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Distribution of dew and its importance in moisture balance for rabi crops in India

A. CHOWDHURY, H. P. DAS and R. K. MUKHOPADHYAY

Meteorological Office, Pune

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सार — इस अध्ययन में, ओस के गिरने के भौगोलिक वितरण को निर्धारित करने का प्रयास किया गया है। इस अध्ययन में स्थानों के सुवितरित संजाल के 18 वर्षों (सन् 1971-88 ई०) के आंकड़ों का उपयोग किया गया है। ओस निक्षेपों के उर्ध्वाधर प्रोफाइल को सैद्धान्तिक वितरण में समज्जित किया गया। इसमें इस बात का परीक्षण किया गया है कि मासिक वृष्टि में ओस के योगदान और ओस-पात फसलों की वाष्पीकरण आवश्यकताओं को पूरा करने में जिस सीमा तक सक्षम होता है सूर्योदय के बाद ओस के वाष्पीकरण में लगने वाले समय पर भी चर्चा की गई है।

ABSTRACT. In this study an attempt has been made to determine geographical distribution of the dewfall. The study utilises 18 years data (1971-88) for a fairly well distributed network of stations. Vertical profile of the dew deposits have been fitted to a theoretical distribution. Contribution of dew to the monthly precipitation and the extent to which dewfall is able to meet the evaporative demands of the crops have been examined. Time taken for the dew to evaporate after sunrise has also been discussed.

1. Introduction

On an average atmosphere contains water vapour in varying degrees from 0 to 3%. On clear nights this moisture condenses as small water droplets known as dew on surface objects when the temprature of the surface drops below the dew point of the ambient air temperature. According to Ashbel (1949) cooling inside the soil during night is insignificant; on the contrary a warming starts with the progress of the night. As such it may be safe to conclude that dew formation occurs solely due to the cooling taking place over objects, close to the ground surface.

Important conditions for formation of dew are (*i*) enough of moisture, (*ii*) clear night skies to facilitate radiational cooling, (*iii*) calm or very light winds and (*iv*) presence of inversion in the vapour pressure gradient or downward transport of water vapour. Thus in spite of high humidity, dew deposits are not possible in monsoon because radiational cooling process is greatly retarted.

In the arid to dry sub-humid spectrum of climatic classification, dew plays a dual role in its contribution to plant growth. It actively provides water for direct plant use. The passive role is to delay the rise in temperature to lethal levels on the following morning thereby reducing evapotranspiration.

Rabi crops in India are sown about October-November and harvested during March-April. This crop season falls outside the main rainy season and hence, rainfall during the period is highly uncertain and irregular in time and smaller in quantum. With very little irrigation facilities, the crops depend heavily on dew deposits for their sustenance and growth.

The present investigation attempts to assess the usefulness of dew to plant growth during rabi crop season in India.

2. Data and scope

In the India Met. Dept. dew is measured by the Duvdevani optical method. The dew gauge consists of a rectangular plank of wood $32 \times 5 \times 2.5$ cm in dimension coated with red oil paint which favours retention of dew deposited on it. The gauge is exposed at sunset on special iron support at heights on 5, 25, 50 and 100 cm above bare soil surface.

From April onwards, the surface wind speed strengthens considerably. High winds and lack of adequate moisture prohibit dew formation in April and May. For these reasons the period October-March has been chosen in the study and categorised as the dew season.

The study utilises monthly dew deposits data for 53 stations (Fig. 1). The data pertains to the period 1971-1988. Dew accumulations at 100 cm height have been chosen. Reason for choosing this height are discussed in a subsequent section.

