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Water consumption by dryland crops as related to pan evaporation

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सार — फसल की वृद्धि के विभिन्न चरणों पर जल की खपत को जानने के लिए विशेषकर सोरघम और मिलेट के लिए लिसजलमापी (लाइसीमीटर) आंकड़ों का विश्लेषण किया गया है। इन फसलों की जल की आवश्यकता का आकलन करने के लिए तत्काल संदर्भ के लिए पैन वाष्पन के साथ परिणामों की तुलना की गई है। अध्ययन से पता चलता है कि वृद्धि के विभिन्न चरणों में वास्तविक वाष्पन वाष्पोत्सर्जन और पैन-वाष्पन के अनुपात में सोरघम और मिलेट के लिए क्रमशः .49 से .71 और .56 से .72 तक परिवर्तनशील है। कुछ अलग-अलग सप्ताहों में ये अनुपात, विशेषकर प्रवर्धनशील अवस्था में एक से अधिक हो जाते हैं। सोरघम और मिलेट द्वारा अपने पूरे जीवन–काल में प्रयुक्त जल औसतन पैन वाष्पन का क्रमशः 61 और 66 प्रतिशत है।

ABSTRACT. Lysimeter data, especially for sorghum and millet have been analysed to know the water consumption at various growth phases. Results are compared with the pan evaporation for ready reference to estimate water requirement of these crops. The study reveals that the ratio of actual evapotranspiration and pan evaporation at different growth phases varies from .49 to .71 and from .56 to .72 for sorghum and millet respectively. These ratios in a few individual weeks, especially in the vegetative phase exceed one. Water used by sorghum and millet during the whole life span is, on an average, **61** and 66 per cent of pan evaporation respectively.

1. Introduction

Water is a limiting factor of agricultural production especially in the semi-arid tropics of the world. Water is lost from fields as transpiration through plants and as evaporation from the soil surface in between the plants. This combined loss is called evapotranspiration (ET). The amount of evapotranspiration loss for a given crop depends on climatic parameters such as radiation received, temperature, wind speed and vapour pressure deficits, type of soil and growth stage of the crop. Actual water loss from land surface is strongly influenced by the supply of moisture in the root zone (Denmead and Shaw 1962).

Many equations (Thornthwaite 1948; Penman 1956; Papadakis 1975; Doorenbos and Pruitt 1975; Kanemasu *et al* 1976; Mukammal and Neumann 1977) have been developed and used for various purposes. But these equations give the potential evapotranspiration rate. In natural environment crops are subjected to some moisture stress during their growing season. Therefore, the potential evapotranspiration is not a good estimate of actual water loss from natural vegetation or of the water which is utilised by a crop. Actual amount of water used by field crops at their various growth stages can only be known from direct measurement. Out of the known methods for measurement of evapotranspiration, use of lysimeter is the best and the most convenient for obtaining ET data on a day to day basis.

The aim of the present study is to find out the water used in the different phytophases by sorghum and millet crops grown in the various soil and climatic zones in the semi-arid tropics of India. The amount of water consumed has been compared with the pan evaporation (EP) so that a ready reference is available for selecting suitable amounts of water for irrigation scheduling and land use planning.

2. Description of lysimeter

Different lysimeters are used to know the amount of water used by crops at various phenophases. India Meteorological Department installed 35 lysimeters in different soil and climatic zones of India of which 29 are of gravimetric type. The gravimetric lysimeter consists of a sensitive dormant type weighing machine of two tonne capacity. It is errected in the middle of field on a reinforced concrete foundation constructed inside a pit of size about 3.5 m × 3.5 m × 2 m when in position the platform of the weighing machine will be at depth of about one metre from the soil surface. A steel tank of size 1.3 m × 1.3 m × 0.9 m in which the plants are grown is mounted on the platform of the machine such that its rim is in level with the surrounding soil surface.

