AGROMETEOROLOGY OF FINGER MILLET IN KARNATAKA STATE OF INDIA

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AICRP ON AGROMETEOROLOGY
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University of Agricultural Sciences, GKVK,
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2015

Traditional 'Akkadi' system of South Karnataka: A wiser choice for abnormalities in South-West monsoon; a lesson that farmers learnt the hard way. Finger millet mixed with nine field crops of domestic requirement [*Navadhanya* crops *viz*., fodder jowar, field bean (green pods as vegetable), mustard (spice), horsegram (poorman's meat), niger (poorman's ghee), creeper cowpea / cucumber (as vegetable), castor (hair oil), grain amaranthus (both as green leafy vegetable and nutri-rich grain for blending with ragi flour) and/or bajra]

An improvement over ‘Akkadi system’: Finger millet and redgram intercropping (8:2 rows). It is an innovative intercropping system to buffer the adverse effect of abnormal monsoon

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Foreword

Millets serve the dual purpose of meeting food and nutrition as well as fodder security. The socio-economic and cultural aspects of cultivation of climate smart small millets such as finger millet, foxtail millet, kodo millet, proso millet, little millet, pearl millet and barnyard millet is that they not only require low water but also have nutrition levels much higher than rice or wheat and thus the name 'nutri-millets' . Among these, finger millet is the only popular small millet even today in rainfed Alfisols due to its high yield against low water requirement and coping mechanism in the wake of climate change .

The major states growing finger millet in the order are Karnataka, Maharashtra, Utharakhand, Tamil Nadu and Andhra Pradesh. Karnataka ranks first with total area of around 12 lakh hectares with a production of about 20 lakh tonnes and productivity of 1673 kgs/ha accounting to more than 40 per cent of its total dryland area and 50 per cent of the production in the country.

It is observed that the area under finger millet crop is reducing since 1980's and the production has stagnated at around 20 lakh tonnes since the year 2000. Keeping in mind the population explosion and the demand to meet the requirement it is very much essential to increase the total production to 30 lakh tonnes by another 10 years. In order to achieve this targeted production, the productivity has to be increased from 1673 kgs/ha to 2500 kgs/ha through improved varieties, cultivation practices and weather based management practices.

The technical bulletin **"Agrometeorology of Finger Millet in Karnataka State of India"** is a compilation of crop-weather relationship of finger millet and the practical component of its utility in giving advisory and crop insurance. The information in the book is of immense value to plan the best agronomic climate smart practices for improved water use efficiency and productivity.

The publication will serve as a reference material to the scientists, extension personnel, policy makers and the farmers. I congratulate the authors in bringing out this bulletin.

Bengaluru
November, 2015

(**H. Shivanna**)
Vice-Chancellor

Preface

The Bangalore centre of All India Coordinated Research Project on Agrometeorology (AICRPAM), came into existence during 1983 under the University of Agricultural Sciences, Bangalore (UAS-B) . It is conducting research on crop-weather relationship linked to rainfed agriculture particularly in Alfisols of Karnataka. As part of the documentation and publication mandate, a technical bulletin entitled **"Agrometeorology of Finger Millet in Karnataka State of India"** has been brought out. It is an exhaustive compilation of three decades research data and analysis on crop-weather relationship and its interpretation leading to operational agrometeorology.

We have presented the association of weather parameters on growth and yield of finger millet and developed yield prediction/simulation models. A separate chapter on operational agrometeorology has been brought out in the book involving finger millet based agro advisory services (AAS), crop insurance, crop weather calendar, contingent crop planning and weather criteria for pests and disease incidence.

The authors express their gratitude to Dr.H. Shivanna, the Vice-Chancellor, Dr. M.A. Shankar, Former Director of Research, Dr. K.P. Viswanath, Director of Research and Dr.D. Nuthan, Associate Director of Research for their guidance and constant encouragement in bringing out this document. We are indeed grateful to the AICRPAM headquarters' team of CRIDA, Hyderabad for correcting the manuscript and their valuable suggestions. We also acknowledge the support and the help of the staff of our department in bringing out of this book.

Bengaluru
November, 2015

(Authors)

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Finger millet (*Eleusine coracana* Gaertn.) commonly known as 'ragi' or madua, is one of the important minor millets and staple food crops, largely grown in southern states of India. It is indispensable to Indian agriculture as a source of grain and straw in a vast dry land tracts of southern India. In the low rainfall region, where crops are frequently affected by drought, finger millet is the best choice.

a. Origin and History

The literature and cytological evidences suggests that finger millet was originated in Ethiopian highlands and introduced to India 3000 years back. African native *Eleusine africana* (2n=36) has more resemblance with cultivated *Eleusine coracana* (tetraploid 2n=36) than Indian local grass *Eleusine indica* (2n=18). The cultivated race *Eleusine coracana* was developed from African lowland race, which was transformed from African highland race. This explains why present varieties of finger millet are successfully grown in plains as well as in hilly regions of India. The high yielding varieties of ragi were evolved by crossing cultivated Indian race *Eleusine coracana* and African race *Eleusine africana* (called Indaf varieties in Karnataka).

b. Adaptability

Finger millet is well adapted to regions of low to medium rainfall and marginal soils also. Attributes like low water requirement, capability to withstand higher temperature and long dry spells make finger millet an attractive choice for marginal semi-arid lands. Due to its greater tolerance, better compatibility for different cropping systems and contingent crop plans, it is cultivated on varied soil and climatic conditions compared to other cereals.

c. Climatic and Soil Requirements

The crop is grown in both tropical and subtropical regions. It can be grown successfully, from sea level to an altitude of 1800 meters and on hill slopes as well as in plains, but preferred altitude range for finger millet is between 1000 and 1800 MSL. It is very hardy crop and can be grown in areas having annual rainfall between 500 to 1000 mm. In regions of higher rainfall, it can be raised on well drained soils as a transplanted crop. It can be grown under rainfed as well as irrigated conditions. It prefers porous and well drained soils particularly alfisols. Deep vertisols and rocky soils are not suitable for this crop owing to poor drainage. It can be grown in soils with a pH of 5.5 to 7.5.

d. Varieties Recommended

About 14 varieties have been recommended for cultivation in Karnataka state, however about 25 varieties are existing in the state. The optimum sowing period is from July to August for drill sowing and for transplantation it may be extended up to September month depending upon the rainfall situations. The optimum growing period is from July to October months. The list of suitable varieties is mentioned in Annexure.

e. Nutritional Value

Finger millet is commonly called as "Nutri-grain" as the grains are nutritionally superior to many other cereals. It is especially valuable as it contains the amino acid methionine, which is lacking in the diets of hundreds of millions of the poor who live on starchy staples such as cassava, plantain, polished rice, or maize meal. It is the cheapest and preferred food of economically weaker and physically hard working people. It is appreciated by the people since it can digest slowly thereby furnish energy for hard work throughout the day. Finger millet besides meeting the nutrition requirement of mankind supplies quality straw for the cattle. The protein of finger millet has been reported to possess a fairly high biological value, which is needed for the maintenance of nitrogen equilibrium of the body. The higher fiber content of finger millet helps in many ways as it prevents constipation, high cholesterol formation and intestinal cancer. Hence, people suffering from diabetes are advised to eat finger millet and other small millets instead of rice.

On an average, finger millet seeds contain following ingredients in 100g dry weight:

- Protein = 7.3 g
- Fat = 1.3 g
- Carbohydrate = 72 g
- Minerals = 2.7 g
- Calcium = 344 mg
- Fiber = 3.6 g
- Energy = 328 K Cal

f. Production of Finger Millet in India

Finger millet is an important cereal crop of the southern India and gaining importance in other parts of the country. Major finger millet growing states in decreasing order of acreage are Karnataka, Maharashtra, Uttarakhand, Tamil Nadu and Andhra Pradesh. Karnataka ranks first with more than 40 per cent of its total dry-land area under finger millet cultivation, accounting for more than 50 per cent production in the country. Area, production and productivity of finger millet over the period of 1951 to 2015 are grouped into pentads and the same is presented in Table 1.1. The area under finger millet has declined in the recent years by about 10-20% due to urbanization, poor profitability of the crop and increased cost of cultivation.

g. Production of Finger Millet in Karnataka

Karnataka occupies a premier position in area, production and productivity of finger millet crop. Mean area, production and productivity of finger millet over different five yearly periods from 1956 to 2015 is presented in table 1.2. The finger millet production has shown steady increase from 7.8 lakh tones in 1956-60 to 18.6 lakh tones during 2006-10 with an increase of more than 138 per cent. However, production during the period of 2010-15 reduced to 12.34 lakh tonnes due to decrease in acreage. The productivity has increased from 796 kg/ha during 1956-60 to 1855 kg/ha during 2010-15. The growth rate of production and productivity was more or less same till 1980's, but during late 80's there was a drastic improvement in the yield (Anon.2012). Area under finger millet in Karnataka was 9.8 lakh hectares during the period 1956-60 and recently it has reduced to 6.9 lakh hectares.

h. Production Constraints

Because of population explosion and food demand, it is very much essential to increase the total production to 25-30 lakh tones in next 10 years. In order to achieve this targeted production, the productivity has to be increased from present level of 1673 kg/ha to the target level (2500 kg/ha). Weather based management practices are to be adopted for sustaining the productivity of finger millet.

Experiments conducted at research stations have indicated that the productivity can be enhanced up to 3500 kg/ha under normal package of practices with proper crop management. The optimum climatic factors at different growth stages have also been identified to produce the potential grain yield. Still there is vast untapped potential of the crop that needs research attention by the researchers. Production gaps exist between yields realized at various levels in both rainfed and irrigated situations between experimental plots and the farmer's fields on one hand and large scale frontline demonstration plots on the other hand. Research gaps, extension gaps and adoption gaps in rainfed finger millet crop and the strategies to improve the yield with reference to each category of gap are described as under.

- **Weather:** Finger millet requires about 325 mm of water to complete its life cycle. In rainfed agriculture, the distribution of rainfall is so erratic that 325 mm of rain water is not available uniformly to crop during its 120 – 130 days growing period. Intermittent medium to long dry spell caused inadequate rain water availability to meet minimum crop water requirement for comfortable growth.

- **Non availability of quality seeds to suit the vagaries of rainfall:** Due to erratic rainfall, varieties and seeds suitable for early or late sowing are not available at right time. This forces the farmers to take up sowing with available variety irrespective of sowing time.
- **Non existence of varieties with high seed yield and multiple disease resistance:** Of the several diseases, blast disease (*Pyricularia grisea*) is widely distributed in almost all the finger millet growing regions of the world and it is the most destructive disease. In India, blast is one of the major disease causing recurring yield losses in all the states.
- **Poor mechanization (Non-availability of harvester and seed drills for intercropping):** Due to non availability of seed drills for simultaneous sowing of finger millet and inter crops like redgram (paired rows), dolichos etc., row proportions are not maintained. Due to dependence on human labor, harvesting is delayed leading to pre and post-harvest yield losses.
- **Non adoption of weather based crop sowing activities:** Due to non-adoption of timely weather based sowing of finger millet, failure of the crop was noticed.

i. Strategies for Improving Finger Millet Productivity

- **Development of multiple disease resistant varieties and supply of quality seeds:** Need to develop and evolve varieties resistant to leaf blast, neck blast etc., in addition to existing popular variety GPU-28. Farmers are to be encouraged to produce their own seeds through seed village concepts/ participatory approach without much dependence on seed production agencies.
- **Integrated nutrient management:** Seed treatment with *Azospirillum* and application of recommended organic manure (7.5 t/ha) and 50:40:25 NPK kg/ha along with zinc sulphate as per schedule will enhance the productivity.
- **Mechanization:** Development and evaluation of suitable seed cum fertilizer drill for sowing inter crops (finger millet + pigeon pea (8:2), finger millet + dolichos (2:1)). Due to scarcity of required labourers for harvesting, suitable mechanized harvester is required. The existing reapers have limitation with regard to their movement in small sized plots. Hence, development of efficient harvester is required.
- **Agromet advisories:** Regular agromet advisories helps farmers to undertake appropriate agricultural practices. Transfer of technology to the farmers field leads to the reduction in yield gap between the experimental plots and farmers field.

Table1.1: Area, production and productivity of finger millet (1951-2015) in the country

Year	Area ('000 ha)	Production ('000t)	Productivity (kg/ha)
1951-55	2246	1520	678
1956-60	2414	1874	778
1961-65	2519	1991	791
1966-70	2465	1721	703
1971-75	2409	1975	820
1976-80	2609	2726	1042
1981-85	2499	2593	1036
1986-90	2346	2544	1084
1991-95	2015	2542	1267
1996-00	1826	2586	1420
2001-05	1630	2098	1276
2006-10	1300	1944	1490
2010-15	1231	2061	1673

Source: All India Coordinated Small Millets Improvement Project, UAS, GKVK, Bangalore

Table 1.2: Mean area, production and productivity of finger millet (1956-2015) in Karnataka state

Year	Area ('000 ha)	Production ('000tons)	Productivity (kg/ha)
1956-60	987	785	796
1961-65	1107	754	681
1966-70	1056	678	642
1971-75	1041	970	932
1976-80	1086	1316	1212
1981-85	1098	1231	1122
1986-90	1132	1200	1060
1991-95	1010	1484	1470
1996-00	1013	1586	1566
2001-02	1070	2024	1892
2006-10	988	1859	1882
2010-15	697	1234	1855

Source: Department of Economic and Statistics, MS Building, GOK, Bangalore.

