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The Progress of Science in India during The Past Twenty-five Years

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starts above 80°C. and is always accompanied by growth of the crystal size and distortion of lattice planes.

Work on the constitution of jute and other fibres by X-ray methods have been started by B. B. Ray [1] and his pupils.

Laue photographs of iridescent crystals of potassium chlorate have been studied by S. C. Sarkar [2], and it has been shown that the iridescence is due to the presence of a large number of twinned strata almost parallel to each other inside the crystal.

XIII. METEOROLOGY [3].

A review of the progress of meteorology in India during the last twenty-five years may appropriately begin with a reference to the valuable pioneer work which had been done by Mr. H. F. Blanford and Sir John Eliot during the last quarter of the nineteenth century. Even to-day, Blanford's 'Indian Meteorologist's Vade-Mecum' and 'The Climate of India, Burma and Ceylon' and Eliot's 'Hand Book of Cyclonic Storms in the Bay of Bengal' and 'Climatological Atlas' form the foundation of our knowledge of weather and climate in India.

(a) *Seasonal Forecasts.*

A meteorological service aims to predict the day to day changes in weather and to issue timely warnings against high winds, heavy rainfall, floods, cyclonic storms, etc., to various interests over land and out at sea. In India the forecasting of seasonal rainfall has also engaged the attention of the meteorologists since the time of Blanford, and in this matter, India has given the lead to other countries.

Seasonal forecasts are of importance to the predominantly agricultural population of this country and incidentally also to Government in estimating financial prospects. This was recognized as early as 1884 when Blanford began issuing monsoon forecasts which were based mainly upon certain previous weather conditions in India. Eliot improved upon this method by considering the possible influence of extra-Indian factors, e.g., pressure at Seychelles, Australia, etc. Both Blanford and Eliot, however, depended much on intuition.

Sir Gilbert Walker [4], who succeeded Eliot as Director-General of Observatories, introduced in 1906-07 the correlation-coefficient and

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1 B. B. Ray, *Sci. and. Cult.*, **2**, 653, 1937.

2 S. C. Sarkar, *Ind. Jour. Phys.*, **5**, 337, 1930.

3 The writer (Dr. A. K. Das) is indebted to Dr. C. W. B. Normand, Director-General of Observatories in India, for advice in the preparation of this article.

4 G. Walker, *Mem. Ind. Met. Dept.*, **21**, 13, 1914; *ibid.*, **23**, 22, 1922; *ibid.*, **24**, 333, 1924.

the multiple regression equation in his monsoon forecasts, thus applying, for the first time, numerical methods to the preparation of seasonal weather forecasts and eliminating the personal factor. By the application of the methods of correlation-coefficients, Walker discovered certain important relationships between weather in distant parts of the earth. The main conclusion reached in his 'World Weather' investigations is that there are three big swayings or oscillations :—

(*a*) The North Atlantic oscillation between the Azores and Iceland,

(*b*) The North Pacific oscillation between the high pressure belt and the winter depression near the Aleutian Islands ; and

(*c*) The Southern oscillation, mainly between the South Pacific and the land areas round the Indian Seas.

The method of correlation-coefficients has ever since been employed in monsoon forecasting in India and considerable improvements have been made in the method by introducing Walker's significance test for selecting correlated factors.

A still further improvement is that introduced by Dr. C. W. B. Normand [1], the present Director-General, and named by him the 'Performance Test of Significance'. Whereas Walker's method aims at eliminating personal bias once the forecasting factors have been chosen, the Performance Test provides a means for surmounting personal bias in the ultimate choice of factors. The application of this idea in practice would be as follows : Suppose we want to forecast rainfall in a particular area. We correlate the rainfall in that area with a number of other factors using part of the available data. We have now to choose, say, four or five suitable factors and form a multiple regression equation. This choice of factors, depending as it does on individual judgments, can be a serious drawback to the usefulness of the forecasting formula. The Performance Test consists in correlating the actual 'unused' data with the corresponding data calculated or 'predicted' from the forecasting formula. The correlation-coefficient should be positive and, if it is significant, the full data may be used for obtaining a more accurate forecasting formula.

Dr. S. R. Savur [2] has shown that the Performance Test can be applied to various other statistical problems and is likely to be an important aid in statistical investigations in general.