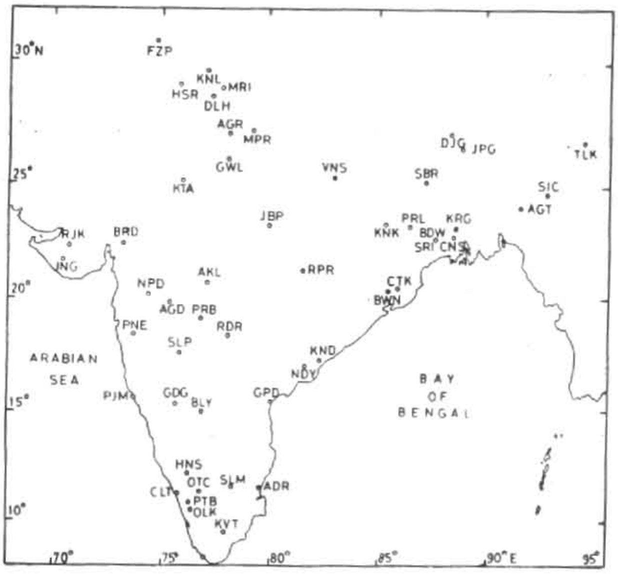

Fig. 1. Locator map.

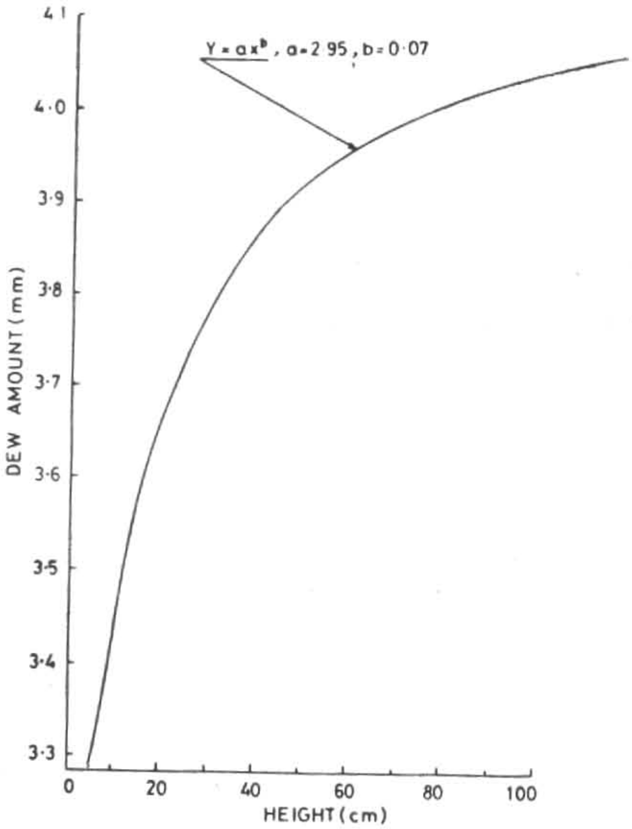

Fig. 2. Vertical distribution of dew deposits

The information collected for 18 years form the basis of regional distribution of dew amounts. Dew accumulation and its seasonal and spatial variation have been discussed. Besides, the dewy nights, an attempt is also made to find out the percentage of dew amount to the monthly rainfall. Contribution of the dew to the climatic moisture balance has also been studied by comparing it with potential evapotranspiration values given by Rao *et al.* (1971). Dew duration is an important factor, among others, in the development of fungal diseases on a number of agricultural crops. An attempt has also been made in this paper to find time taken for the dew to evaporate after the sunrise.

3. Results and discussion

3. 1. *Vertical profile*

The dew deposits vary from season to season and also with heights because of variations in the sensible heat transfer, *i. e.*, effective outgoing radiation. Within the plant community dewfalls vary according to prevailing weather and surface conditions.

Ramdas (1943) believed that dew deposits in India were maximum at 30 cm height above the ground. Raman *et al.* (1973) found that dew deposits at 50 cm height were consistently higher than those at 25 cm block. In the present study highest dew deposits were found to occur at 100 cm level, on about 65% of the cases studied. On the contrary, maximum deposition at

TABLE 1

Comparison between estimated and actual dew deposits

Ht (cm)	Actual dew deposits (mm)	Estimated deposits (mm)
5	3.29	3.29
10	3.45	3.45
20	3.67	3.67
30	3.78	3.72
40	3.87	3.80
50	3.92	3.89
60	3.96	3.89
70	3.98	3.98
80	4.01	3.98
90	4.03	4.03
100	4.04	4.03

$\chi^2 = 0.004$

Note : The actual values at levels other than 5, 25, 50 and 100 cm have been generated from the curve of the actual values at the four levels.