II Crop-Weather-Soil Relationships

Finger millet is an important crop over centuries, but more concentrated research efforts have been geared up in recent years to evolve improved varieties and develop production technology. However, some research studies on finger millet have been conducted between year 1991 to 2001 at Zonal Agricultural Research Station Centre, GKVK, Bengaluru to study the climatic effect on crop growth and productivity and also to develop the crop weather relationship under rainfed conditions. This chapter explains the research activities conducted and some important observations on the biomass accumulated over different stages of crop and at different sowing dates over different years (1991-2001) presented in Table 2.1. Studies indicated that the finger millet sown in the month of July between 15th to 30th has recorded significantly higher accumulated biomass compared to the crop sown in the month of August between 1st day to 30th day.

a. Biomass

Table 2.1: **Mean LAI and biomass accumulated over different stages of crop and at different sowing windows over different years (1991-2001)**

Date of Sowing-I: July

Stages	Partition of biomass (g/m^2)					
	LAI	**Roots**	**Stem**	**Leaf**	**Earhead**	**Total**
Sowing	-	-	-	-	-	-
Beginning of tiller	1.70	88.37	150.55	98.44	-	339.06
Ear emergence	4.03	174.05	341.80	235.79	32.72	788.39
50% Flowering	4.27	244.21	401.13	242.13	119.44	1011.19
Grain formation	4.23	233.04	566.49	280.95	467.80	1552.50
Harvest	**-**	**193.29**	**658.43**	**331.63**	**933.47**	**2116.82**

Date of Sowing –II: August

Stages	Partition of biomass (g/m^2)					
	LAI	**Roots**	**Stem**	**Leaf**	**Earhead**	**Total**
Sowing	-	-	-	-	-	-
Beginning of tiller	1.83	68.59	127.22	98.81	-	296.45
Ear emergence	4.24	204.07	380.59	255.83	47.09	891.80
50% Flowering	4.35	202.27	503.94	272.67	126.71	1109.94
Grain formation	3.64	181.32	573.61	249.75	419.32	1427.64
Harvest	-	**162.40**	**578.85**	**328.02**	**805.28**	**1874.54**

b. Water Balance Studies for Better Management of Finger Millet

In view of realizing the water requirement by finger millet, using the Climatic Water Balance Model, day wise water balance has been worked out for the three dates of sowings for the given soil, crop and rainfall situation. Model describes the actual amount of water available to the crop during its crop growth, water storage and runoff water. Sowing window and growing period could be decided using such information i.e., based on the long term rainfall probability analysis and water balance studies based on FAO approach (Higgins and Kassam, 1981). It is observed that the period from July 15th to November 15th is the optimum crop growing period [Figure 2.1] in the zone. The water balance generated by averaging the daily rainfall, AETo, AET for both dates of sowings is tabulated in the Table 2.2.

Table 2.2: **Water balance for different varieties and sowing windows**

Sowing Window: July

Variety: INDAF -8

Phenological stages	No. of days	Rainfall (mm)	Water required(mm)	Water used
Sowing	-	-	-	-
Tillering	36	153.6	56.7	56.7
Ear emergence	46	403.5	158.0	158.0
50% flowering	8	29.8	61.8	61.8
Grain formation	21	41.0	59.5	59.5
Harvest	17	219.3	27.5	27.5
Total	**128**	**847.2**	**363.5**	**363.5**

Variety: GPU-28

Phenological stages	No. of days	Rainfall (mm)	Water required(mm)	Water used
Sowing	-	-	-	-
Tillering	36	153.6	56.7	56.7
Ear emergence	35	336.3	113.0	113.0
50% flowering	8	63.7	30.9	30.9
Grain formation	14	74.6	43.4	43.4
Harvest	25	184.6	73.0	73.0
Total	**118**	**812.8**	**317**	**317**

Variety: GPU-26

Phenological stages	No. of days	Rainfall (mm)	Water required(mm)	Water used
Sowing	-	-	-	-
Tillering	36	153.6	56.7	56.7
Ear emergence	32	315.7	106.4	106.4
50% flowering	7	36.8	25.5	25.5
Grain formation	11	54.8	39.8	39.8
Harvest	18	100.4	51.5	51.5
Total	**104**	**661.3**	**279.9**	**279.9**

Sowing Window: August

Variety: INDAF-8

Phenological stages	No. of days	Rainfall (mm)	Water required(mm)	Water used
Sowing	-	-	-	-
Tillering	41	107.5	75.3	75.3
Ear emergence	26	353.6	86.6	86.6
50% flowering	14	48.6	46.9	46.9
Grain formation	18	48.4	55.4	55.4
Harvest	28	6.4	47.9	47.9
Total	**127**	**564.5**	**312.1**	**312.1**

GPU-28

Phenological stages	No. of days	Rainfall (mm)	Water required(mm)	Water used
Sowing	-	-	-	-
Tillering	41	107.5	75.3	75.3
Ear emergence	28	357.4	93.6	93.6
50% flowering	7	37	19.8	19.8
Grain formation	16	30	56.3	56.3
Harvest	24	32.6	42.3	42.3
Total	**116**	**564.5**	**287.3**	**287.3**

GPU-26

Phenological stages	No. of days	Rainfall (mm)	Water required(mm)	Water used
Sowing	-	-	-	-
Tillering	41	107.5	75.3	75.3
Ear emergence	26	353.6	86.6	86.6
50% flowering	6	20	19.4	19.4
Grain formation	14	50.8	48.9	48.9
Harvest	17	28.4	43.1	43.1
Total	**104**	**560.3**	**273.3**	**273.3**

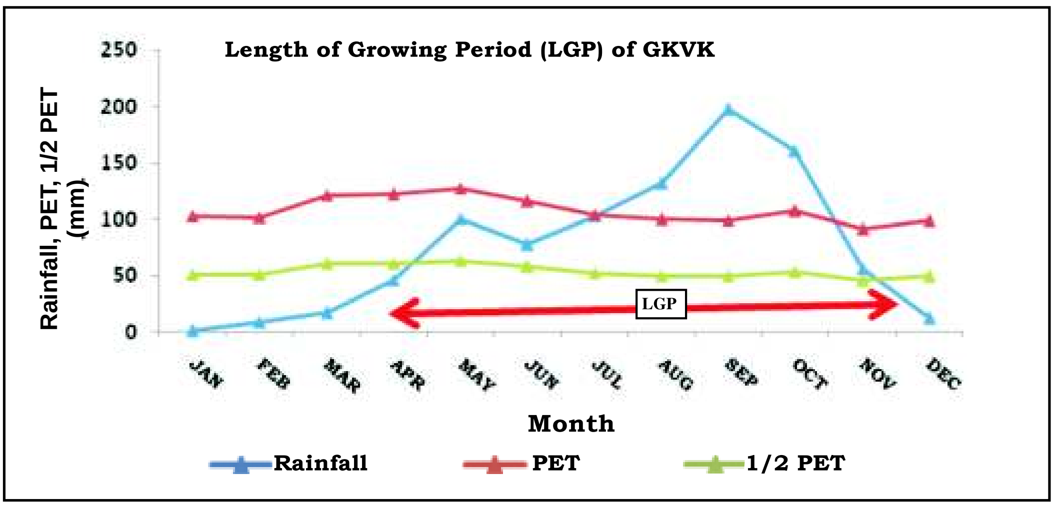

Figure 2.1: Optimum crop growing period with adequate moisture

c. Yield and Weekly Weather Relationship in Respect of Finger Millet

Multiple linear regression equation was obtained to understand the relationship between the grain yield and important weekly accumulated values of weather parameters like (a) water use, (b) Growing degree days and (c) water requirement satisfaction index (%). The grain yields of finger millet over the year 1976 to 2001 were related with above said parameters. The relationship obtained was;

$$Y = 7.6859\ a + 0.1454\ b + 6.6905\ c - 427.6336;\ R^2 = 0.67$$

This multiple regression was found to predict the grain yield fairly well when above said parameters were considered. The estimated grain yield was compared with the observed values and it is found that the predicted yields were very close to the observed yield as shown in Fig. 2.2. Further, this yield prediction equation is validated for the grain yields realized during the year 1999 to 2001 and it was possible to predict the grain yield to an extent of 99.9 per cent for the first date sown crop and 93.2 per cent for the second date sown crop.

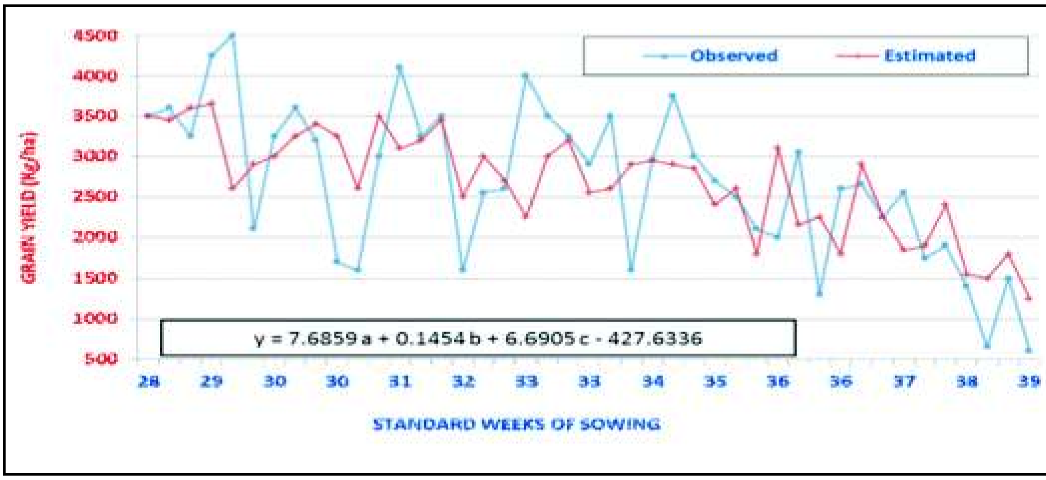

Fig. 2.2: Observed and estimated grain yield of finger millet

d. Range of Grain Yield of Finger Millet with Respect to Dates of Sowing

Based on the data recorded in the experiments conducted during 1976 - 2001, the dates of sowing of finger millet (variety Indaf-8) commenced earliest from 28th met. week and continued up to 39th met. week. According date of sowing, sowing weeks were grouped as early sown (28th to 31st), normal (32nd to 35th) and late sown (35th and above). It is interesting to note that, the early sown crop on an average recorded on an average grain yield of 3636 kg/ha, normal sown crop recorded 2966 kg/ha and late sown recorded lowest yield of 1960 kg/ ha. The reasons for the realization of higher grain yield in case of early sown is due to the fact that the average rainfall during the crop growth period was 590 mm as against 500 mm and 375 mm during normal and late sowing groups. The probability at different levels also proved that the early sowing group will receive sufficient amount of rainfall for the completion of the crop growth without affecting at any stage. The probability of rainfall and yields are presented in the Table 2.3 and shown in Fig 2.3 & 2.4. The minimum and maximum grain yield obtained based on the different dates of sowing conducted during 1976- 2001 is shown in Fig. 2.5.