Daily Weather Forecasting

(*a*) *Utilization of Upper Air data.*—Prior to 1914 daily weather prediction in India was made mainly from surface data. Since then upper air data from a slowly increasing number of stations have come to

[1] C. W. B. Normand, *Q.J.R. Met. Soc.*, 58, 3, 1932.
[2] S. R. Savur, *Ind. Jour. Physics*, 8, 27, 1932.

the forecaster's aid. The pioneer in upper air organization in India was J. H. Field. The work initiated by him is being continued by G. Chatterji. The upper air data used for daily weather work are the velocity and direction of wind at various heights above the ground telegraphed from a net-work of 38 stations. More detailed information such as pressure, temperature and humidity at various levels would have been very valuable, but there are practical difficulties in obtaining this information for the use of the forecaster. It is gratifying to note, however, that G. Chatterji[1] has invented temperature indicators (based on the principle of the bimetallic thermometer) for use in the first few kilometres above ground. He has also designed a hygrograph for obtaining continuous records of dry and wet bulb temperatures in the lower levels of the upper atmosphere and an improved type of Dines Meteorograph which is particularly suitable, on account of its enlarged scale, for sounding the lower layers of the atmosphere. Another set of very inexpensive instruments has been designed by A. K. Das[2] for obtaining quickly the values of temperature and pressure and the heights of inversions in the lower levels of the free atmosphere. These instruments are based on the principle of the air thermometer so that any one with a reasonable experience of glass-blowing can make them with little trouble. The use of aeroplanes for obtaining direct information of conditions in the first few miles of the atmosphere is at present confined, in India, to a few R.A.F. stations in North-West India.

(*b*) *Frontal Analysis.*—A powerful method that has come to the forecaster's aid is the analysis of air masses first introduced by V. Bjerknes. It is now well recognized that weather is caused by interaction between different types of air masses. Several ways of recognizing air masses have been suggested, but a very useful, yet simple, method is the use of the 'Wet-bulb potential temperature' first put forward by Normand[3]. The importance of this method is at once recognized when it is seen that the wet-bulb potential temperature 'has a definite meaning as a heat function, has an intimate relation with adiabatic process in general, and provides us with a measure of the entropy of atmospheric air', as shown by Normand. The invariance of the wet-bulb potential temperature has been the guiding factor in all the work on air mass analysis that has been recently done in India. Dr. Normand[4] also identified wet-bulb temperatures with the saturated adiabats that appear on the well-known adiabatic diagrams of Hertz and Neuhoff, and later in 1931 showed how wet-bulb curves (or 'Estergrams') entered on such diagrams can, in conjunction with dry bulb curves

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1 G. Chatterji, *Gerl. Beitr. Z. Geoph.*, **34**, 252, 1931.

2 A. K. Das, *Gerl. Beitr. Z. Geoph.*, **36**, 1, 1932 ; *ibid.*, **36**, 4, 1932 ; *ibid.*, **37**, 224, 1932.

3 C. W. B. Normand, *Memoirs Ind. Met. Dept.*, **23**, 1, 1921.

4 C. W. B. Normand, *Nature*, **128**, 583, 1931.

(or 'T-ϕ diograms') be used for the rapid classification of atmospheric layers for stability or latent instability. An account of the method is to be found in a Memoir by Mr. V. V. Sohoni and Miss Paranjpe [1], who have classified many T-ϕ diograms by this method and correlated subsequent weather with the degree of stability or latent instability evinced by the soundings.

(b) *Investigations of the Upper Air.*

The technique of pilot balloon observations and sounding work and the conclusions that could be drawn from the data collected up to the end of 1919 was elaborated in a series of memoirs by J. H. Field and W. A. Harwood [2] entitled 'The Free Atmosphere in India'.

K. R. Ramanathan [3] who made a general study of the soundings of the free atmosphere both in India and other countries, gave, for the first time, a concrete picture of the distribution of temperature up to 25 kilometres over the northern hemisphere during summer and winter. Some of his main conclusions are quoted below :—

> 'The stratosphere is not isothermal over any particular place, but above a certain level there is a tendency for the temperature to increase with height.
>
> The coldest air over the earth, of temperature about 185°A (—88°C) lies at a height of some 17 geodynamic kilometres over the equator in the form of a flat ring surrounded by rings of warm air.'