TABLE 1

Ratio of AET/EP at various growth phases of sorghum

Station	Year	Variety	Date of Sowing	Date of Harvest	Duration (days)	Ratio of AET/EP Germination	Elongation	Flowering	Maturity	Life span	Grain yield (q/ha)
Solapur	78-79	M-35-1	8 Sep 78	18 Jan 79	132	.45	.88	.94	.34	.68	24.70
	79-80	M-35-80	7 Sep 79	25 Jan 80	140	.43	.47	.82	.65	.58	18.10
Rahuri	80-81	CSR-8	10 Oct 80	15 Feb 81	128	.29	.77	.88	.53	.65	37.34
Bellary	75-76	B-16	6 Sep 75	8 Jan 76	124	.47	.76	.60	.26	.56	15.45
	78-79	SPV-86	23 Sep 78	22 Jan 79	121	.47	.37	.53	.27	.50	13.81
	79-80	CHS-5	11 Nov 79	10 Mar 80	119	.49	.90	.93	.47	.67	26.84
	81-82	SVP-86	7 Sep 81	27 Jan 82	142	.49	.65	.77	.25	.56	25.00
Mean					128	.44	.68	.78	.38	.61	23.03

The steel tank carried a perforated plate at a depth of 75 cm so as to form a hollow chamber at the bottom. A tube inserted through the perforated sheet into the bottom of the hollow chamber facilitates the removal of percolated water. A tap is also fitted to drain out the percolated water from the chamber. The soil is back filled in the steel tank to simulate the natural soil profile. Weighing machine can be read correctly to 200 gm. The weight can be estimated up to 100 gm and the accuracy is 0.12 mm of water.

3. Data

Rabi (dry) sorghum is sown in the middle of the monsoon season and maintained on stored moisture. Lysimeter data of rabi sorghum are available for 3 stations, *viz.*, Solapur for two years, Rahuri for one year and Bellary for four years. millet is mostly grown on monsoon rainfall. Data of millet are available for four stations, *viz.*, Bellary for three years, Jodhpur for one year, Rajkot for two years and Kovilpatti for two years. Daily ET data collected have been converted to weekly form. Pan evaporation and other meteorological parameters have been collected from the observatory located nearby. Crop data are easily available from field observations.

4. Some characteristics of sorghum and millet

The ability of sorghum and millet to produce good yields under conditions of low soil moisture and high temperature that are unsuitable for any other grain crops, make them the 'Camel' of the plant world. Complete failures due to limited rainfall are much less frequent for sorghum and millet than any other crop. Quinby *et al.* (1958) observed that minimum temperature for sorghum is 8°-12° C for germination, about 15°C for growth and optimum air temperature for growth is 25°-30° C. Sorghum and millet are better than most of the grain crops to withstand high temperature, but yields are adversely affected when mean temperature exceeds 26°C during heading period (Karper *et al.* 1931).

Sorghum are well adopted to semi-arid tropics with minimum average precipitation as 350-600 mm. Their main importance as a crop has been in areas that are too hot and dry for growing maize. Sorghum, however, is also very productive under irrigation. Most of the varieties of millets produce reasonably well on poor sandy soils on which most of other crops even sorghum fail. Millets require well aerated soil and they are not adopted to heavy soil (Marchal 1950). Pearl millet is capable of producing reasonable grain with less moisture than sorghum. With certain early maturing varieties yields have been obtained with 200 mm of moisture during growing period (Cocheme and Franquin 1967).

The drought resistance of sorghum is due to extensive root system and profusion of rootlets as well as morphological characteristics of its leaves and stalks which effectively reduce transpiration with onset of the water stress. Sorghum and millet show the lowest rate of decline in relative turbidity and the least diurnal depression as compared with the other crops because they reduce the transpiration rate to a much greater extent than did other crops (Slatyer 1956). ET reduction incurred some yield reduction (Dennis *et al.* 1982).

All types of pearl millet can endure drought period two to four weeks but water stress during ear emergence has disastrous effect on yield (Cocheme and Franquin 1967). Heavy rainfall during the flowering period