Table 2.3: Influence of different date of sowing and rainfall on yield of finger millet

Date of Sowing	Grain Yield (kg/ha)	RF (mm)60% Probability	RF (mm) 75% Probability	Mean RF (mm)
I (July 9 to Aug.5)	3636	370	490	560
II (Aug. 6 to Sep.2)	2966	300	380	480
III (Sep.3 to Sep.30)	1960	200	260	360

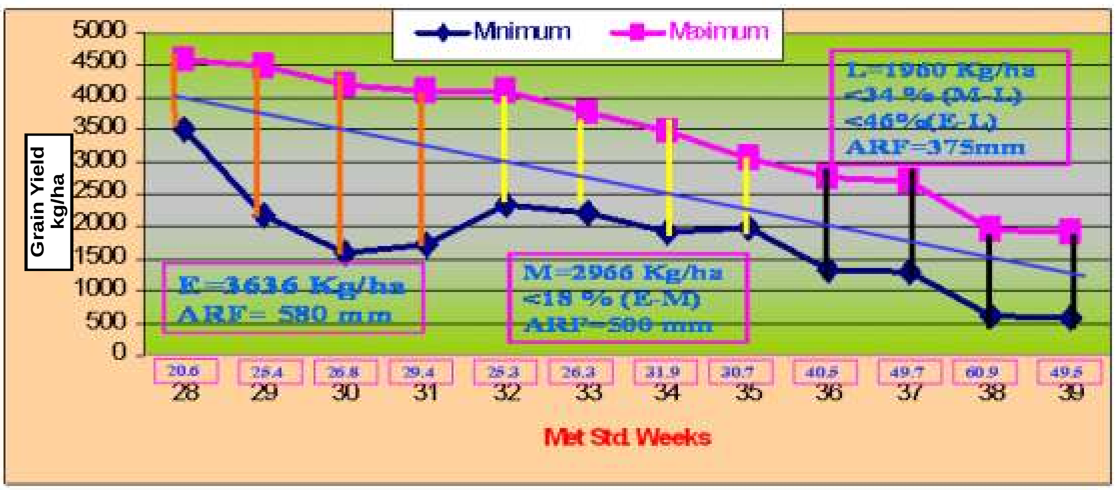

Fig.2.3: Range of finger millet grain yield sown on different sowing windows

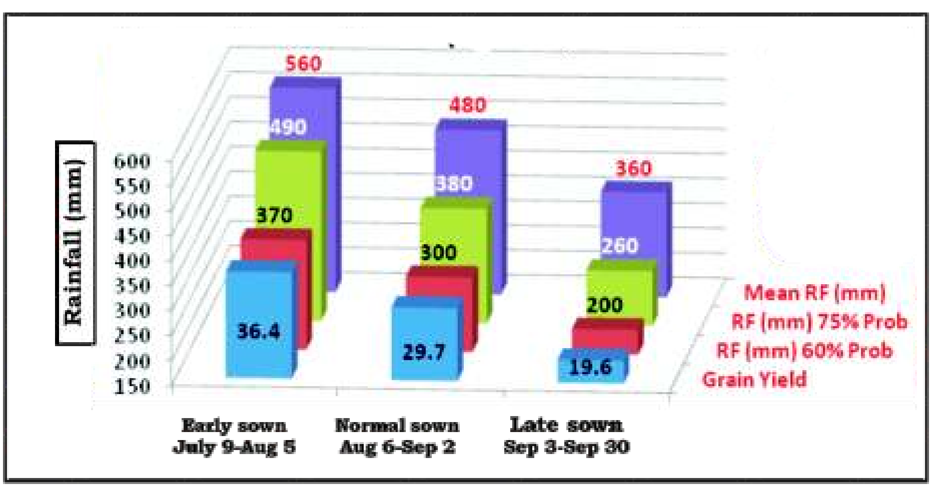

Fig 2.4: Rainfall available for finger millet during sowing periods (1972-95)

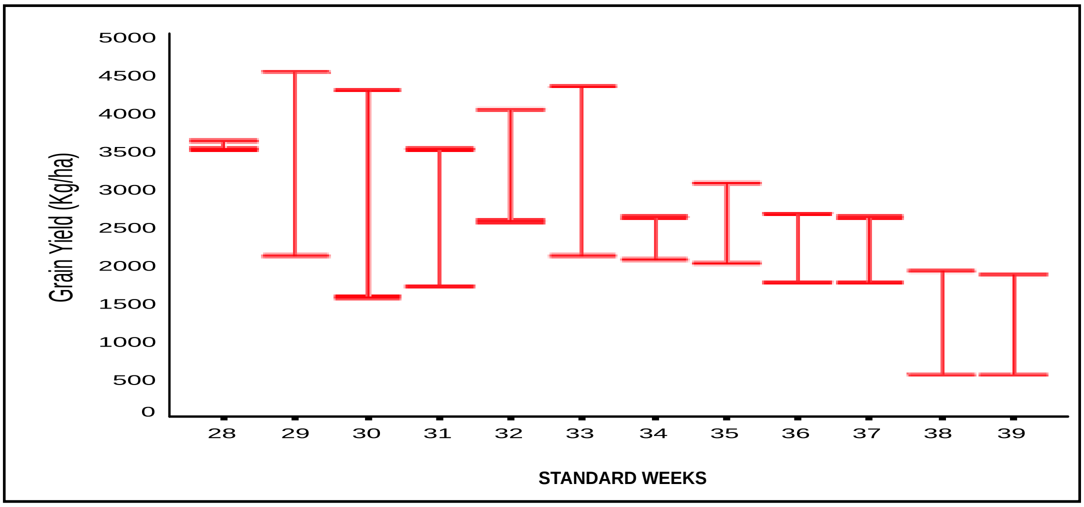

Figure 2.5: Range of grain yield of finger millet with respect to dates of sowing (1976-2001)

e. Finger Millet Production in Southern Karnataka - An Agroclimatic Analysis

An agro climatic analysis of finger millet was attempted by Bapuji Rao *et al.* (2013). The crop-weather relationship of finger millet is not much explored by the scientists and hence an attempt is made to study the relation of finger millet with weather, which may help in the better understanding of the crop response to weather aberrations. This may ultimately culminate in the development of a finger millet yield prediction function for Karnataka state.

In the study, data on finger millet crop from 1985 to 2001 were utilized. A minimum gross plot size of 40 m^2 was maintained in all the years. The meteorological data collected from meteorological observatory nearby was used. The moisture adequacy index (MAI) was estimated with the help of weekly Thornthwaite water balance model (1948). The inputs for the Thornthwaite water balance model are weekly rainfall, potential evapo-transpiration (PET) and average water holding capacity of the soil. The PET in the present study has been estimated through FAO Penman Montieth (Allen *et.al.,* 1998) method, which is expressed as;

$$\text{PET} = \frac{0.408\Delta\,(R_n - G) + \gamma \dfrac{900}{T+273} U_2\,(e_a - e_d)}{\Delta + \gamma\,(1+0.34U_2)}$$

where R_n is the net radiation at crop surface (M J m^{-2} d^{-1}), G is soil heat flux (M J m^{-2} d^{-1}), T is average temperature at 2 m height (°C), U_2 is the wind speed measured at 2 m height (ms^{-1}), (e_a-e_d) is the vapour pressure deficit for measurement at 2 m height (kPa), Δ is slope of vapour pressure curve (kPa°C^{-1}), γ is psychrometric constant (k Pa °C^{-1}), 900 is coefficient for the reference crop (J^{-1} kg K d^{-1}), 0.34 is wind coefficient for the reference crop (sm^{-1}).

The MAI in turn was determined using the relation.

$$\mathbf{MAI} = \left(\frac{\mathbf{AET}}{\mathbf{PET}}\right) * \mathbf{100}$$

Where AET is the actual evapotranspiration computed through Water Balance procedure of Thornthwaite and Mather (1955). Attainment of different phenological events, growth in terms of dry matter accumulation and its subsequent partition into different organs in crops are primarily determined by temperature, photo period and moisture availability and finger millet is no exception. The response of finger millet (Indaf-8) to variations in temperature and moisture availability was examined at Bengaluru by correlating weather during different fortnights of crop growth with its grain yield. For a better understanding of the role played by the weather at different phenophases, fortnightly average values of weather variables were computed and related to grain yield. The resultant correlation matrix is presented in Table 2.4.

Table 2.4: Pearson's correlation coefficients between weather parameters and finger millet yield

Parameter	1st FAS	2nd FAS	3rd FAS	4th FAS	5th FAS	6th FAS	7th FAS	8th FAS	9th FAS
T_{Max}	-0.18	-0.04	-0.2	0.05	0.28	0.24	0.24	0.23	0.01
T_{Min}	0.3	0.34	0.34	0.57*	0.68**	0.70**	0.59*	0.48*	0.3
DTR	-0.42	-0.28	-0.37	-0.38	-0.44	-0.55*	-0.45	-0.36	-0.06
RH1	0.24	0.24	0.22	0.28	0.3	0.34	0.32	0.23	0.22
RH2	-0.12	-0.18	-0.05	0.04	-0.06	0.26	0.33	0.18	-0.06
RF	-0.38	-0.28	0.23	0.16	0.45	0.39	0.29	0.26	0.06
SS	-0.44	-0.22	-0.24	-0.02	-0.09	-0.43	-0.37	-0.23	-0.17
MAI	0.28	0.53*	0.42	0.57*	0.55*	0.66**	0.43	0.70**	0.04

(**FAS -** Fortnight after Sowing; *- Significant at 95% level; **- Significant at 99% level)

The Table 2.4 indicates that minimum temperature (T_{min}) and MAI during all the fortnights after sowing had a positive influence on the finger millet yields. Maximum temperature (T_{max}) in the earlier crop growth stages had negative but non-significant influence which became positive as the crop growth advanced. Morning relative humidity (RH1) and afternoon relative humidity (RH2) showed a non-significant association with yield. Rainfall during 5th to 7th fortnight after sowing showed statistically non-significant positive influence on yield while, hours of bright sunshine (SS) showed a non-significant negative influence on yield. Response of finger millet to moisture availability was found to be positive as reflected in the highly significant positive correlation coefficient values during 4th to 8th FAS which coincided with flowering and grain development stages. In pearl millet, mid-season moisture stress was found to have severe effect on grain yield (Seetharama *et al.,* 1984). Moisture stress during the grain filling period in pearl millet has far more drastic effects. Timing of such a stress is particularly important, yield being reduced by as much as 70% if the stress period begins at or just before flowering. Similarly, the yield reduction due to varying levels of stress is linearly proportional to the severity of the stress during grain filling.

1. Influence of Temperature on Finger Millet Yields

The maximum temperature, minimum temperature and mean temperature averaged over the entire crop growing season were related with corresponding yields and the associations were presented in Fig. 2.6. It was noticed from Fig. 2.6 that seasonal maximum temperature does not have any influence on the finger millet yields as evident from the low R^2 value. On the other hand, seasonal minimum temperature had a significant influence on the finger millet yield and the variations in seasonal minimum temperature accounted for 46% variation in yields (R^2 = 0.46). Seasonal mean temperature also showed influence of lesser degree on the finger millet yields (Fig. 2.6) compared to minimum temperature with R^2 value of 0.35. Though the day time temperatures were found to have no influence on the finger millet yields, the night time temperatures that prevailed during 4th to 8th fortnights after sowing, which coincides with flowering and grain development stages, were found to have a significant positive impact on the finger millet yields (Table 2.5). The influence of temperature was also recorded

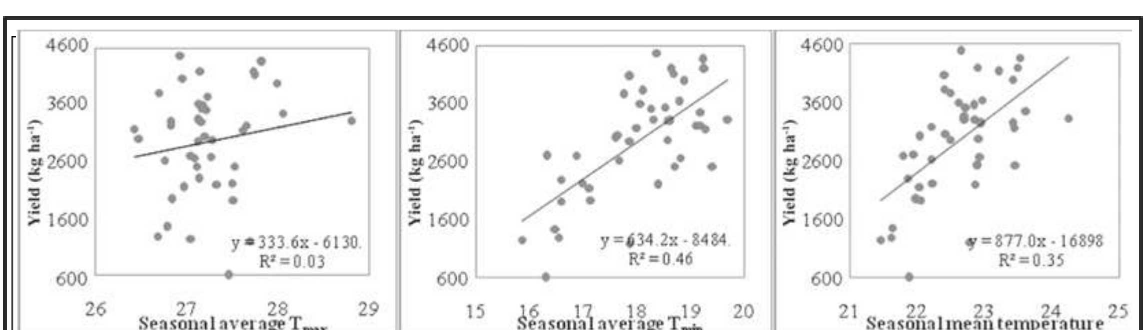

Fig. 2.6: Influence of maximum, minimum and mean temperature on the yield of finger millet

in pearl millet, another crop from the millet group where longer photo period, higher temperatures and a wide range of day and night temperatures affected the crop phenology (Maitai and Sotto, 1990).

Diurnal temperature range in some millets was found to have influence on the phenological development as well as tillering ability. Fusel *et al.,* (1980) found that higher temperature (33°/28°C day/ night) reduced basal tillering whereas lower temperatures (21/16°C day/ night) increased tillering in pearl millet. In the present investigations, negative influence of diurnal temperature range (DTR) during 6th FAS that coincides with grain development period of finger millet was noticed. With an increase in the temperature range the yields were found to decrease. To have an insight on the role of maximum, minimum temperatures as well as their range, the frequency of their prevalence over specified temperature limits in crop growing season were correlated with corresponding yields. The specified limits were fixed arbitrarily for diurnal temperature range as 8, 9, 10 and 11°C and then a frequency of days above these specified limits in each season were correlated and regressed on the corresponding finger millet yields. The frequency of days with DTR greater than the mentioned values are also presented in Table 2.5.