The observations in the upper air both as regards soundings and wind measurements were made at Poona, Hyderabad and Madras under the direction of the Upper Air Section at Poona, with materials supplied by the Upper Air Observatory at Agra, which under the able guidance of Mr. G. Chatterji developed the necessary technique. These observations together with those made by G. Chatterji and his co-workers at Agra have been analyzed and discussed by G. Chatterji, N. K. Sur, K. R. Ramanathan and their collaborators in a number of papers [4]. It is not possible to give an account of the many results obtained from all these investigations within the limited space of this article, but we will mention some of the important points brought out by these researches. One is that the tropopause or

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[1] V. V. Sohoni and Paranjpe, *Memoirs Ind. Met. Dept.*, **26**, 131, 1937.

[2] J. H. Field and W. A. Harwood, *Memoirs Ind. Met. Dept.*, **24**, Parts 5 and 6, 1921–23.

[3] K. R. Ramanathan, *Memoirs Ind. Met. Dept.*, **25**, 163, 1930.

[4] G. Chatterji and N. K. Sur, *Gerl. Beitr. Z. Geoph.*, **25**, 266, 1930; Ramnathan and Ramakrishnan, *Memoirs Ind. Met. Dept.*, **25**, 51, 1934; H. C. Banerjee and Ramanathan, *Ind. Met. Dept. Sc. Notes*, **3**, 21, 1930.

the transition layer between the troposphere and the stratosphere over Northern India occurs at a height of 14–18 kilometres. But there are fluctuations in the height in the different seasons, the mean height being 16·5 gkm. (temperature 194·5°K.) during the period middle of May to end of October and 14·9 gkm. (temperature 203·5°K). during the rest of the year. It is also remarkable that the temperature of the base of the stratosphere is higher in the colder months than in the hotter ones. Another striking fact is that the monsoon season (July-August) is the hottest of all the seasons up to nearly 14 gkm.

Finally it may be mentioned that upper air studies in India have led to a substantial modification of the picture of the general circulation of the atmosphere as presented by Teisserenc de Bort and Hildebrandsson.

(c) *Investigations on structure and movements of tropical storms, depressions, etc., in the Indian Seas.*

A considerable amount of research work has been done by meteorologists in India on the nature of the major weather phenomena, such as storms or depressions originating in the Indian Seas, thunderstorms of land origin, winter depressions which move from the west over Persia and Northern India. It has been well known from the time of Eliot (*vide* Eliot's *Cyclone Memoirs*, Parts I–V) that the outer storm areas of cyclones of the Indian Seas do not possess a symmetrical structure contrary to what was generally believed to be the case with tropical cyclones. Recently, however, B. N. Desai and S. Basu [1] have brought forward clear evidence in favour of non-symmetrical structure in the inner storm area of five Indian cyclones. An important point which emerges from Desai and Basu's investigation is that the calm centre or 'eye' of an Indian cyclone does not coincide with the lowest pressure, nor is the strength of winds in the inner hurricane zone symmetrical with respect to the centre. This conclusion, though not completely invalidating the usual theory of the formation of the calm centre according to which the central calm is due to the complete compensation of the pressure gradient by the centrifugal force acting on the rapidly rotating air mass, throws considerable doubt on the validity of this theory. It is well known that the Indian cyclonic storms form on a diffuse boundary between two air currents one of which is essentially of oceanic and the other of land origin. Several attempts have been made recently to investigate the structure of individual cyclones by applying the methods of Norwegian meteorologists for the extra-tropical cyclones. S. C. Roy and

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[1] B. N. Desai and S. Basu, *Gerl. Beitr. Z. Geoph.*, **40**, 1, 1933; Basu and Desai, *ibid.*, **42**, 353, 1934.