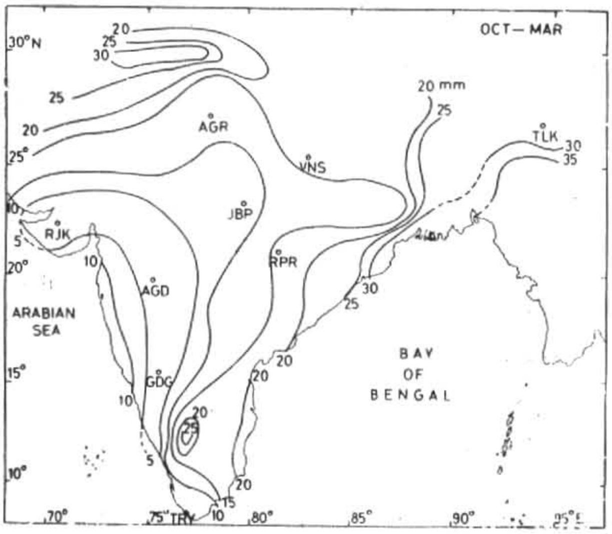

Fig. 3(a). Spatial distribution of dew deposits (October-March)

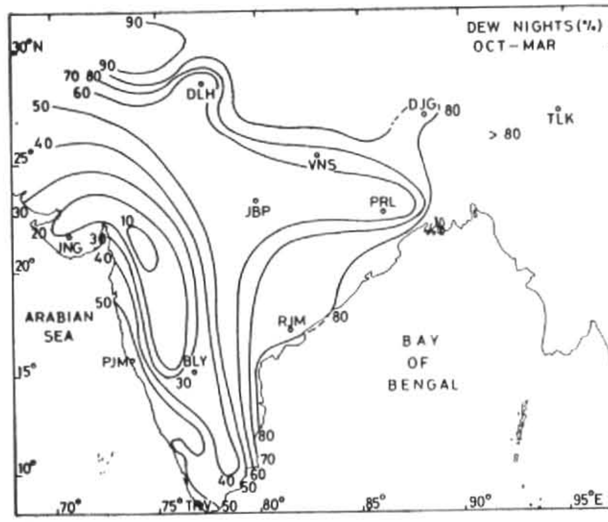

Fig. 3(b). Spatial distribution of dew nights (%)

50 cm contributed to only 7% of the instances while the remaining contribution came from either 25 or 5 cm levels. The higher values found by Ramdas (1943) and Raman *et al.* (1973) at lower levels were perhaps due to the small sample used by them in their studies.

Mean dew deposits for all months at all heights for all stations have been computed and shown in Fig. 2. The largest dew deposits are observed at 100 cm height decreasing downward. In the mean, the deposit at this height was nearly 25% more than that at 5 cm, 10% more than that at 25 cm and about 5% more than that at 50 cm. It was for this reason that dew deposits at 100 cm height are chosen in the study.

The distribution can be approximated by the curve

$$y = ax^b$$

where, y is the dew amount (mm) deposited at the height x (cm) and a & b are the constants. The values of a and b were found as 2.95 and 0.07 respectively. Table 1 shows a comparison between the actual values of dew deposits and those estimated from the fitted equation. A remarkable closeness between the two sets confirms that dew distribution within the friction layers follows an exponential distribution.

3.2. *Spatial distribution*

Areas of maximum dew deposits (Fig. 3 a) during the dew season are :

(a) Orissa-Bengal coast and Tripura and adjoining areas in the northeast with dew amounts 25-35 mm.

(b) Punjab and adjoining Haryana where deposits vary from 25 to 30 mm.

Dewfall over Nilgiri hills in the south also registers large amount, often exceeding 25 mm. Gujarat and interior areas of Peninsula on the lee side of the Western Ghats receive hardly 5 mm of deposit during the entire six months period. In fact over Madhya Maharashtra and north Karnataka the deposits hardly exceed 1 mm.