Table 2.5: Frequency of days with DTR greater than specified values (8/9/ 10/11°C)

Year	DOS	DOH	Number of days with DTR				Yield (kg ha^{-1})
			> 8°C	> 9°C	> 10°C	> 11°C	
1985	7/23/1985	11/19/1985	90	65	43	21	3189
1985	8/12/1985	12/09/1985	98	76	59	34	3012
1985	9/7/1985	01/04/1986	102	82	70	55	1289
1986	7/22/1986	11/18/1986	93	78	59	29	3822
1986	8/5/1986	12/02/1986	98	83	64	34	2628
1986	9/17/1986	01/14/1987	110	91	77	50	1449
1987	7/19/1987	11/15/1987	99	90	49	22	3238
1987	8/7/1987	12/04/1987	101	71	44	19	3301
1987	9/17/1987	01/14/1988	95	74	51	29	1940
1988	7/19/1988	11/15/1988	69	40	33	24	4475
1988	8/4/1988	12/01/1988	81	54	48	39	4075
1988	8/19/1988	12/16/1988	89	54	57	47	2150
1989	8/25/1989	12/22/1989	102	90	74	46	2708
1989	9/18/1989	01/15/1990	110	97	86	63	1250
1990	8/7/1990	12/22/1990	113	104	36	22	2667

Year	DOS	DOH	Number of days with DTR				Yield (kg ha^{-1})
			> 8°C	> 9°C	> 10°C	> 11°C	
1990	8/20/1990	12/27/1990	86	63	38	23	2517
1991	8/2/1991	11/29/1991	87	66	25	5	3342
1991	8/17/1991	12/14/1991	113	69	39	20	2967
1991	9/11/1991	01/08/1992	97	77	52	41	2300
1992	7/9/1992	11/05/1992	100	76	19	5	3634
1992	7/25/1992	11/21/1992	67	40	20	5	4198
1992	8/8/1992	12/05/1992	68	43	26	9	3549
1993	7/26/1993	11/22/1993	71	40	18	7	3307
1993	8/14/1993	12/11/1993	67	50	27	16	3607
1993	8/27/1993	12/24/1993	75	52	30	17	3060
1994	8/1/1994	12/08/1994	76	71	45	26	3523
1994	8/16/1994	12/20/1994	92	72	48	30	3763
1994	9/10/1994	01/05/1995	92	77	57	37	2700
1995	7/28/1995	11/30/1995	96	66	39	15	2988
1995	8/19/1995	12/18/1995	94	76	50	30	2200
1995	9/25/1995	01/16/1996	103	91	72	54	600
1996	8/13/1996	12/06/1996	95	81	65	39	2225
1996	8/26/1996	12/18/1996	89	76	61	39	1925
1997	8/1/1997	12/05/1997	74	39	22	13	2525
1997	8/13/1997	12/18/1997	74	38	22	12	3163
1998	7/30/1998	11/26/1998	61	39	20	13	3238
1998	9/3/1998	12/30/1998	73	57	43	33	1200
1999	8/1/1999	11/28/1999	72	44	27	19	4200
1999	8/13/1999	12/10/1999	75	51	35	23	4125
2000	7/4/2000	10/31/2000	57	33	17	11	4363
2000	7/31/2000	11/27/2000	67	42	25	15	3991
2001	7/18/2001	11/14/2001	57	36	18	6	3463
2001	7/2/2001	10/29/2001	53	28	11	2	3330

DOS = Date of sowing
DOH = Date of harvest

The Pearson's correlation coefficients of the relation between yield and days with DTR more than threshold values are presented in Table 2.6. The finger millet yields were found to have an inverse association with diurnal temperature range as indicated from the values of correlation coefficient (r). The 'r' values progressively increased from -0.55 to -0.69, indicating adverse impact of increased DTR on the finger millet yield. The impact became stronger as the DTR values increased from 8 to 11.

Table 2.6: Pearson's correlation coefficients between frequencies of days above a DTR threshold in a season and finger millet yield

Days with DTR	Pearson's correlation coefficients (r)
> 8 °C	-0.55
>9 °C	-0.58
>10 °C	-0.66
>11 °C	-0.69

The scatter plots showing the relation between yield and days with different thresholds of DTR are presented in Fig. 2.7(a-d). The frequency of days above all the threshold limits considered was found to influence crop yields and the yields declined as the temperature thresholds increased from 8 to 11°C. The negative impact became stronger with increase in threshold temperature limit as evident from the increasing R^2 values from 0.31 for a temperature threshold of 8°C to 0.48 for a threshold temperature limit of 11°C. It can be inferred that during the seasons with higher diurnal temperature range *i.e.,* warmer days and cooler nights the finger millet yields would decrease. The influence of diurnal temperature range on the finger millet can be mathematically expressed for each temperature limit as presented in Table 2.7.

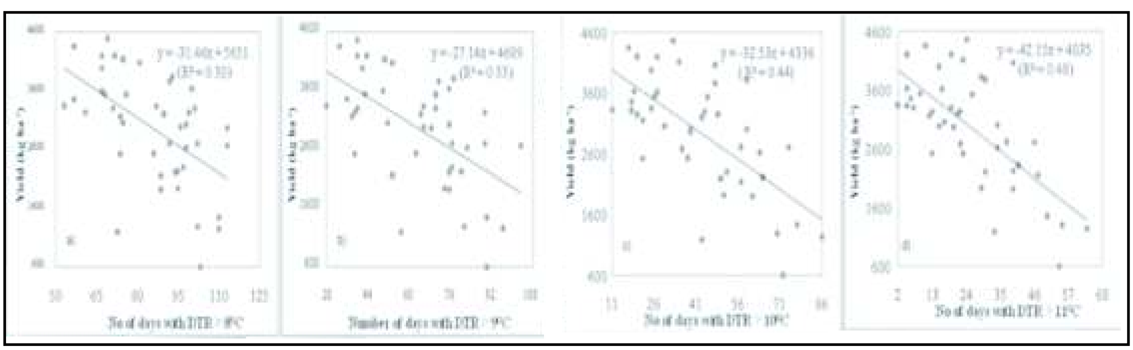

Fig. 2.7(a-d): Scatter plot between frequency of days in a season with DTR > 8°C, 9°C, 10°C and 11°C

Table 2.7: Response functions for different DTR thresholds

Temperature threshold	Equation	R^2
8°C	Y = 5651 - 31.46X	0.31
9°C	Y = 4689 - 27.14X	0.33
10°C	Y = 4336 - 32.53X	0.44
11°C	Y = 4035 - 42.15X	0.48

Where, Y is finger millet yield in kg ha^{-1} and X is frequency of days above the temperature thresholds in a crop season.

2. Yield Prediction Model

A reliable estimate of crop production available in advance of harvest helps in planning, formulation and implementation of policies relating to food procurement and distribution, price policies, import, export policies and for exercising several administrative measures for storage and marketing of agricultural commodities. A fairly reliable estimate of yield requires, apart from other parameters a good yield forecasting model. Yield forecast model based on weather and input supplies as well as forecast based on techniques of remote sensing are presently being employed in India for regional crop yield estimates. Keeping the importance of this aspect, the yield prediction model for finger millet was developed in the present study. Since, minimum temperature during 4^{th} to 8^{th} FAS, moisture availability during 8^{th} FAS and DTR during 6^{th} FAS were found to exert considerable influence on the finger millet yields at Bengaluru, these three variables among the meteorological parameters were only chosen to develop a yield prediction equation which has yielded into the following relations.

$Y = 464.0\ T_{min}$ (4-8 FAS) - 5204.7 ($R^2 = 0.46$)

$Y = 2067.6$ MAI 8^{th} FAS + 1534.7 ($R^2 = 0.48$)

$Y = 5674.4 - 285.2$ DTR 6^{th} FAS ($R^2 = 0.30$)

$Y = 293.6\ T_{min}$ (4-8 FAS) + 1366.0 MAI 8^{th} FAS - 3147.4 ($R^2 = 0.61$)

$Y = 399.0\ T_{min}$ (4-8 FAS) - 71.4 DTR 6^{th} FAS - 3381.9 ($R^2 = 0.47$)

$Y = 202.7\ T_{min}$ (4-8 FAS) + 1403.3 MAI 8^{th} FAS - 94.6 DTR 6^{th} FAS-673.1 ($R^2 = 0.63$)

Where, Y is finger millet yield in kg ha^{-1}. It can be inferred from the coefficient of determination (R^2) values of the above relations that the variations in the finger millet yields are better explained by considering more than two variables and relation involving minimum temperature, DTR and moisture adequacy index (MAI) accounted for 63% variations in finger millet yields.

3. Step-wise Regression Analysis

The multiple linear regression analysis presented above comprised of $T_{min,}$ MAI, DTR and a combination of all of them. However, it is desirable to quantify the influence of each of them and identify the most critical parameter among them so that a simplified yield production function can be proposed from the present investigation. The step-wise regression analysis ultimately resulted in removing of DTR from the final equation indicating the non-significant effect of DTR. This leaves with the relation based on Tmin and MAI as the predictor variables that can be used for predicting finger millet yields at Bengaluru center.

Among the ten weather variables / indices studied, minimum temperature (4^{th} - 8^{th} FAS), daily temperature range (6^{th} FAS) and moisture adequacy index (8^{th} FAS) were found to influence finger millet yields. Fluctuations in seasonal minimum temperature accounted for 46% variation in finger millet yields. Additionally, the frequency of days in a season above a threshold value of 11°C was found to have an impact on the finger millet yields. Moisture adequacy index during 8^{th} FAS coinciding with grain development stage were found to have a strong positive correlation with yields. The variations in the finger millet yields are better explained by considering more than two variables and relation involving Tmin (4^{th} - 8^{th} FAS), DTR (6^{th} FAS) and MAI (8^{th} FAS) accounted for 63% variation in finger millet yields. The stepwise regression analysis resulted in identifying minimum temperature and moisture availability as critical weather parameters influencing the finger millet yields.

4. Radiation Interception by Finger Millet Crop at Bengaluru

Solar radiation being a major controlling factor for crops (Muralidhara *et al.,* 2003) its interaction in finger millet was studied. The light exerts many stimulating effects on plants especially upon the differentiation of organs. Although light energy from sun is unlimited, an account of its interception by crop for their growth is needed. It is known that some of the incidental radiation is reflected back, some amount can penetrate to ground and only small portion is intercepted by plant to satisfy its need of photosynthesis.

Here, an attempt has been made to determine the amount of solar radiation intercepted by the crop during different phenological stages. A relation between this trapped or intercepted energy with leaf area index and total biomass in finger millet raised in different dates of sowing in *kharif* season were also worked out.

Finger millet crop was sown on two different dates. The 1^{st} date of sowing was on 1-8-97 (early sowing) and 2^{nd} of sowing was on 13-8-1997 (late sowing). The crop was raised following the standard package of practices with 30 cm inter row spacing and 15 cm inter plant distance under rainfed condition. Hourly solar radiation observations of direct (D), reflected (R) and transmitted (T) components were made in the crop according to standard procedure using a (integrating) photo/radiometer LI 188B (with the pyranometer sensor PY - 7178). The intercepted radiation 'I' was computed using the formula I = D - (R+T). These observations were made every week from morning 8.00 hrs to the evening 17.00 hrs at an hourly interval. Along with these, the crop growth observations like plant height, leaf area index (LAI) and total dry matter (TDM) accumulated were also observed at each phenological stage of the crop. The LAI and TDM were computed by graphical interpolation for the dates of observations of radiation.

The percentages of I, R, and T to D was computed to know the percentage of energy intercepted, reflected and transmitted during the different phenological stages of crop growing period. The radiation components during different stages were related with the LAI and TDM and simple linear regression equations have been worked out to know the influence of intercepted PAR on LAI and TDM. The leaf area index (LAI), total dry matter (TDM) of the crop at different date of observation in both dates of sowing is given in the Table 2.8. LAI in 1st date sown crop started to decrease from 21/11 and in 2nd date sown crop it decreased from 26/11. The total dry matter increased steadily till the end of its harvest.

Table.2.8: LAI and total dry matter of finger millet crop at different dates of observation

Date	LAI		Total dry matter (gm m^{-2}) (TDM)	
	I date	II date	I date	II date
08/10	5.1	3.8	1194.23	1026.21
15/10	5.7	4.3	1449.03	1380.48
29/10	6.0	5.2	1845.23	2089.02
05/11	6.2	5.7	2231.58	2374.69
12/11	6.5	6.1	2699.23	2685.18
21/11	5.3	6.3	3126.13	3164.16
26/11	3.6	5.8	3188.17	3293.93
03/12	0.5	3.9	3274.98	3372.96
10/12		2.1		3411.18
17/12		0.3		3449.40

The simple linear regression equations have been worked out between percentages of intercepted radiation at particular hour and LAI and TDM. The computed equations showed better relation with the measurements of radiation interception made during 11 hour, 12 hour and 15 hour with relatively high value of 'r' as shown below.

For 11th hour observation

for TDM Y = M * 27.72 + 1177.381 r = 0.71

for LAI Y = M * (-0.036) + 6.486 r = 0.45

For 12th hour observation

for TDM Y = M * 25.850 + 1284.966 r = 0.64

for LAI Y = M * -0.038 + 1.789 r = 0.42

For 15th hour observation

for TDM Y = M * (17.819) + 1635.569 r = 0.47

for LAI Y = M (-0.0567) + 7.376 r = 0.65

In observations made during monsoon period where cloud amount fluctuates frequently during observation time, there is variation in incoming radiation. The solar radiation components measured in 1st date and 2nd date sown crops are given in Table 2.9.