A. K. Roy[1] showed, for the first time, by analyzing a number of typical Indian cyclones that there is a close analogy between the structure of the Indian cyclone and that of the extra-tropical cyclone. In fact they showed that in a fully developed Indian cyclone, there are two clear fronts similar to the warm and cold fronts of extra-tropical depressions, and that the severity of a cyclone is greatest in the pre-monsoon and post-monsoon seasons when the two constituent air masses are most strongly contrasted in their properties. The later investigations of Ramanathan[2], Sobhag Mal and B. N. Desai[3] and N. K. Sur[4] on individual cyclones have also brought forward a certain amount of evidence pointing to the existence of fronts in Indian cyclones. In some recent investigations an attempt has been made to show, by the method of air mass analysis, that there occur in the atmosphere in India surfaces of discontinuity of the inclined or ' front ' type even in the absence of marked storm conditions. N. K. Sur[5] has shown by analyzing a few typical weather situations that occasionally a wedge of dry north-westerly continental air extends between the south-westerly winds from the Arabian Sea and the easterly winds of the monsoon traversing the Gangetic valley and gives rise to typical fronts with characteristic rainfall over the western United Provinces and adjacent parts.

In a recent memoir V. Doraiswami Iyer[6] has shown that an appreciable number of the residual lows from the typhoons of the Pacific Ocean and the China Sea, which strike the coast of Indo-China or South China during the period July to November, travel across the intervening hilly country and enter the Indian area. Many of these, which cross over in the months of September to November, develop into storms or well-marked depressions, those that develop into storms in the Indian Seas being of small extent.

Although our knowledge of the structure of the Indian cyclones has considerably improved in recent times, the directions of movements of storms in the Indian Seas are still not clearly understood. It may be that the track of a cyclone depends, as Harwood concluded from a statistical study, upon the wind directions at the cirrus level, but it would seem that the inclination of the spatial axis of a cyclone ought to give a better indication of the direction of travel. The winter depressions, which move into India from the west across Persia and Baluchistan were studied by B. N. Banerji[7] who showed that they present practically the same character-

[1] S. C. Roy and A. K. Roy, *Beitr. Z. Ph. fr. Atm.*, **16**, 224, 1930.
[2] K. R. Ramanathan, *Memoirs Ind. Met. Dept.*, **26**, 79, 1936 ; Ramanathan and Ramakrishnan, *ibid.*, **26**, 13, 1933.
[3] S. Mal and B. N. Desai, *Ind. Met. Dept. Sc. Notes*, **4**, 87, 1931.
[4] N. K. Sur, *Ind. Met. Dept. Sc. Notes*, **6**, 113, 1935.
[5] N. K. Sur, *Memoirs Ind. Met. Dept.*, **26**, 37, 1933.
[6] V. Doraiswami Iyer, *Memoirs Ind. Met. Dept.*, **26**, 93, 1936.
[7] B. N. Banerji, ' Meteorology of the Persian Gulf and Mekran ', Central Publication Branch (Govt. of India), 1931.

istics as the occluded depressions of the extra-tropical regions. Although the rainfall associated with these depressions is of considerable importance to agriculturists in north-west India, they do not in themselves present any particularly unintelligible feature which would require a special study. But there is an important type of weather phenomenon which appears in some way to be closely connected with these western depressions, namely, the series of dust or thunderstorms that occur in Northern India particularly in Bengal, Bihar, and the United Provinces during the transition seasons immediately before and after the proper winter months. These thunderstorms or 'norwesters' often occur well in front of an advancing western depression and in some parts of the country, especially in Bengal, cause violent squalls of a destructiveness, sometimes surpassing that of the severe cyclones of the Bay of Bengal. The origin and mode of occurrence of 'norwesters' have been investigated by V. V. Sohoni [1], S. N. Sen [2] and A. K. Das [3]. The effect of over-running of the damp and warm air mass over Bengal by potentially colder air above has been considered by Sohoni. The same process has been invoked by B. N. Desai [4] and by S. P. Venkateswaran [5] to explain the thunderstorms of Poona and the Peninsula. Sen however concludes from his studies on the norwesters of Bengal that these thunderstorms are caused by the undercutting of the warm moist air from the Bay by a colder and drier sample of air, which rushes down the river valleys from the eastern Himalayas. The propagation of norwester squalls has been compared by A. K. Das to the movement of cold waves in Europe and America. Assuming that the cold air moves as in W. Schmidt's laboratory experiments not as a thin-tripped wedge but as a more or less thick 'Squall-head', A. K. Das has theoretically calculated the squall-velocities for a large number of norwesters recorded at the Alipore Observatory. By this quantitative method he has shown for the first time that there is a good agreement between the theoretically calculated squall-velocities and the wind-velocities recorded by anemographs during the norwesters of Bengal; it has also been shown that the principal features of norwesters including the occasional formation of tornadoes in Bengal can be explained satisfactorily on the basis of this mechanism.