Distribution of dew nights in the season is shown in Fig. 3 (b). The natural vegetation in the mountainous northeast region provides continuous supply of moisture. It is seen that dew may occur over this region in about 150 nights of the season with a maximum of 0.32 mm on any night. Another area with even higher frequency is Punjab and neighbourhood where dew forms practically every night after the withdrawal of monsoon and lasts till the onset of dry summer conditions in April. Here passage of westerly systems in quick succession not only give rain but leave enough moisture in the atmosphere to get condensed after they have moved away. The amount varies between 0.11-0.32 mm per night. Minimum dew nights are observed over western parts of the Peninsula with a frequency of 20%, *i. e.*, about 35 nights in the season. This location significantly coincides with areas where lowest dewfalls are observed. Over the west coast on nearly 50% of the nights in October-March, dew formation could occur while on east coast it is more frequent in comparison. The maximum dew amounts observed in other parts of the global are given below :

Country	*Max. dew amount (mm) in a night*	*Reference*
Austria	0.1-0.3	Tuller and Chilton (1973)
British Columbia	0.15-0.2	Muller (1968)
England	0.2-0.5	Monteith (1963)
Germany	0.3-0.4	Hofmann (1958)
India	0.1-0.3	Raman *et al.* (1973)
Israel	0.2	Duvdevani (1957)

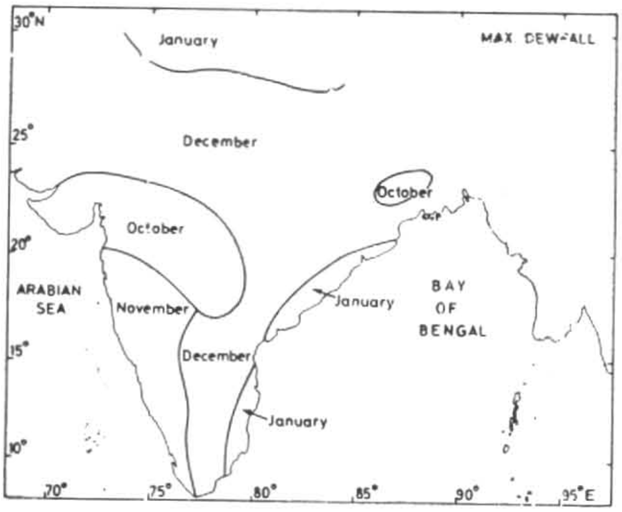

Fig. 4. Month of maximum dew formation

Dew catches in India thus appear comparable not only with tropical areas but even those in extra-tropics.

3.3. *Month of largest dew accumulation*

Dewfall in varying degree of magnitude, occurs in all months of the dew season. However, over different areas maximum dew accumulation is conditioned by large scale synoptic features. Local factors like orography, proximity to large water bodies, distance from the forest edge (Tuller and Chilton 1973), cause changes in the net outgoing radiation, air temperature and relative humidity and produce variation in dewfalls. Areal distribution of month of maximum dewfalls is shown in Fig. 4.

The maximum dew amounts in the lee side of Western Ghats and this area extends northwards to Gujarat in October. Because of good amount of moisture, consequent to the withdrawal of monsoon and clear nights allowing unhindered nocturnal radiation provide ideal condition for dew formation in this month. Another plateau region in the east, *viz.*, Bihar plateau also experiences maximum dewfall in October. Over the Nilgiri hills in the south and Kerala and adjoining areas, largest dewfall occurs in November. Here probably orography and presence of moisture after frequent spells of rain by northeast monsoon, cause heavy dew accumulations. On the east coast, on the contrary, maximum dew formation is favoured in January. As we know an anticyclone in the lower troposphere is located in the Bay during this month. Under the influence of this system moist air flow takes place over the coastal areas. Some of this moisture condense down as dew when mechanism for nocturnal cooling becomes pronounced in January. Similarly, largest dew amounts are observed over Punjab, Haryana, north Rajasthan and west Uttar Pradesh in January and over the rest of India in December. Increased moisture incursion during these two winter months in association with eastward moving westerly system, clear nights with stable radiation, temperature inversions and the low wind speed provide optimum conditions for large scale dew formation in these two months.

3.4. *Dewfall and the rainfall—A comparison*

For better understanding the significant of dew for rainfed agriculture, a comparison has been made between the two 'falls', *i. e.*, dewfall and rainfall. For selected stations this has been shown in Table 2.