Table 2.9: Solar radiation observations during the crop growing period on different dates of sowing

Date	I Date of Sowing							II Date of Sowing						
	D	R	(%)	T	(%)	I	(%)	D	R	(%)	T	(%)	I	(%)
08/10	19.4	6.9	35.6	5.6	28.6	6.93	35.8	18.6	5.9	31.5	8.7	46.9	4.1	21.6
15/10	25.4	7.2	28.7	3.7	14.6	14.5	57.1	25.1	7.6	30.1	7.9	31.5	9.7	38.4
29/10	14.3	4.3	30.0	3.1	21.7	6.9	48.3	12.8	4.2	32.7	2.2	17.0	6.4	50.3
05/11	20.1	4.3	21.4	5.1	25.4	10.7	53.2	15.7	5.3	33.6	4.0	25.6	6.4	40.8
12/11	23.0	5.7	24.7	4.0	17.3	13.3	57.8	23.9	5.3	22.4	7.2	30.3	11.4	47.8
21/11	12.2	3.5	28.3	1.9	15.3	6.9	56.4	12.9	3.0	23.7	3.7	28.5	6.2	48.1
26/11	25.7	4.8	18.7	3.4	13.2	17.5	68.1	18.4	4.3	23.5	3.5	19.1	10.5	57.3
03/12	23.9	3.8	15.9	4.1	16.9	16.1	67.3	22.2	3.9	17.1	4.9	21.4	14.1	61.5
10/12	-	-	-	-	-	-	-	24.5	4.6	18.8	3.2	13.0	16.7	68.1
17/12	-	-	-	-	-	-	-	17.8	2.8	15.9	2.6	14.1	12.4	69.8

(D, T, R and I are in MJm^{-2})

From the Table 2.9, it was observed that maximum D of 25.7 MJ m^{-2} received on 1st date sown crop was on 26/11, the highest interception of 16.0 MJ m^{-2} was on 3/12 which was observed on two days before the crop harvest. The D was almost same in second date crop with some marginal variations. The highest recorded D of 25.1 MJ m^{-2} on second date sown crop was on 15/10 and the interception was high one week before the harvest in both the dates of sowing.

In the Table 2.9, it was observed that on 15/10 in the 1st date crop, the per cent of I increased and R decreased but they reversed during next observations that is on 29/10 and 05/11. The same trend was observed in 2nd date crop on 29/10 and 5/11. The increase in I and decrease in R was observed in ear emergence stage of both the dates sown crops. The reverse trend in I and R was observed during 50% flowering stage. This may be inferred that the presence of ear head without flowers intercepts most of the radiation by reducing the reflection. Reflection increases during flowering stages due to the presence of flowers in ear head. The interception of more radiation leads to the accumulation of more TDM in further stages. In both dates sown crops, young leaves after tillering stage before ear emergence stage (8/10 and 15/10 in 1st date crop and 8/10, 15/10 and 29/10 of 2nd date crop) reflected more incident radiation than in other stages. The T was almost negligible during that stage. After a drop in percentage of 'I' in ear emergence stage of both date crops, it further increases almost linearly in remaining stages.

The variation of I shows good response with TDM than LAI. The T has good relation with LAI when compared to R and I. On the other hand, the T at ground level decreases with increase in biomass above ground. All these results were supported by the 'r' values of the regression equations worked out between I, R & T and LAI & TDM. These 'r' values and corresponding regression equation were given below in Table 2.10.

Table 2.10: Correlation coefficient (r) between different constants of radiation with LAI and TDM

Parameters	R	T	I
LAI	0.2	0.5	0.4
TDM	0.6	0.7	0.7

Further, R, T and I were computed graphically using the daily observations for important crop phenological stages and is given in Table 2.11.

Although 13 days difference is there between two dates of sowing, both crops were exposed to almost same amount of radiation. The slight variation of total amount may be attributed to varying cloud cover. Both crops show almost equal response to R, T and I. But when analyzed critically at different phenological stages of both date sown crops, marginal differences in the amount of energy reflected, transmitted and intercepted were observed. This may be due to the different period to which the crop was exposed to the radiation between any two stages of the crop. As enunciated earlier, the interception was more in ear emergence stage compared to 50 per cent flowering stage in both early and late sown crops.

Table 2.11: Radiation at different phenological stages of early and late sown finger millet

Sl. No.	Stages	Duration (days)		D (MJm^{-2})		I (MJm^{-2})		R (MJm^{-2})		T (MJm^{-2})	
		Early	Late	Early	Late	Early	Late	Early	Late	Early	Late
1.	Sowing to beginning of tiller	47	42	941.4	804.5	25.0 (2.6)	17.6 (2.2)	22.2 (2.3)	16.9 (2.1)	894.2 (95.1)	770.1 (95.7)
2.	Ear emergence	26	35	490.7	672.2	286.1 (58.4)	361.4 (53.8)	102.0 (20.8)	165.6 (24.6)	102.5 (20.9)	145.3 (21.6)
3.	50% flowering	18	12	420.4	189.3	197.7 (45.5)	89.2 (47.1)	154.4 (36.7)	77.8 (41.1)	68.3 (16.2)	22.3 (11.7)
4.	Grain formation	18	14	316.8	238.9	197.8 (62.4)	140.2 (58.7)	108.2 (34.2)	45.5 (19.0)	10.9 (3.4)	53.2 (22.3)
5.	Harvest	17	24	305.7	554.7	201.1 (65.8)	343.6 (61.9)	65.1 (21.3)	62.1 (11.2)	39.5 (12.9)	149.0 (26.8)
Total		**126**	**127**	**2475.1**	**2459.6**	**907.7 (36.7)**	**952.0 (38.7)**	**451.9 (19.0)**	**352.9 (14.3)**	**1115.4 (46.9)**	**1140.3 (46.4)**

Simultaneously the reflection was low. But the situation reversed in next phonological stage. At 50 per cent flowering stage of late sown crop, only 189.3 MJ m^{-2} of direct radiation was received and it was able to intercept 47 per cent (89.2 MJ m^{-2}) of radiation. The transmission at this stage of the crop was low compared to the same stage of early sown crop. The LAI here also higher than that of 1st date crop. The larger LAI of 2nd date sown crop resulted in 41 per cent of reflection compared to only 37 per cent reflection of 1st date crop. The TDM of 2nd date crop at ear emergence stage increased largely as compared to 1st date crop (33% higher). But 2nd date crop has taken 9 more days to complete ear emergence stage, and naturally exposed to more radiation than 1st date crop in same stage.

In the grain formation stage of 1st date crop, the R was high (34.2%) compared to 2nd date crop. At the same stage, the T at ground level was low (only 3.4%) but the 2nd date crop was having 22.3% transmission. The variation of R, T and I was tested with TDM and LAI using simple linear regression equation. The ‘r’ values are given in the Table 2.12.

Table 2.12: Correlation coefficient (r) between different constants of radiation with LAI and TDM

Parameters	Reflect	Transmitted	Intercepted
LAI	0.56	0.78	0.36
TDM	0.90	0.46	0.96

The solar radiation, the solar energy Intercepted (I) by the crop have been computed. The total energy intercepted by the crop during different phenological stages and in turn during the whole crop growing period has been computed for different date of sowings during South-West monsoon season. It is found that out of 2475.1 MJm^{-2} incident radiation available to the 1st date crop 451.9 MJm^{-2} (14.3%) reflected back (albedo), 1115.4 MJm^{-2} (46.9%) transmitted below the canopy and remaining 907.7 MJm^{-2} (36.7%) was intercepted by the crop canopy. Out of 2459.6 MJm^{-2} incident radiation, 352.9 MJm^{-2} (14.3%) reflected back, 1140.3 MJm^{-2} (646.4%) transmitted below the canopy and remaining 952.0 MJm^{-2} (38.7%) was intercepted by 2nd date sown crop. Very good relations between the total dry matter (TDM) with intercepted radiation during different phenological stages have been obtained. Late sown crop was found to yield more straw and grain yield (5033.3kg/ha and 3162.5 kg/ha, respectively) as compared to the early sown crop (4666.7 kg/ha and 2525.0 kg/ha, respectively) as higher amount of intercepted radiation was available for the late sown crop.

f. Finger Millet Production in South Karnataka: Land Suitability Analysis

An exhaustive land suitability analysis of finger millet was attempted by Shivaramu and Niranjan (2010). Since finger millet is largely grown in alfisols of South India, its interpretation for cultivation of finger millet goes a long way in (i) defining the soil suitability for finger millet and (ii) quantifying the limits of soil related parameters to achieve the potential yield.

Field studies on the impact of soil-site characters on finger millet were conducted on 11 varying soil series for four years (1996-98 and 2006) in Kuthanagere watershed near Bangalore during the rainy cropping season (June-November). Before experimentation, the detailed soil survey of these soil units was undertaken as per the procedure outlined in Soil Survey Manual (IARI,1971). The site characteristics, *viz.* erosion and drainage after judging their extent as per the manual, were numerically rated for statistical analysis like nil to slight erosion as one, moderate as two, severe as three and very severe as four; poorly/ excessively drained as one, imperfectly/well drained as two and moderately well drained as three. The physical and chemical properties of the profiles *vis-à-vis* soil units were analyzed horizon wise, using standard procedure and then arrived at single weighted averaged values for each soil series (Table 2.13). The difference in moisture holding capacity at 33 and 1500 kPa was multiplied by bulk density and soil depth to calculate the total plant available water holding capacity of each soil series. The length of growing period was calculated following the FAO model (Higgins and Kassam, 1981). However, to calculate the LGP after the cessation of rains, the actual stored soil moisture (PAWC) in each soil unit was used instead of the assumed 100 mm in the FAO model. The crop was raised as per the package of cultivation practices recommended by the University of Agricultural Sciences (Bengaluru). The grain yield (q ha^{-1}) was calculated from the sun-dried grain weights of harvested net plots.

Correlation matrix was worked out to study the relationship of the soil-site parameters among themselves and on crop yield. In order to find the optimum range of any given soil parameter (x) for obtaining maximum crop yield (y) under both management levels, a quadratic equation ($y = a+bx+cx^2$) was fitted. Where 'a' is an intercept and 'b' and 'c' are the regression coefficients. Further, the statistical relationships between the soil-site characteristics (x_1 to x_n) altogether and the seed yield were established by multiple linear regression (MLR) equations ($y = a + b_1x_1 + b_2x_2 + ... + b_nx_n$). Where 'a' is an intercept and 'b_1' to 'b_n' are the partial regression coefficients of 'x_1' to 'x_n', respectively. The R^2 value obtained, was tested at / or below 5 per cent level of significance. Using the step-down regression analysis by least square technique (Barrie *et al.,* 1986), the less important soil parameters were dropped one after another and the MLR models with seed yield were developed keeping the remaining important ones. Among the number of models so developed, the best models were chosen based on the following criteria: (a) R^2 value should be higher and significant at or below 5 per cent level of significance, (b) more number of independent variables in the model should also be significant at or below 5 per cent and (c) the SE of 'a', SE of 'y' estimate and the index of multi-colinearity should be comparatively low (d) the intercept 'a' should also be significant at or below 5 per cent .

It was observed that among the 26 soil- site characteristics studied (Table 2.13), 16 of them, particularly the soil depth, coarse fragments, soil texture, CEC, PAWC and LGP had significant correlation with grain yield of finger millet. Soil depth being highly and positively correlated with seed yield, the relationship was more of a quadratic in nature (Table 2). The optimum soil depth from the fitted equation ($y = 12.37 + 0.23x-0.001x^2$) was observed to be around 1m. Coarse fragments in the soil had negative relationship with seed yield ($y = 28.97 + 0.19 x- 0.01x^2$, $r = -0.51^{**}$). Among the soil particles, the silt content had positive and prominently quadratic relationship with seed yield ($y = -49.18 + 10.36x – 0.33x^2$, $r = 0.57$ **) and accordingly the optimum content was worked to be 16 per cent. With increase in clay from 30 per cent onwards, there was a steep increase in yield. On the other side, below 30 per cent of clay, the yield did not decrease proportionately ($y = 30.35 - 0.88x + 0.02x^2$). On the contrary, increase in sand up to 50 per cent brought down the yield drastically. Thus, right proportion of sand (<35 %) and clay (>50 %), keeping the optimum silt at 16 per cent, play an important role in determining the yield of finger millet. CEC being an index of native fertility status of soil, showed significant positive and quadratic relationship with finger millet yield ($y = -26.87 + 13.12x - 0.73x^2$, $r = 0.52^{**}$). CEC greater than 9 cmol (p^+) kg^{-1}, showed an increase in grain yield. From among the cationic nutrient elements, exchangeable calcium showed a significant quadratic relationship with grain yield of finger millet to the extent of 27 per cent ($y=-100.9 + 75.41x - 10.69x^2$, $R2 = 0.27^{**}$), thus showing the importance of calcium nutrition in finger millet. Accordingly, the optimum concentration of exchangeable calcium in the soil was observed to be 3.5 cmol (p^+) kg^{-1}. The results of calcium nutrition are in conformity with the findings of Nathan (1995) who has recommended 16.8 kg calcium per ha in addition to recommended levels of NPK for optimum yield. PAWC and LGP being the indices of moisture storage capacity and moisture availability periods were positively correlated with finger millet with optimum values of >120mm and 240 days, respectively. However, the optimum value of LGP depends mainly on the duration of the crop rather than its yield potential.