TABLE 2

Ratio of AET/EP at various growth phases of millet

Station	Year	Variety	Date of Sowing	Date of Harvest	Duration (days)	Ratio AET/EP Germination	Elongation	Flowering	Maturity	Life span	Grain yield (q/ha)
Bellary	1979	BJ-104	16 Jul 79	29 Sep 79	75	.34	.47	.73	1.14	.70	37.5
	1980	BJ-104	17 Jul 80	25 Sep 80	70	.37	.46	.79	.69	.58	41.9
	1981	BJ-104	17 Jul 81	27 Sep 81	72	.29	.48	.87	1.00	.69	36.5
Jodhpur	1977	BJ-104	9 Jul 77	30 Sep 77	83	.63	.59	.84	.47	.66	27.7
Rajkot	1978	BJ-104	24 Jun 78	12 Sep 78	81	.39	.78	.83	.79	.72	14.5
	1980	BJ-104	26 Jun 80	29 Sep 80	97	.53	.69	1.18	.40	.69	23.3
Kovilpatti	78-79	Kg	1 Nov 78	10 Feb 79	102	.40	.78	.65	.41	.56	10.8
Mean					83	.42	.59	.84	.70	.66	27.5

interferes with fertilization and causes reduced yield (Catherint *et al.* 1963). Although markedly drought resistant, sorghum can stand considerable water logging. In parts of Sudan, in the early stage of growth, sorghum is frequently flooded for long period, yet it is capable of surviving and producing a satisfactory yield (Tarr 1962).

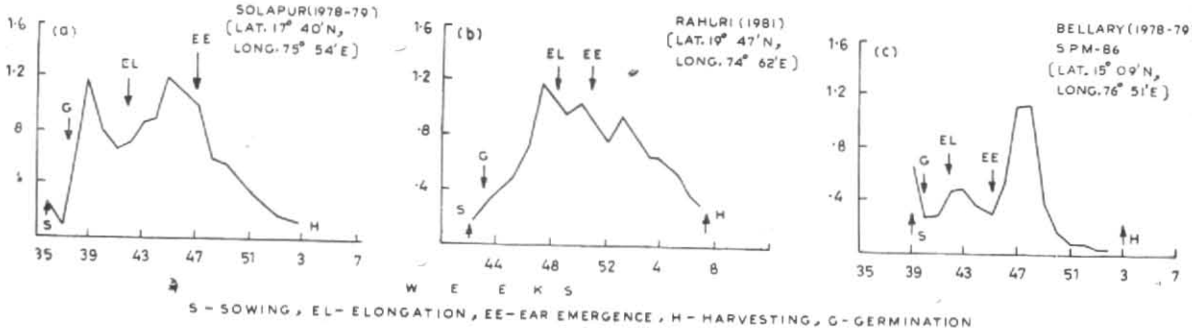
5. Discussion

Sorghum and millet are considered drought tolerant and able to give good yield under dryland condition. Yield of these crops increases significantly on supplimental irrigation. The life cycle of sorghum and millet may be divided into four stages, *i.e.*, germination, elongation, ear emergence/flowering and maturity. Tables 1 and 2 give the ratio of the actual evapotranspiration (AET) and pan evaporation (EP) by sorghum and millet respectively at their different growth phases. During the early stage of the crop cycle, the ratio is very low. Greater part of the water loss in the young stage of the crop is by evaporation from bare soil. In absence of rain or irrigation, evaporation rate is quickly reduced by the formation on a surface mulch of dry soil. Thus, when the crop is young the ratio will vary according to the frequency of rainfall and irrigation. This picture is also reflected at the ripening stage of the crop.