The ground surface creates a favourable soil moisture condition for dew formation. This is because it not only cools the atmosphere but also provides enough moisture for condensations. Maximum dew amount could be seen in the table to occur in months following large rainfall after the cessation of regular rainy period. This is particularly so in November to February when the normal rainfall over the most parts of India is itself very low.

As we have seen in an earlier section over most parts of India, the dewfall is maximum in December. During this month rainfall over the country is negligible except south India which receives rainfall due to passage of cyclonic systems and the north India, which gets precipitation due to western disturbances.

TABLE 2

Monthly dew amounts, rainfall, potential evapotranspiration and evapotranspiration

Month	DD (mm)	RF (mm)	DD/RF	PE (mm)	ET (mm)	DD/PE
Silicoorie (24°50′N, 92°52′E)						
Oct	5.635	197.6	0.03	112	112	0.0050
Nov	7.776	43.4	0.18	89	89	0.0087
Dec	8.988	8.6	1.05	71	71	0.0126
Jan	8.099	20.6	0.39	75	75	0.0107
Feb	4.704	48.8	0.09	96	96	0.0048
Mar	1.920	147.1	0.01	148	148	0.0012
Kanke (23°25′N, 85°20′E)						
Oct	3.234	108.7	0.03	103	103	0.0031
Nov	3.275	19.1	0.17	77	76	0.0043
Dec	3.321	6.9	0.50	56	62	0.0059
Jan	2.020	29.0	0.07	68	68	0.0029
Feb	1.020	35.8	0.03	89	88	0.0011
Mar	0.189	22.6	0.01	140	28	0.0001
Cuttack (20°29′N, 85°52′E)						
Oct	3.358	14.7	0.23	115	115	0.0029
Nov	4.950	45.2	0.11	95	95	0.0052
Dec	7.308	7.1	1.03	81	65	0.0090
Jan	6.244	11.2	0.60	88	17	0.0071
Feb	5.040	27.7	0.18	106	33	0.0047
Mar	4.320	21.6	0.20	157	26	0.0027
Adhutarai (11°01′N, 79°32′E)						
Oct	1.547	232.2	0.01	131	131	0.0012
Nov	2.286	389.6	0.01	111	111	0.0020
Dec	2.840	184.4	0.01	118	118	0.0024
Jan	5.238	76.2	0.07	132	132	0.0039
Feb	5.346	21.3	0.25	137	126	0.0039
Mar	5.130	19.1	0.27	172	24	0.0030
Hunsur (12°18′N, 76°08′E)						
Oct	4.410	149.6	0.03	111	110	0.0040
Nov	4.554	61.5	0.07	106	106	0.0042
Dec	3.952	12.9	0.31	114	24	0.0034
Jan	3.952	2.8	1.41	128	7	0.0030
Feb	3.696	4.6	0.80	133	8	0.0027
Mar	4.026	9.7	0.41	166	14	0.0024
Karnal (29°43′N, 76°58′E)						
Oct	6.448	12.9	0.50	114	101	0.0056
Nov	6.075	4.1	1.48	70	10	0.0086
Dec	5.148	10.4	0.49	62	16	0.0083
Jan	5.874	32.0	0.18	53	38	0.0110
Feb	5.229	31.0	0.17	76	36	0.0068
Mar	3.895	15.5	0.25	131	19	0.0029
Panjim (15°29′N, 73°49′E)						
Oct	2.000	96.0	0.02	123	123	0.0016
Nov	2.128	34.3	0.06	091	86	0.0023
Dec	1.512	4.3	0.35	130	6	0.0011
Jan	1.725	1.3	1.32	136	3	0.0012
Feb	1.600	0.5	3.20	135	2	0.0012
Mar	1.458	1.0	1.46	167	2	0.0008

RF — Rainfall amount (mm), DD — Dew deposit (mm),
PE — Potential evapotranspiration (mm),
ET — Evapotranspiration (mm)

Fig. 5 shows fraction of dew deposits to the rainfall during December. Over most parts of Peninsula the dew amounts are less than 20% of the rainfall. In the interior areas of the Peninsula they are even less than 5%. Over some parts of Bihar plateau, also the dewfall is less than 20% of the rainfall. On the other hand, whereas in northwest India, dew amount is 60% or more of the rainfall, in the northeastern India, these amounts are even larger. In particular over West Bengal, Assam and adjoining States, the dewfall exceeds monthly rainfall, in some cases by as large as 20% in December. Thus, it is clear that dew contributes an important portion of total rainfall.