From the correlation matrix, it was observed that the soil depth, clay content, PAWC, LGP and CEC were closely related with each other and altogether on grain yield (Shivaramu *et al.*, 1997). Therefore, instead of looking at their individual effects, the overall interaction of different soil parameters on grain yield, seemed to be appropriate and hence 13 MLR equations were worked out. The significant R^2 values of these MLR equations ranged from 0.72 in model no. I (Table 2.14), when 13 soil parameters were regressed, to 0.34 in model no XIII involving only soil depth. However, the two soil parameters *viz.* soil depth and sand could explain 47 percent of the variation in grain yield ($R^2 = 0.47$). Among these 13 models presented in Table 2.15, the better models as per the set out criteria, were found to be model no.V ($R^2 = 0.61$), model VII ($R^2 = 0.57$) and Model XII ($R^2 = 0.47$). However, one can use any of these models for judging the suitability of a land depending on the information generated on soil-site parameters and the management level of the crop, but bearing the risk of associated standard errors.

Sys *et al.,* (1993) have attempted to establish the crop requirements by setting the suitability classes and the range of limits of climate, land scape and soil characters for all the important crops including millets, however not specific to finger millet. Further, NBSS & LUP (2003) attempted to establish the soil-site suitability criteria for finger millet, but seemed to be generalized and hence refined in the light of the present findings particularly of LGP, depth, CEC, drainage, texture, coarse fragments and slope (Table-2.16). Besides, model no V (R^2 =0.61) was found to be the best in judging the suitability of land for finger millet.

Table 2.13: Salient characteristics of soil series and the corresponding ranges of grain yield of finger millet over four years

Properties	Soil Series										
	Kuthanagere-1	**Kuthanagere-2**	**Kuthanagere-3**	**Kuthanagere-4**	**Kuthanagere-6**	**Kuthanagere-7**	**Kuthanagere-9**	**Kuthanagere-10**	**Kuthanagere-11**	**Kuthanagere-12**	**Kuthanagere-13**
Slope (%)	2	0.5	0.5	5.5	5.5	3.5	2	2	0.5	0.5	5.5
Erosion rating	2	1	1	2	3	2	2	2	2	2	3
Drainage rating	2	2	2	2	3	2	2	2	2	2	3
GW table (m)	12	12	12	12	7.5	20	7.5	12	7.5	12	7.5
Depth (cm)	106	155	140	65	79	90	150	102	150	77	13
C. Fragments	13.6	14.6	14.4	28.8	16.5	48.4	7.5	45.6	0	30.8	40
Sand (%)	47.4	58.9	52.6	61.9	54.7	61.2	57.5	50.5	75.8	64.3	64.8
Silt (%)	13.5	18.3	14.9	9	13.3	12.5	12.2	16.6	9.7	20.5	9.5
Clay (%)	39.1	22.7	32.5	28.6	31.9	26.3	30.2	37.4	14.5	15.2	25
OC (%)	0.3	0.21	0.24	0.2	0.65	0.41	0.29	0.65	0.21	0.25	0.42
CEC	8.2	6.4	7.6	5.7	7	6.3	8.4	11.6	4.9	4.4	5.1
BS (%)	58.2	85.7	62.9	69	63.8	64	62.5	60.6	66	87.1	75.1
pH	6.5	7.2	6.5	6.2	6.1	6.4	6.5	6.3	5.9	6.4	6.8
EC (dSm^{-1})	0.1	0.1	0.03	0.08	0.1	0.1	0.19	0.13	0.1	0.1	0.23
ESP	1.23	1.65	1.67	2.2	1.44	1.64	2.24	1.6	7.92	2.27	5.6
Av. N $kgha^{-1}$	234.5	212.8	241.9	220.9	182.6	143.8	210.1	232.5	153.2	174.1	174.1
Av. P ($kgha^{-1}$)	22.6	16.4	21.7	25.1	14.1	10.8	22.2	18.8	17.5	15	21.5
exch.K (ppm)	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.2
Exch.Ca (cmol (p+) kg+)	3.3	3.9	3.1	2.6	2.7	2.6	3.3	3	2.3	2.7	2.5
Exch.Mg (cmol (p+) kg+)	1.3	1.3	1.5	1	1.5	1.3	1.6	1.4	0.8	1.1	0.8
Fe (ppm)	1.51	1.44	1	1.67	1.85	1.46	1.35	1.84	0.85	1.52	0.98
Cu (ppm)	0.14	0.11	0.22	0.22	0.14	0.13	0.14	0.19	0.16	0.14	0.29

Properties	Soil Series										
	Kuthanagere-1	Kuthanagere-2	Kuthanagere-3	Kuthanagere-4	Kuthanagere-6	Kuthanagere-7	Kuthanagere-9	Kuthanagere-10	Kuthanagere-11	Kuthanagere-12	Kuthanagere-13
Zn (ppm)	0.33	0.58	0.63	0.39	0.2	0.36	0.44	0.63	0.42	0.48	0.87
Mn (ppm)	3.12	2.48	2.01	7.24	6.12	3.6	6.48	4.81	2.78	8.73	2.3
PWAC (mm)	41.4	118.3	108.6	40.4	31.5	43.9	111.7	108.2	68.5	61.2	10.9
LGP (days)	206	224	221	206	202	207	223	221	213	211	195
Grain yield (qha^{-1})	17.1-40.8	18.4--42.5	37.5-39.8	20.2-26.5	29.0-38.5	07.5-28.5	19.2-28.1	25.0-30.1	20.0-28.0	20.5-23.4	12.5-18.8
Mean Grain yield (qha^{-1})	31.85	30.86	38.4	24.2	34.3	18.96	24.62	27.9	24.0	22.24	16.12

Table 2.14: Relationship of significant soil parameters and regression equations established with the seed yield of finger millet

Parameters	Type	r value	Regression Equation	R^2 Value
1. Slope (%)	Linear	-0.37*	$Y=30.48-1.67X$	0.14*
	Quadratic	-0.38*	$Y=31.32-0.63X+0.17X^2$	0.14*
2. Erosion (rating)	Linear	-0.44**	$Y=38.14-5.91X$	0.20**
	Quadratic	-0.46**	$Y=47.09-15.83X+2.44X^2$	0.22**
3. Depth (cm)	Linear	0.58**	$Y=15.87+0.11X$	0.34**
	Quadratic	0.61**	$Y=12.37+0.23X-0.001X^2$	0.37**
4. C.frag. (% v/v)	Linear	-0.48**	$Y=33.37-0.21X$	0.23**
	Quadratic	-0.51**	$Y=28.97+0.19X-0.01X^2$	0.26**
5. Sand (%)	Linear	-0.52**	$Y=65.62-0.67X$	0.27**
	Quadratic	-0.53**	$Y=131.97-2.93X+0.02X^2$	0.28**
6. Silt (%)	Linear	0.35*	$Y=14.10+0.88X$	0.12*
	Quadratic	0.57**	$Y=-49.18+10.36X-0.33X^2$	0.32**
7. Clay (%)	Linear	0.35*	$Y=13.48+0.45X$	0.13*
	Quadratic	0.39*	$Y=30.35-0.88X+0.02X^2$	0.15*
8. CEC(cmol (p^+) kg^+)	Linear	0.37*	$Y=13.78+1.82X$	0.14*
	Quadratic	0.52**	$Y=-26.87+13.12X-0.73X^2$	0.27**

Parameters	Type	r value	Regression Equation	R^2 Value
9. ECe (dSm^{-1})	Linear	-0.56**	Y=36.87-86.41X	0.32**
	Quadratic	-0.57**	$Y=39.04-122.76X+124.51X^2$	0.32**
10. ESP	Linear	-0.48**	Y=32.23-2.26X	0.23**
	Quadratic	-0.61**	$Y=45.59-11.89X+1.17X^2$	0.37**
11. Exch.Ca(cmol (p^+) kg^+)	Linear	0.45**	Y=0.87+8.54X	0.20**
	Quadratic	0.52**	$Y=-100.90+75.41X-10.69X^2$	0.27**
12.Exch.Mg(cmol (p^+) kg^+)	Linear	0.55**	Y=3.83+18.37X	0.30**
	Quadratic	0.56**	$Y=-17.37+57.14X-16.73X^2$	0.31**
13.Cu (ppm)	Linear	-0.38**	Y=35.90-55.08X	0.14**
	Quadratic	-0.48**	$Y=3.45+302.21X-879.67X^2$	0.22**
14.Zn (ppm)	Linear	-0.36*	Y=34.48-16.06X	0.13*
	Quadratic	-0.40*	$Y=23.00+30.41X-40.92X^2$	0.16*
15.PAWC (mm)	Linear	0.45**	Y=19.15+0.11X	0.20**
	Quadratic	0.45**	$Y=-18.19+0.15X-0.0003X^2$	0.20**
16.LGP (days)	Linear	0.45**	Y=-63.06+0.42X	0.20**
	Quadratic	0.45**	$Y=-326.51+2.93X-0.006X^2$	0.20**

Table 2.15:Multiple linear regression coefficients of soil parameters on yield of finger millet in different models

Parameters	Coefficient of parameters in Model I to XIII												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
1. Slope	2.8489	11.4405**	1.1686	1.2311									
2. Erosion	5.9225	-13.0067	-1.2338	0.8731	1.4670	-2.6029							
3. Depth	0.4425**	0.4161**	0.2282	0.2907**	0.2518*	0.1708	0.1884*	0.0992	0.1018	0.0572	0.0897**	0.0888**	0.1094**
4. C. Frgs	0.0479	0.1608	0.2498	0.1714	0.0936	-0.1161	-0.0898	-0.1030	-0.0711	-0.1271			
5. Sand	7.2924	-7.7471	-1.7511*	-1.4717*	-1.1334	-0.2435	-0.1825	-0.5150	-0.4660	-0.4687	-0.5178	-0.4919**	
6. Silt	8.9584												
7. Clay	9.9100	-5.3424											
8. CEC	-13.5764	0.8149	-4.6161	-4.0496	-3.1046								
9. ESP	-0.5585	9.7065	2.2128	0.2949	-0.7324	-2.2577	-2.3772	-0.4470	-0.2452	-0.2574	0.1267		
10. Exch.Ca	-5.9535	-18.8652	-6.7131	-8.9856	-9.4549*	-9.0673	-7.5241	-3.3924					
11. Zn	19.1922	13.7477	-19.8319										
12. PAWC	0.1720	-0.9577	0.8840	0.5734	0.7040	0.8140*	0.7759*						
13. LGP	-0.6877	3.6880	-3.2428	-2.2670	-2.9243	-3.6247*	-3.4382*	-0.1081	-0.1824				
a	-627.45	-116.62	782.50	569.82	685.54*	776.81*	724.54*	83.73	84.90	52.24	47.85**	46.77**	15.87**
S.E. of a	714.63	560.84	478.52	325.54	307.12	308.83	299.14	57.61	57.38	14.30	13.73	10.66	2.62
S.E. of Y	5.96	6.00	6.58	6.51	6.52	6.68	6.63	7.01	6.98	6.91	6.93	6.83	7.52
R^2	0.7200**	0.7054**	0.6317**	0.6266**	0.6118**	0.5788**	0.5706**	0.5048**	0.4930**	0.4877**	0.4704**	0.4701**	0.3402**

Table 2.16: Land suitability criteria for finger millet

Land quality	Land use requirement		Rating			
	Soil-site characteristics	Unit	Highly suitable	Moderately suitable	Marginally suitable	Not suitable
Temperature regime	Mean temperature in growing season	°C	28-34	25-28; 34-38	38-40; 20-25	>40; <20
Moisture availability	Length of growing period	days	>110	90-110	60-90	<60
Oxygen availability to roots	Soil drainage	class	Well drained; moderately well drained	Imperfectly drained; somewhat excessively drained	Poorly drained; excessively drained	
Nutrient availability	Soil reaction	pH	5.5-7.5	7.6-8.5; 4.5-5.4	8.6-9.5; 4.0-4.4	<4.0
Nutrient retention	Texture	class	l, sil, sl, cl, sicl, scl	sic, c, sc	ls, s, c>60%	
Rooting conditions	Effective soil depth Gravel contents	cm % by vol.	>75 <15	51-75 15-35	26-50 35-50	<25 >50
Soil toxicity	Salinity (EC saturation extract)	dSm^{-1}	<1.0	1.0-2.0	2.0-4.0	
	Sodicity (ESP)	%	<10	10-15	15-25	>25
Erosion hazard	Slope	%	<3	3-5	5-10	>10

(**Source:** NBSS & LUP, 2003)

***Note**: l: Loam, sil: silty loam, sl: sandy loam, cl: clay loam sicl: silty clay, scl: sandy clay loam, sic: silty clay, c: clay, sc: sandy clay, ls:loamy sand, s: sand, dSm^{-1}: deci Siemens per meter, EC: Electrical conductivity, ESP: Exchangeable Sodium percentage

g. Meteorological Aspects of Pests and Diseases

The important diseases are leaf blast, finger and neck blast (Sanath Kumar, 2002). Major pests are stem borer, hairy caterpillars, grass hoppers and aphids. Proper disease management practices reduce the loss of crop above threshold level (Anil Kumar *et al.,* 2003). Incidence of diseases at different crop growth stages and their development with weather parameters after the date of sowings are indicated in Table 2.17. The important pests and their control is given Table 2.18.

