean density were significantly higher than sole crop (0.23), while SYI of sole mung bean was significantly higher than any of the intercropping density combinations. Moderate density of pearl millet with low density of mung bean resulted in the highest SYI (0.37) of pearl millet, which indicated that at least 37% of the maximum observed yield over years is assured with high probability in intercropping system, as against 23% in sole cropping system. Thus, intercropping provided better stability in yield of pearl millet. The pearl millet density itself had improved sustainably upto moderate density only, owing to population optima.

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