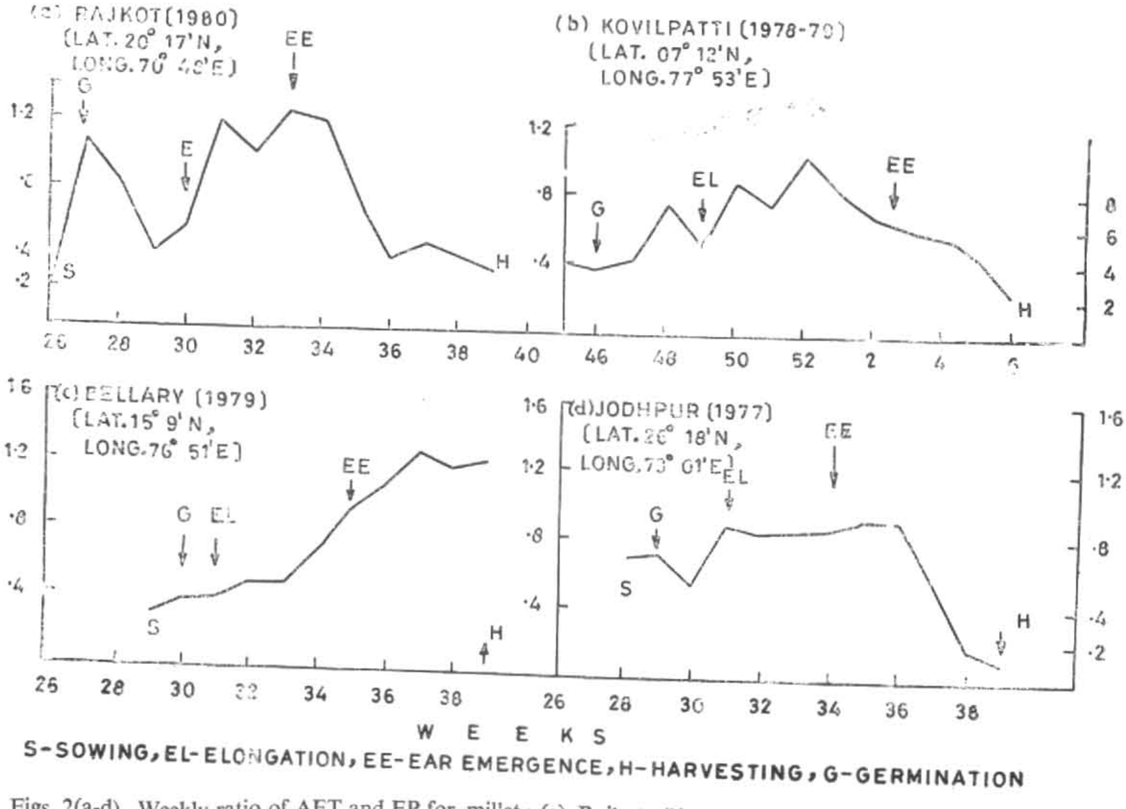
5.1. *Water used at different growth stages*

Ratio of evapotranspiration and pan evaporation varies from crop to crop and also changes during the different growth stages of the same crop. This ratio in the early stage was found to be .30 by Doss *et al.* (1964) for sorghum, .26 by Kanemasu *et al.* (1976) for Soyabean, .20 by Stanthill (1957) for cotton and .40 by Chang (1961) in the sugarcane field. Minimum ratio .35 in the vegetative stage for pineapple was reported by Ekern (1965).

Tables 1 and 2 give the date of sowing, date of harvest, ratios of AET and EP during different growth stages as well as during the whole life span, and also yield of sorghum and millet crops respectively. Table 1 shows that the ratio AET/EP of sorghum in the germination phase varies from .29 at Rahuri to .49 at Bellary and average value is .44. The highest ratio .94 among these four stages is observed in the flowering stage at Solapur in 1978-79. These ratios during the elongation & maturing stages vary from .37 to .90 and from .25 to .65 respectively. The highest average ratio .78 is observed in the flowering phase. It seems sorghum needs more water in this stage. Values of AET/EP during the whole life span ranges from .50 to .68 with an average .61. Yield of this crop in different years varies from 13.81 to 37.34 q/ha. Three varieties of hybrid sorghum, *viz.*, B-16, SPV-86 and CHS-5 were grown at Bellary of which SPV-86 was used two years. In 1978-79, SPV-86 gave the lowest yield 13.8 q/ha and water used was shown also the least and in 1981-82 it recorded good yield 25.00 q/ha with ratio of AET/EP for whole life span .56. Although generalization of water used is very difficult with this scanty data, it seems that SPV-86 can give better yield under water stress condition. These ratios seems to be corroborated with the findings of Eagleman (1967) who examined the water consumption of various crops grown in USA. His findings vary from .52 to .83 with an



Figs. 1(a-c). Weekly ratio of AET and EP for sorghum : (a) Solapur, (b) Rohuri and (c) Bellary