Table 2.17: Favorable weather conditions during ear head emergence for the development of the diseases (60 days after sowing)

Date of sowing	Favorable weather conditions	Expected per cent disease (neck blast)	Expected per cent disease (finger blast)
20th June	Mean Temp.: 19.7 to 25.9 °C RH I : 91 RH II : 64 Cloudy days: >3 days	7.77 to 38	4.80 to 77.70
30th June	Mean Temp.:19.80 to 26.60 °C RH I : 94 RH II : 64 Cloudy days: >3 days	21 to 35.15	16.50 to 84.28
10th July	Mean Temp.:18.90 to 24.70 °C RH I : 93% RH II : 68% Cloudy days: >3 days	15.65 to 45.21	29.12 to 96.25
20th July	Temp.: 16.50 to 27.40 °C RH I : 86% RH II :65% Cloudy days: >3 days	9.78 to 34.78	19.99 to 83.70
30th July	Temp. :18 to 26.80 °C RH I : 92% RH II: 64% Cloudy days: >3 days	7.92 to 24.52	10.80 to 66.90
10th August	Temp.: 17.20 to 26.90 °C RH I : 94% RH II : 58% Cloudy days: >3 days	6.23 to 15.13	8.75 to 47.78
20th August	Temp.: 16.20 to 26.50 °C RH I : 92% RH II : 58% Cloudy days: >3 days	4.57 to 10.32	6.51 to 37.33
30th August	Temp.: 13 to 26.11 °C RH I : 90% RH II : 56% Cloudy days: >3 days	4.88 to 12.04	7.80 to 38.31

Note: Adequate fungal inoculum is required for the build up of the disease

Management

- Remove collateral hosts nearby the ragi field
- If the disease incidence of leaf blast, neck blast and finger blast diseases are 20.60, 36.89 and 42.50%, respectively then go for fungicide sprays
- One spray with Tricyclazole (Beam) @ 0.6g/litre at earhead emergence to control neck blast or two sprays of Bavistin @ 1g/litre at 10 days intervals will minimizes the disease.

Table 2.18: Conducive weather and associated pests in finger millet and management Practices

Sl No	Weather aberration	Pest incidence	Nature of damage	Stage	Management practices
1	Temperature 25-29^{0}C, Relative humidity 83-95%	Stem borer	Damage at basal portion of the stem and drying of main shoot	Seedling stage to Tillering stage August-September	Spray Methyl Parathion 1 ml/ Litre of water at seedling stage and at tillering stage
2	Temperature 26-30^{0}C Relative humidity 65-87%	Aphids	Sucking the saps at tip of the seedlings and spikelets.	Seedling stage to Flowering stage June - July to September – October	Spray Phospho midon 1000 EC (0.5 ml/Lit) or Dimethoate 30 EC(0.7 ml/lit)
3	Temperature 25-29^0 C Relative humidity 80-90%, Rainfall 20-30 mm	Gross hopper	Feed on young leaves and panicles	Nursery stage and Flowering stage August-September	Spray Methyl Parathion 1 ml/ Litre of water
4	Temperature 25-29^0 C, Relative humidity 82-90%	Gross hopper	Leaf folder	Seedling and reproductive stage August-September (rainy season)	Remove weeds, judicious use of fertilizer. avoid narrow spacing. Dust Carbaryl (10%) -15 kg/ha or 5% Malathion dust-15 Kg/ha.
5	Temperature 25-29^0 C, Relative humidity 83-90%	Leaf feeding insects	Damage the growing leaves	Tillering to Growth stage August-September	Spray Methyl Parathion 1 ml/ Litre of water

III Crop Weather Models

a. Stocheometric Crop Weather Model to Predict Growth and Grain Yield of Finger Millet

A Stocheometric crop weather model has been developed to predict growth and grain yield of finger millet based on the dry matter accumulation at each stage. Multiple linear regression equations relating the Growing Degree Days (GDD), Sunshine hours (SSH) and actual evapo transpiration (AET) with the accumulated dry matter during each growth stage and also the final grain yield were generated using the field experimental data collected for the period 1992-98. The GDD, also known as thermal time or heat unit or heat sums has been calculated using the equation;

$$T_d = (T_a + T_b)/2 - T_c$$

Where, T_d = GDD, T_a = Maximum temperature, T_b = Minimum temperature and T_c = Base temperature (10°C) .

The daily GDD was calculated and summed up to a particular crop phenological stage. SSH was calculated from the data recorded in the agrometeorological observatory for different phenological stages of the crop growth. AET was computed following the procedure suggested by FAO water balance method (Doorenbos and Pruitt, 1977). The five phenological growth stages of the crop, considered for the study are;

1. Sowing to beginning of tiller,
2. Beginning of tiller to ear emergence,
3. Ear emergence to 50 per cent flowering
4. 50 per cent flowering to grain formation and
5. Grain formation to harvest.

In the Stocheometric crop weather models, it is necessary to consider the initial status of the crop to know the influence of weather parameter on further accumulation of the dry matter. Therefore, while generating the model for the prediction of dry matter at any particular stage, the initial bio-mass (TDM) of the crop available for exposure to the environment has been considered as one of the independent parameters along with the GDD, SSH and AET to know the bio-mass accumulated at the end of each stage. From the date of sowing to the beginning of tillering, considering the accumulated environmental factors as independent parameters, a multiple linear equation was been generated. In the same way, taking the TDM accumulated at the end of the beginning of tillering stage as the initial TDM for the second stage along with the accumulated environmental factors as independent parameters and the TDM accumulated at the end of second stage as dependent parameter, next multiple linear equation for second stage has been worked out. Following the similar procedure, five multiple linear regression equations (model forced through origin to avoid the constants) for the estimation of the TDM at the end of five different phenological stages of the crop have been generated (equation 1 to 5).

$$T_1 = (A_1X_1+B_1Y_1+C_1Z_1) \quad \ldots \quad (1)$$

$$T_2 = T_1S_2 + (A_2X_2+B_2Y_2+C_2Z_2) \quad \ldots \quad (2)$$

$$T_3 = T_2S_3 + (A_3X_3+B_1Y_3+C_3Z_3) \quad \ldots \quad (3)$$

$$T_4 = T_3S_4 + (A_4X_4+B_4Y_4+C_4Z_4) \quad \ldots \quad (4)$$

$$T_5 = T_4S_5 + (A_5X_5+B_5Y_5+C_5Z_5) \quad \ldots \quad (5)$$

Where, subscript indicates the respective stages, $T_1 \ldots T_5$ are the accumulated bio-mass or TDM at the end of respective stage, A, B and C are the coefficients of the variables X, Y and Z (GDD, SSH and AET), S is the coefficients of accumulated bio-mass in the previous stage.

Taking the observed TDM accumulated at the end of first four stages and the predicted TDM at the end of fifth (final) stage as independent parameters and the observed grain yield as dependent parameter, another multiple linear equation (Equation 6) to estimate the grain yield using the accumulated TDM has been generated and expressed as,

$$Yg = IT_1(O) + JT_2(O) + KT_3(O) + LT_4(O) + MT_5(P) \quad \ldots. \quad (6)$$

Where, $T_1(O)$, $T_2(O)$, $T_3(O)$ and $T_4(O)$ are the observed total dry-matter at the end of first four stages and $T_5(P)$ is the predicted total dry-matter for 5th stage. I, J, K, L, and M are the coefficients. With the help of such equation the grain yield could be estimated well before the harvest of the crop.

The coefficients of variable and coefficients of determination (R^2) generated for the prediction of the TDM in each stage and the grain yield using the accumulated TDM in each stage are tabulated in Table 3.1.

A multiple regression equation relating the yield with the observed TDM at the end of first four stages and the predicted yield at fifth stage is given by

$Yg = -1.845\, T_1(O) + 1.157\, T_2(O) + 1.530\, T_3(O) - 1.4877\, T_4(O) + 1.364\, T_5(P)$ — (6).

Table 3.1: Coefficient of variables and Coefficient of determination (R^2) at different stages

Stages the crop	Initial TDM	GDD	SSH	AET	R^2
Tillering	-	1.11	-1.45	2.46	0.93
Ear emergence	1.14	2.77	0.98	-6.26	0.95
50% flowering	1.34	3.36	-2.63	-7.94	0.97
Grain formation	1.35	-0.24	-1.83	5.02	0.97
Harvest	0.81	1.22	4.45	0.49	0.98
Grain Yield					0.99

The model was further validated for two varieties of finger millet and for two dates of sowing (DOS) during 2001 *kharif*. The bio-mass accumulated at different stages of the crop have been estimated using the weather parameter tabulated in Table 3.2 (a-d) and these estimated values were in good agreement with the observed yield and they are tabulated along with the grain yield in Table 3.3.

Table 3.2(a): Observed and predicted biomass and grain yield (g/m^2) of 18.07.2001 sown INDAF-8 variety

Phenological Stages	SSH	GDD	AET	Predicted biomass	Observed biomass	Grain yield	
						Predicted	Observed
Tillering	126.2	472.7	56.7	479.1	144.9	3308.0	3463.0
Ear emergence	246.7	631.0	158.0	1549.6	1175.1		
50% flowering	18.4	104.4	61.8	1881.0	1489.0		
Grain formation	108.7	258.0	59.5	2572.0	2116.3		
Harvest	80.2	186.7	27.5	2685.8	2262.5		

$R^2 = 0.999$, Coefficient = 1.0515

Table 3.2 (b): Observed and predicted biomass and grain yield (g/m^2) of 02.08.2001 sown INDAF-8 variety

Phenological Stages	SSH	GDD	AET	Predicted biomass	Observed biomass	Grain yield	
						Predicted	Observed
Tillering	192.0	541.6	75.3	505.6	159.0	3316.0	3330.0
Ear emergence	110.7	346.2	86.6	1103.9	1126.0		
50% flowering	34.8	175.0	46.9	1598.0	1478.4		
Grain formation	101.4	226.0	55.4	2191.2	2046.0		
Harvest	116.0	250.0	47.9	2623.5	2265.8		

$R^2 = 0.964$, Coefficient = 0.968

Table 3.2 (c): Observed and predicted biomass and grain yield (g/m^2) of 18.07.2001 sown GPU–28 variety

Phenological Stages	SSH	GDD	AET	Predicted biomass	Observed biomass	Grain yield	
						Predicted	Observed
Tillering	126.2	472.7	56.7	479.1	141.6	3182.9	3155.0
Ear emergence	198.0	476.6	113.0	1355.4	1092.9		
50% flowering	24.9	104.2	30.9	1849.3	1368.5		
Grain formation	108.7	174.9	43.9	2468.1	1823.6		
Harvest	80.2	312.7	73	2777.5	2051.9		

R^2 = 0.985, Coefficient = 1.216

Table 3.2 (d): Observed and predicted biomass and grain yield (g/ m^2) of 02.08.2001 sown GPU – 28 variety

Phenological Stages	SSH	GDD	AET	Predicted biomass	Observed biomass	Grain yield	
						Predicted	Observed
Tillering	192.0	541.6	75.3	505.6	149.8	3111.6	3124.0
Ear emergence	115.0	372.0	93.6	1135.8	1084.4		
50% flowering	14.1	90.1	19.8	1625.2	1359.9		
Grain formation	83.5	199.8	56.3	2271.4	1873.7		
Maturity/Harvest	134.4	292.0	42.3	2819.0	2042.0		

R^2 = 0.933, Coefficient = 1.173

Table 3.3: Grain yield (kg/ha) prediction using the observed and predicted biomass during 2001 under I & II dates of sowing (DOS)

Year	Biomass	Sowing to beginning of tillering	Ear emergence	50% flowering	Grain formation	Maturity/ Harvest	Grain Yield (observed)	Grain Yield (predicted)
Indaf-8	Observed	144.9	1175.9	1489.0	2116.3	2262.5	3463.0	3308.8
I-DOS	Predicted	479.1	1549.6	1881.0	2572.0	2685.8	3463.0	3623.8
Indaf-8	Observed	159.6	1126.0	1478.4	2046.0	2265.8	3330.0	3316.8
II-DOS	Predicted	505.6	1103.9	1589.0	2191.2	2623.5	3330.0	3107.6
GPU-28	Observed	141.57	1092.9	1386.5	1823.6	2051.9	3155.0	3182.9
I-DOS	Predicted	479.1	1355.4	1849.3	2468.1	2777.5	3155.0	3630.2
GPU-28	Observed	149.8	1084.4	1395.9	1873.7	2042.0	3124.0	3111.6
II-DOS	Predicted	505.6	1135.8	1625.2	2271.4	2819.0	3124.0	3333.4

Favorable influence of AET at the time of beginning of tiller and grain formation stage, and higher GDD during ear emergence and harvest stages was noticed. Increase in AET during pre-harvest stage did not favor to produce higher grain yield. The coefficient of determination of the Stocheometric crop weather model consisting of the six multiple linear regression equations indicate that the climatic parameters considered and the initial TDM used to estimate the final TDM in each stage could be able to predict the final yield to an accuracy of 93 to 98 per cent (coefficients of determination) in different stages. Considering the observed total dry matter up to the first four stages and the predicted total dry matter at the end of the harvesting stage, the model has been validated for the year 2001. Comparison of the observed and the predicted yields indicate the close agreement between them in all the stages. There is a very good agreement between the observed and the predicted yield. Hence, this Stocheometric crop weather model could be used to predict the grain yield along with their dry matters well before harvest of the crop. This helps the planners for future action to meet the shortage in production.

b. Statistical Crop Weather Model to Predict the Grain Yield

A statistical crop weather model has been developed (Rajegowda *et al.*, 1999 and 2000) by relating the measured actual evapo-transpiration (AET) of the crop, growing degree days (thermal unit *i.e.*, GDD) and bright sunshine hours (SSH) during the crop growth period in each stage with final crop yield. Following growth stages of the finger millet crop were considered.