A detailed study of a few thunderstorms at Colaba led S. K. Banerji [6] to uphold the view first advanced by G. C. Simpson,

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1 V. V. Sohoni, *Ind. Met. Dept. Sc. Notes*, **4**, 19, 1931.
2 S. N. Sen, *Nature*, **127**, 128, 1931.
3 A. K. Das, *Gerl. Beitr. Z. Geoph.*, **39**, 144, 1933; *Current Science*, **1**, 386, 1933; *Ibid.*, **2**, 418, 1934.
4 B. N. Desai, *Ind. Met. Dept. Sc. Notes*, **3**, 89, 1931.
5 S. P. Venkateswaran, *Ind. Met. Dept. Sc. Notes*, **5**, 63, 1933.
6 S. K. Banerji, *Q.J.R. Met. Soc.*, **56**, 305, 1930; *Phil. Trans. Roy. Soc.*, **231**, 1, 1933.

viz., that the electricity in thunderstorms originates from the breaking of rain drops in clouds by ascending air.

(d) *Radiative and Convective processes in the Atmosphere.*

The problems of radiation and turbulence in the atmosphere have received a good deal of attention from meteorologists in India during the last few years, and a number of experimental as well as theoretical investigations have been carried out. In a suggestive paper K. R. Ramanathan[1] has examined the effect of radiation on the equilibrium of the higher layers of the troposphere by employing the method used by Simpson in his famous papers on Atmospheric Radiation. It is a well-known fact that the tropical tropopause is much higher and colder than the tropopause over the middle latitudes, but this fact has not yet received a thoroughly satisfactory explanation. Ramanathan has arrived at the conclusion that over the tropics there should be a region of active convection between about 8 and 12 km. and weaker convection for two or three km. further above, both during the day and the night. Now, since in the lower levels of the troposphere up to about 8 km. the potential temperature and the moisture content are higher over the tropical regions than over the temperate zones it follows that a larger quantity of moisture can be pushed up by convection to levels of lower temperature over the tropics and consequently the level of radiative equilibrium or the tropopause should be higher and colder over the tropical regions than over the temperate latitudes. Sobhag Mal, S. Basu and B. N. Desai[2] have studied the formation of inversions of lapse-rate in the Upper Atmosphere in anticyclonic weather due to radiation from humidity and haze boundaries.

Problems connected with heat (water-vapour) radiation from the night sky have received considerable attention from K. R. Ramanathan, L. A. Ramdas and their co-workers[3]. It is found that there is a decrease in the radiation during the night due to the fall of temperature in the lower layers of the atmosphere. Radiative equilibrium is attained with near layers for regions of the spectrum for which water-vapour has high absorption and with distant layers for regions of the spectrum with low absorption by water-vapour.

In a theoretical paper (1925) on the depth of Earthquake Foci, S. K. Banerji[4] pointed out for the first time that in the seismo-

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[1] K. R. Ramanathan, *Beitr. Z. Ph. fr. Atm.*, 18, 196, 1932.

[2] S. Mal, S. Basu and B. N. Desai, *Beitr. Z. Ph. fr. Atm.*, 20, 56, 1932.

[3] K. R. Ramanathan and L. A. Ramdas, *Proc. Ind. Acad. Sc.*, 1, 822, 1935; K. R. Ramanathan and B. N. Desai, *Gerl. Beitr. Z. Geoph.*, 35, 68, 1932; S. L. Malurkar, *Gerl. Beitr. Z. Geoph.*, 37, 410, 1932; P. K. Raman, *Proc. Ind. Acad. Sc.*, 1, 815, 1935.

[4] S. K. Banerji, *Phil. Mag.*, 49, 65, 1925.

grams of earthquakes with deep foci, the long waves would be inconspicuous.