3.5. *Contribution to water budget*

Dew is a significant item in the water budget during the period when dew formation is favoured by excessive nocturnal cooling and rainfall is scarce.

Plants, during the period when active growth coincide with dry spell, have to rely on dew for important part of their moisture. It is also reported that earth ploughed into lumps absorbs maximum water vapour in the form of dew which subsequently becomes available to the plants. Although in many cases its total cannot come near to make up for the rainfall, dew acts as buffer and even in its small amount is critical in allowing plants to survive during a period of crop drought.

The ground surface is an important factor in water budget of atmosphere. In water budgeting, evaporation takes place and this stream is upward. Water returns to the earth in the form of precipitation (rainfall or snowfall). But in special situations at night there is a downward transport of water vapour in the form of dew.

Normally, more moisture is returned to atmosphere as upward stream of vapour than the downward stream. In December, for instance, about 80 mm of moisture is lost purely as evaporation. Since the dewfall in most parts is about 20 mm, it follows that this downward stream is about 1/4 of the upward stream in this month.

How effective the dewfall is in contributing to the water balance, has been examined in this study by comparing dewfall with potential evapotranspiration (PE) values. For some selected stations this is given in Table 2.

The contribution of dew to the water balance hardly exceeds 1% of PE with higher proportions seen in December or January, when PE itself is lower. In all other months, PE greatly outweighs the dew, emphasizing the dryness of the climate. At a glance, it may appear that though dew contributes an appreciable portion of the monthly precipitation during October-March, its effect in meeting the evapotranspirative demand is rather insignificant. It may, however, mentioned that the total deposits on leafy vegetation is significantl

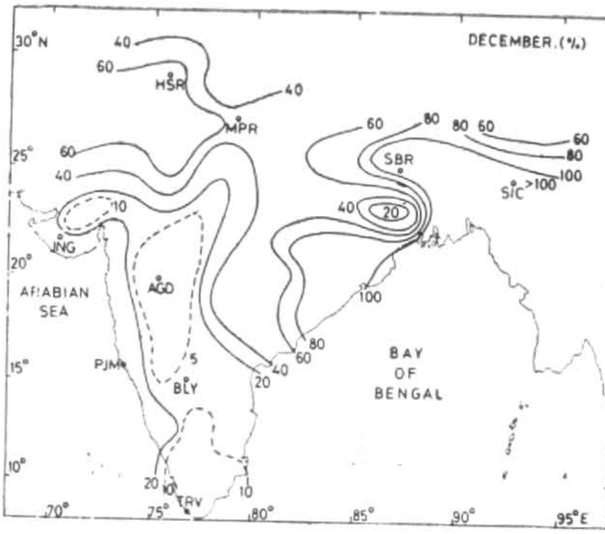

Fig. 5. Dew deposit *versus* rainfall : December

TABLE 3

Time taken for dew evaporation (minutes)

Station	Oct		Nov		Dec		Jan		Feb		Mar	
	D/N	T	D/N	T	D/N	T	D/N	T	D/N	T	D/N	T
Agartala (25°53′N, 91°15′E)	0.213	46	0.250	73	0.267	90	0.222	68	0.154	42	0.095	28
Adhutarai (11°01′N, 79°32′E)	0.091	25	0.127	52	0.142	56	0.194	55	0.198	48	0.171	38
Bhubaneshwar (20°15′N, 78°14′E)	0.154	46	0.145	60	0.138	58	0.140	52	0.154	45	0.120	21
Chinsurah (22°52′N, 89°28′E)	0.250	72	0.236	84	0.266	90	0.258	84	0.177	49	0.112	20
Ferozpur (30°55′N, 74°40′E)	0.101	40	0.129	43	0.135	66	0.112	44	0.114	40	0.097	35
Jabalpur (23°12′N, 79°57′E)	0.090	22	0.082	21	0.111	38	0.111	37	0.072	22	0.023	06
Ollulkura (10°32′N, 76°16′E)	0.197	44	0.192	47	0.182	52	0.141	36	0.123	22	0.096	28
Karanal (29°43′N, 76°58′E)	0.248	66	0.225	63	0.234	96	0.267	108	0.249	72	0.205	48