Figs. 2(a-d). Weekly ratio of AET and EP for millet : (a) Rajkot, (b) Kovilpatti, (c) Bellary and (d) Jodhpur average .72 for all the crops. Jenson (1968) observed that the cumulative seasonal evapotranspiration for grain sorghum even in relatively favourable moisture condition was found only 65% of potential evapotranspiration. Table 2 gives the similar values for millet. In the germination stage values of AET/EP range from .29 to .63 with an average value .42. The highest average ratio .84 was observed during flowering stage. It appears that both the crops require more water in the flowering stage. During the ripening stage these ratios were found varying from .40 to 1.14 with an average value 0.70 which is much higher than that of sorghum .38. The ratio for the whole life span of millet ranges from .56 to .72. Dancette (1978) also found that it varies from .63 to .77 for Senegal (Africa). The average value .66 of all the years is also higher that of sorghum .61. Data of three years of variety BJ 104 grown at Bellary are available of which the highest yield was recorded in 1980 when the crop used minimum water among these three years (Table 2). Ratio of AET/EP was found more than one at the maturity stage in 1979 and 1981 because of copious rainfall. Unlike rice and other dryland crops millet can use more water than pan evaporation at maturity stage if supply is unlimited, because leaves and stalks remain green at this stage. The yield of millet ranges from 10.8 to 41.9 q/ha with an average value 27.5 which is also higher than that of sorghum 23.0. Duration of sorghum on an average is 128 days against for millet 83 days. It is evident from the literature already cited that millet requires less water than that of sorghum, but the present analysis indicates that the water consumption by millet is more than that of sorghum. This may be due to the fact that millet received adequate soil water at the root zone.

Figs. 1 (a) to 1(c) give the water consumption curves at three different stations during the life span of sorghum crop. Fig. 1(a) depicts the week by week AET/EP for Solapur. At the beginning this ratio was less than .35 and gradually increased. During the elongation and flowering phases the crops used adequate moisture which is about 90% of pan evaporation. At the maturity stage water consumption is about one-third of pan evaporation. Yield of crop is good (24.7 q/ha). It seems that the crop did not encounter water stress in the critical stages.

Fig. 1(b) gives the similar figure for Rahuri. In this station ratio of AET/EP during germination was only .29. It did not affect the germination. It seems that germination will not be affected if the crop gets water 25 to 30 per cent of pan evaporation. Similar result was also reported by Doss *et al.* (1964). During the other periods availability of moisture was adequate and yield was quite high.

In the year 1978-79 (Fig. 1c) Bellary experienced severe water stress. At the germination phase the ratio of AET/EP was .47 which incidates good germination but this ratio was found only .37 during elongation phase. The crop passed under severe water stress condition. Due to good rain during flowering phase this ratio becomes more than one and in the maturity stage it again encountered severe water stress. Yield of the crop is only 13.8 q/ha. It seems that there would have been hardly any yield without one week good rainfall at the beginning of flowering phase. It appears that water availability just before flowering plays a very significant role for yield.

Figs. 2(a) to 2(d) give the water use efficiency curves of millet for four stations. It is evident from Fig. 2(a) (Rajkot) that water availability was very good except two weeks during elongation period. Yield was quite high 23.3 q/ha. Evapotranspiration rate was more than pan evaporation at least four weeks at this station. It seems that yield of the sorghum is not affected much due to moderate to severe water stress period for one or two weeks.

Fig. 2(b) shows the week by week ratio for millet crop at Kovilpatti. It appears from the curve that the crop hardly suffered from severe water stress at any time during the growing period although yield is very low, *viz.*, 10.8 q/ha. As variety is a traditional one, its, yield is always low.

Fig. 2(c) gives the week by week water use efficiency at Bellary. The ratios of AET/EP were found .34 and .47 during germination and elongation period. Water used by the crop during the maturity phase was about 114 per cent of pan evaporation due to copious rainfall at that stage. Yield is very high 37.5 q/ha. It seems that germination may not be affected if the crop gets water about 30% of pan evaporation.

Fig. 2(d) depicts the water use efficiency curve of Jodhpur, a station in the arid zone. Distribution of rain at this station during the growing period was good and the crop consumed water about 66% of pan evaporation. The ratio of AET/EP did not exceed 0.8 at any time of the growing period but yield was quite good 27.7 q/ha.

6. Conclusion

This investigation has brought out many interesting features regarding water use efficiency of sorghum and millet grown in the dryland tract which are as follows :

(*i*) During the whole life span water consumption by sorghum and millet was found 61 and 66 per cent of pan evaporation respectively.

(*ii*) Germination of sorghum and millet crop may not be affected if these crops get water 25-30 per cent of pan evaporation.

(*iii*) These crops require maximum water at the flowering stage. The study indicates that 70-75 per cent of pan evaporation may be adequate for proper growth and development at this stage.