The distribution of temperature in the lowest levels of the troposphere up to about 200 metres above ground has been examined by Barkat Ali [1], who has shown that in Northern India the vertical distribution of temperature as well as the structure of the wind is more or less in accord with G. I. Taylor and W. Schmidt's theories of turbulence in the atmosphere. Another problem usually not considered in theories of large-scale eddy motion has been studied both experimentally and theoretically by S. L. Malurkar and L. A. Ramdas [2], namely, the question of the vertical gradient of temperature in the layer of 10 or 15 cm. next to the ground heated by intense solar radiation in India. Malurkar and Ramdas have experimentally determined the temperature lapse-rate in the surface layer to be 1 or 2°C. per centimetre and have also given a mathematical explanation of the observed lapse-rates taking into consideration the balance between the heat received by conduction or convection process and the net loss of heat by radiation process. It is, however, extremely difficult to attain a satisfactory degree of accuracy in such measurements. L. A. Ramdas and Paranjpe [3] have attempted to obtain greater precision in the measurement of lapse-rate very close to a hot surface by the introduction of interferometric methods. Measurements of (*a*) the various factors controlling the disposal of the radiation from the sun and the sunlit sky by processes taking place near the surface of the ground, and (*b*) the factors concerned with the 'moisture balance' at the ground, have been made by Ramdas and co-workers.

Various other investigations dealing with other atmospheric problems some of which fall on the borderland of geophysics and astrophysics have been carried out by Indian meteorologists. Particularly noteworthy are the works of Simpson and S. K. Banerji [4] on atmospheric electricity and of S. K. Banerji [5] on the application of microseismic records to the determination of cyclone centres. Mention should be made also of the work of K. R. Ramanathan [6] on the observations of the spectrum of the night sky, of A. K. Das [7] on the theory of the emission of the forbidden OI lines by the night sky and of the cause of the high

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1 Barkat Ali, *Memoirs Ind. Met. Dept.*, **25**, 195, 1930; *Q.J.R. Met. Soc.*, **58**, 285, 1932.

2 S. L. Malurkar and L. A. Ramdas, *Ind. Jour. Phys.*, **6**, 495, 1932; Ramdas and Malurkar, *ibid.*, **7**, 1, 1932.

3 L. A. Ramdas and Paranjpe, *Current Science*, **4**, 642, 1936; M. K. Paranjpe, *Proc. Ind. Acad. Sc.*, **4**, 639, 1935.

4 S. K. Banerji, *vide* ref. 6 on p. 738.

5 S. K. Banerji, *Phil. Trans. Roy. Soc.*, **229**, 287, 1930.

6 K. R. Ramanathan, *Ind. Jour. Phys.*, **7**, 405, 1932.

7 A. K. Das, *Gerl. Beitr. Z. Geoph.*, **47**, 136, 1936; *ibid.*, **49**, 241, 1937.

temperature of the earth's outer atmosphere, of S. K. Pramanik [1] on Lunar atmospheric tides, of S. R. Savur [2] on some points in statistical theory and of J. M. Sil [3] on the measurement of the electric gradient in the atmosphere during dust storms at Poona. There is also the programme in agricultural meteorology recently begun by L. A. Ramdas [4] and his collaborators, who have already collected a substantial amount of meteorological data which should prove valuable for agriculture in India.

In concluding this brief review reference may be made to the important line of research on the ionosphere which is being conducted by S. K. Mitra at Calcutta and M. N. Saha at Allahabad. The recent observations on atmospherics and atmospheric electricity at Bangalore and the investigations in meteorological optics carried out by B. B. Ray [5] at Calcutta are also worthy of mention.

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[1] S. K. Pramanik, *Memoirs Ind. Met. Dept.*, **25**, 279, 1931; S. K. Pramanik, S. C. Chatterjee and P. P. Joshi, *Ind. Met. Dept. Sc. Notes*, **4**, 1, 1931.

[2] S. R. Savur, *Ind. Jour. Phys.*, **6**, 527, 1931; *Ind. Met. Dept. Sc. Notes*, **4**, 153, 1932; *Proc. Ind. Acad. Sc.*, **2**, 336, 1935.

[3] J. M. Sil, *Q.J.R. Met. Soc.*, **59**, 23, 1933.

[4] L. A. Ramdas, *Proc. Nat. Inst. India*, **2**, 131, 1936; Ramdas and Katti, *Ind. Jour. Agri. Sc.*, **4**, 923, 1934; Ramdas and Katti, *ibid.*, **6**, 1163, 1936.

[5] B. B. Ray, *Proc. Ind. Assoc. Cult. Sc.*, **8**, 23, 1923.