T — Time for dew evaporation (minutes) D/N — Dew amount per night (mm)

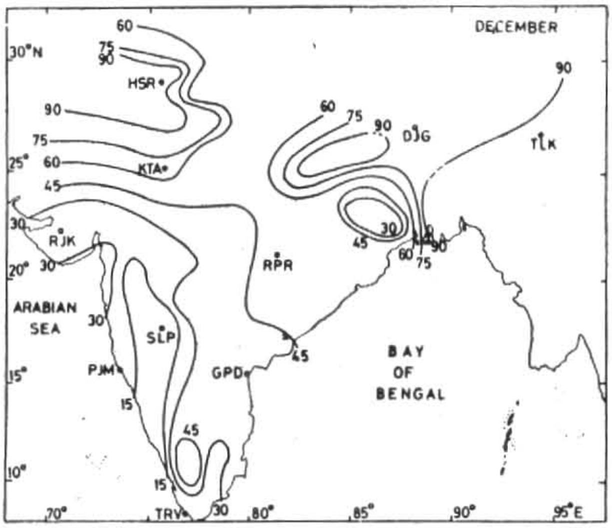

Fig. 6. Distribution of dew duration : December

larger than that recorded by the Duvdevani system. Factors between 5 & 10 have been suggested for estimating probable dew catches (Slatyer and Mc Ilroy 1961). Ashbel (1949) believed that the dew amount on an entire plant could range up to 6-7 times the amount recorded on a horizontal surface. The amount of dew reported in the study may substantially under estimate the actual quantity of moisture available to the plants. It is obvious that if this factor is taken into consideration, dew can be found to provide considerable moisture in most months for evapotranspirative needs of the crops.

3.6. *Dew duration*

Dewfalls affect the growing crops not only beneficially but could exert a devastating influence too. Persistent dew occurrences for instance, help in the development of spores of pathogenic fungi. For cost-effective disease management it is necessary to have an estimate of the dew duration. Gillespie and Barr (1984) forwarded a dew estimation scheme to estimate the dew duration. The method, however, is based on leaf-energy factors, *e.g.*, crop and air temperatures, convective heat transfer coefficients for crops etc. Such data are not available for Indian conditions. We have, therefore, tried to look into this aspect from another angle.

If m cm is the dew deposit in a night and L the latent heat of vapourisation, the amount of heat required to evaporate m cm of dew is $m\,L$ cal cm^{-2}. In this study we have taken $L = 596$ cal gm^{-1}. Radiation Atlas of India brought out by India Met. Dept. (1985) contains diurnal variation of global radiation. From the curves given in the publication, we have tried to find the time required for the accumulation of the heat energy necessary to deplete the amount of dew. Interpolation has been done for stations not having curves. For selected locations the time taken to evaporate the accumulated dew for different month is shown in Table 3. Since December is the month of maximum dewfall over large areas, this analysis is confined to this month and is shown in Fig. 6. It may be seen in the figure that over Madhya Maharashtra and north Karnataka it takes less than 15 minutes from sunrise for the dew to evaporate; in interior areas they are as small as 5 minutes. Over Bihar plateau, another area marked by low dewfalls, the time of dew evaporation is less than 30 minutes. Over the Nilgiri hills, the time taken is about 45 minutes. But in the northeast and northwest India, where dewfalls are significant in amount, dew may take more than 90 minutes to evaporate out. This seems parallel to the pattern for dew accumulation for the month.

4. Conclusion

The following conclusions could be drawn from the study:

(*i*) Dew occurs mostly between October to March with maximum accumulation in December and January.

(*ii*) Maximum dewfall occurs at a height of 100 cm above ground surface and decreases exponentially downwards.

(*iii*) During the months of pronounced plant water need, dewfall is 30-100% of the monthly normal precipitation.

(*iv*) In interior Peninsula dew evaporates within 30 minutes of sunrise, in the north dew remains on the surface for as large as 90 minutes.

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