(*iv*) It appears that the yield of these crops may not be affected much due to one to two weeks severe water stress condition.

(*v*) These crops need water normally 30-35 per cent of pan evaporation during the maturity stage, but can use water more than pan evaporation at this stage if sufficient soil moisture is available at the root zone.

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References

Catherint, M.D., Dumont, S.P. and Mayaka, A.A., 1963, Le nil et sorgho dans 1 agriculture due Ninger, *Agron. Trop.*, **18** (1). pp. 1-18.

Chang, Jen Ju, 1961, '*Micro climate of Sugarcane*', Hawaian Bahters Record, 56, pp. 195-223.

Cocheme, J. and Franquin, P., 1967, 'An agroclimatology survey of a semi-arid area in Africa south of Sahara', Tech. Note No. 86, 136 pp.

Dancette, C., 1978, 'Water requirements and adaptations to the rainy season of Millet in Senegal'. Proc. Agroclima. Res. Needs of the Semi-arid Tropics, ICRISAT, India.

Denmead, O.T. and Shaw, R.H., 1962, 'Availability of soil moisture content and meteorological conditions', *Agron. J.*, **45**, pp. 385-390.

Dennis, P., Garrity. Darrell, G. Watts, Charles Y., Sullivan and James. R. Gilley, 1982, 'Moisture Deficits and Grain Sorghum, Performance in Evapotranspiration Yield Relationships', *Agron. J.*, **74** (5).

Doorenbos, J. and Pruitt, W.O., 1975, 'Crop water re quirements'. Irrigation and Drainage Paper 75, FAO, Rome.

Doss, B.D., Bennett, O. L. and Ashley, D.A., 1964, 'Moisture used by forage species as related to pan evaporation and net radiation', *Soil science*, **98**, pp. 322-327.

Eagleman, 1967, 'Pan evaporation, potential and actual evapotranspiration', *J. appl. Met.*, **6**, No. 3.

Ekern, P.C. 1965, 'Evapotranspiration of Pineapple in Hawaii, *Plant Physiology*, **40**, pp. 736-739.

Jensen, M.E., 1968, '*Water consumption by agricu ltural plants in water Deficit and Plant Growth*', Vol. II, Kozlowske, T.T. (ed.) Academic Press, New York, pp. 1-22.

Kanemasu, E.T., Stone, L.R. and Powers, W.L., 1976, 'Evapotranspiration model tested for Soyabean and Sorghum, *Agron. J.*, **68**, pp. 569-572.

Karper, R.E., Quinby, J.R. and Jones, D.L., 1931, 'Grain Sorghum date of planting and spacing experiments', *Bull. Tex. Agric. Exp. Stn.*, 424, 71 pp.

Marchal, A., 1950, 'Less penicillaires cultives au Nigar, *Agron. Trop.*, 582-592.

Mukammal, E.I. and Neumann, H.H., 1977, 'Application of the Priestley-Taylor evaporation model to assess the influence of soil moisture on the evaporation from a large weighing lysimeter and class A pan, *Boundary Layer Met.* **12**, pp. 241-256.

Papadakis, J., 1975, *Climates of the world and their agricultural potentialities*, Buenos Aires, Argentina.

Penman, H.L., 1956, 'Estimating evaporation', *Trans. Am. geophys. Un.*, **37**, pp. 43-50.

Quinby, J.R., Kramer, N.W., Stephens, J.C., Lahar, K.A. and Karper, R.E., 1958, 'Grain Sorghum Production in Texas', *Bull. Tex. Agri. Exp. Stn.*, 912, 35 pp.

Slatyer, R.O., 1956, 'Absorption of water from atmosphere of different humidity and its transport through plants', *Agri. J. Biol. Sci.*, **9**, pp. 532-558.

Stanthill, G., 1957, 'The effect of differences in soil moisture structure on plant growth', *Soil Science*, **61**, pp. 205-219.

Tarr, S.A.J., 1962, 'Diseases of Sorghum Sudan Grass and Broom Corn', Tech. Commission Mycol. Inst. Kow 605.

Thornthwaite, C.W., 1948, 'An approach towards a rational classification of climate', *Geogra. Rev.*, **38**, pp. 55-94.