(1) Tillering, (2) Ear emergence, (3) Flowering, (4) Grain formation and (5) Grain growth / Maturity. For all the years of study, the GDD, AET and SSH were computed as independent parameters for the above said stages and a multiple linear regression was developed with grain yield. Each of the five crop phenological stages were included in the same equation to relate the meteorological parameters to grain yield as follows:

The regression equation is

$$Y = D+(A_1*X_1+B_1*Y_1+C_1*Z_1+A_2*X_2+B_2*Y_2+C_2*Z_2+A_3*X_3+B_3*Y_3+C_3*Z_{3+}$$
$$A_4*X_4+B_4*Y_4+C_4*Z_{4+}\ A_5*X_5+B_5*Y_5+C_5*Z_5)$$

Where D is a Constant. A, B and C are GDD, SSH, and AET respectively and subscript indicates the growth stages. X_1, Y_1, Z_1,……. X_5, Y_5, Z_5 are coefficients of the variable GDD, SSH and AET at respective stages. The accumulated values of GDD, SSH and AET for each stage are shown in Table 3.4.

Table 3.4: Accumulated GDD, SSH and AET during growth stages of finger millet under three sowing dates in years 1992-2001

GDD (°C deg.)

Year	Growth stages				
	Tillering	Ear emergence	Flowering	Grain formation	Maturity
First date of sowing					
1992	363.9	341.3	137.5	194.6	355.6
1993	335.0	495.9	124.2	266.7	158.4
1994	381.1	342.6	189.9	184.2	263.6
1995	543.1	256.6	188.8	166.3	376.2
1996	615.5	136.0	136.1	174.3	246.2
1997	591.5	347.2	244.7	232.8	209.9
1998	496.0	459.8	129.8	129.8	131.2
1999	441.7	454.7	134.9	253.5	374.4
2000	583.7	416.3	103.3	272.8	267.3
2001	472.7	519.1	100.0	192.0	237.6
Second date of sowing					
1992	494.7	137.5	194.6	251.2	254.6
1993	301.1	408.3	254.1	204.7	170.7
1994	445.4	316.8	174.0	157.3	226.1
1995	509.2	137.1	129.8	177.7	376.2
1996	581.5	114.5	192.1	165.1	221.6
1997	603.3	470.6	154.3	178.8	297.9
1998	509.7	136.0	247.5	213.7	193.1
1999	475.6	416.0	129.8	136.2	349.6
2000	531.8	230.3	208.8	190.2	309.6
2001	541.6	354.8	114.9	199.6	268.7
Third date of sowing					
1992	548.9	220.3	290.6	213.3	172.0
1993	401.7	354.1	241.4	72.9	119.4
1994	492.9	280.3	143.1	134	150.3
1995	553.9	186.3	133.4	172.4	191.9

SSH (hours)

Year	Growth stages				
	Tillering	Ear emergence	Flowering	Grain formation	Maturity
First date of sowing					
1992	116.1	162.7	72.5	64.2	199.1
1993	141.7	256.6	35.6	143.6	82.8
1994	185.2	180.6	113.7	67.0	233.6
1995	256.2	132.1	81.5	99.9	243.5
1996	237.5	38.6	88.5	101.5	136.0
1997	202.4	196.6	120.9	90.9	89.5
1998	152.0	129.1	56.4	56.4	83.3
1999	159.3	204.0	49.6	124.4	211.0
2000	197.8	138.2	48.2	92.4	149.5
2001	121.2	211.2	19.1	90.9	92.5
Second date of sowing					
1992	214.0	72.5	64.2	143.8	114.6
1993	151.6	182.6	137.7	110.2	112.3
1994	244.2	168.9	66.5	104.3	239.4
1995	252.4	50.9	73.6	111.2	243.5
1996	218.0	63.8	116.7	62.8	94.6
1997	232.6	260.0	51.7	74.7	123.6
1998	144.1	97.1	114.6	114.9	126.0
1999	221.8	146	64.4	97.3	197.0
2000	174.5	102.1	82.3	72.9	188.0
2001	192.0	112.1	22.2	79.3	134.1
Third date of sowing					
1992	237.6	72.2	156.3	66.9	110.6
1993	225.6	156.2	133.2	54.0	76.5
1994	266.4	128.5	143.4	138.3	118.0
1995	303.7	130.4	102.0	175.6	90.6

AET (mm)

Year	Growth stages				
	Tillering	**Ear emergence**	**Flowering**	**Grain formation**	**Maturity**
First date of sowing					
1992	47.8	94.6	57.8	50.4	66.2
1993	38.8	117.3	34.6	71.8	26.0
1994	74.3	93.5	61.6	48.5	51.8
1995	84.8	71.9	57.5	45.0	76.7
1996	79.4	32.6	39.3	50.9	54.4
1997	74.1	102.7	71.50	49.9	28.7
1998	72.8	128.0	56.7	27.2	17.0
1999	56.9	110.9	36.9	67.9	58.5
2000	74.0	112.6	32.5	70.4	49.1
2001	56.7	125.8	39.4	47.6	50.7
Second date of sowing					
1992	84.0	52.3	34.8	68.5	41.2
1993	35.3	84.4	76.7	51.8	31.6
1994	66.5	84.8	55.1	44.5	46.8
1995	72.9	30.5	36.4	58.1	113.7
1996	75.7	29.7	56.5	46.0	31.3
1997	41.2	127.6	42.5	49.9	42.1
1998	61.5	39.8	64.6	3.1	11.7
1999	78.2	110.9	31.7	14.3	36.1
2000	64.7	53.3	58.3	53.8	32.2
2001	75.3	88.9	28.7	53.5	44.4
Third date of sowing					
1992	99.70	50.9	87.5	41.0	32.9
1993	87.1	99.2	64.9	17.2	19.4
1994	65.1	75.9	51.3	41.6	24.3
1995	95.4	50.3	39.9	62.5	46.1

The coefficients generated using the multiple regression equations are presented in Table 3.5.

Table 3.5: Coefficients of the independent variables of regression equation

Variables	Tillering	Ear emergence	Flowering	Grain formation	Grain growth/ maturity
GDD (°C)	-14.25 (-3.7*)	-1.39 (-0.19)	7.82 (1.19)	27.28 (1.46)	11.79 (2.11*)
SSH (hrs)	31.34 (3.1*)	-26.70 (-3.4)	-22.05 (-1.56)	-16.52 (-1.79)	-6.45 (-0.86)
AET (mm)	-27.66 (-1.62*)	51.14 (1.44)	-0.1 (0.0)	3.9 (0.41)	-26.33 (-1.22)

* 5 per cent significance Constant = 5321.7 $R^2 = 0.97$

The Table 3.5 indicates that higher GDD during flowering, grain formation and pre-harvest stages of the crop is favorable for increasing the grain yield. Particularly, during the harvest stage influence of GDD is highly significant. But GDD is not favorable during the beginning of tiller stage, where it has significant negative effect. The SSH coefficients show that SSH factor is favorable in the tillering stage and in this stage it has high significant value (+3.1). During the maturity and ear emergence stages, SSH has negative impact on the grain yield. Results also showed that increase in AET during the stage of ear emergence is a favorable factor (Table 3.5) to achieve high grain yield. In this stage an increase in one unit of AET would increase the grain yield by 51.14 kg ha^{-1} and this factor has higher student's t-value. The AET is appeared to be non-significant at flowering stage. This may be due to occurence of rain during this phenological stage (during this stage in all experimental years, the average rainfall was more than 30 mm). The variation in grain yield may not be due to AET of this stage. Therefore, contribution of AET on yield at this stage is non-significant. AET is not favorable during maturity/harvest and tillering stages. During the tillering stage AET has significantly negative and negative influence on crop yield.

Regression of Yield Against Accumulated Weather Parameters, Growth Parameters and Length of Growing Period (LGP)

Simple linear, quadratic linear and multiple linear regression equations for grain yield of finger millet was established using accumulated weather parameters, growth parameters and LGP as described by Barrie *et al.,* 1986. The detailed procedure is presented in chapter II. Simple linear and quadratic regressions revealed that, rainy day was strongly and positively associated with grain yield of finger millet followed by PET, growing degree days (GDD) and the accumulated total dry matter (Table 3.6). Since finger millet is a tropical C4 cereal needs more of heat units and hence positive relationship with GDD.

However, bright sunshine hours (BSS) showed a negative relationship with grain yield of finger millet thus indicating the abundance of sunshine hours in dry lands of semi-arid areas affecting adversely the yield where moisture is a limiting factor.

The multiple linear regression models for predicting the yield of finger millet worked out using climatic and growth parameters are presented in table 3.7. Among the nine models developed, model IV was found to be the best describing 84% of the yield variation using six significant parameters *viz.,* rainfall, BSS, growing degree days, evaporation, length of growing period and total dry matter accumulation. Model number VI with five parameters *viz.,* rainfall, BSS, GDD, evaporation and LGP explaining 81 per cent of the yield variation was also observed to be the next best model.

Shivaramu and Niranjana (2010) have also worked out MLR models for finger millet using predominantly soil-site parameters for alfisols of Karnataka explaining the yield variation to the extent of 72 per cent.

Further, the model predicted grain yield values of finger millet were compared (Fig. 3.1) with observed yields for all years. The yield values are given in Table 3.8. A simple linear regression was worked out between observed and predicted grain yield. The close agreement between observed and predicted yield is supported by significant R^2 value (0.854). This model was validated for grain yield observed during 1999 to 2001 (Table-3.9) for two dates of sowing (DOS). The model was able to predict the grain yield to an extent of 80 per cent that reveals its reliability for yield prediction.

Table 3.6: Simple linear regression (SLR) and simple quadratic regression (SQR) of weather parameters with finger millet grain yield

Parameters	Type	r Value	Equation	R^2 Value	Adjusted R^2
Rainfall (mm)	**Linear** **Quadratic**	**0.624**** **0.654****	$Y=785.815 + 4.886x$ $Y=-1758.817 + 15.55x - 0.010x^2$	**0.389** **0.428**	**0.371** **0.393**
Rainy days	**Linear** **Quadratic**	**0.816**** **0.824****	$Y=124.25 + 112.211x$ $Y=1507.42 - 10.200x + 2.424x^2$	**0.665** **0.679**	**0.656** **0.659**
Bright sunshine hours	**Linear** **Quadratic**	**-0.565**** **-0.573****	$Y=9264.81 - 9.237x$ $Y=1464.73 + 14.277x - 0.017x^2$	**0.319** **0.328**	**0.299** **0.287**
Growing degree days	**Linear** **Quadratic**	**0.400*** **0.412***	$Y=-4829.59 + 5.02x$ $Y=-38578.58 + 47.35x - 0.013x^2$	**0.160** **0.169**	**0.135** **0.119**
Evaporation (mm)	**Linear** **Quadratic**	**-0.555**** **-0.705****	$Y=8764.68 - 12.267x$ $Y=-46240.41 + 225.65x - 0.254x^2$	**0.308** **0.500**	**0.288** **0.466**
Potential evapo transpiration (mm)	**Linear** **Quadratic**	**0.551**** **0.654****	$Y=-4811.47 + 20.08x$ $Y=58911.4 - 307.54x + 0.418x^2$	**0.304** **0.428**	**0.283** **0.393**
Length of growing period	**Linear** **Quadratic**	**0.255**^{NS} **0.318**^{NS}	$Y=1601.06 + 15.91x$ $Y=-6587.02 + 181.79x - 0.816x^2$	**0.064** **0.101**	**0.040** **0.047**
Leaf area duration	**Linear** **Quadratic**	**0.157**^{NS} **0.280**^{NS}	$Y=2866.49 + 1.264x$ $Y=4169.61 - 6.519x + 0.010x^2$	**0.025** **0.078**	**0.004** **0.023**
Total dry matter (g/plant)	**Linear** **Quadratic**	**0.417*** **0.420***	$Y=1866.85 + 19.96x$ $Y=1469.19 + 31.01x - 0.07x^2$	**0.174** **0.177**	**0.150** **0.127**

Table 3.7: Multiple linear regression model of climatic, soil- site and growth parameters against grain yield of finger millet

	Coefficients of the parameter in Model I to IX								
Parameters	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**
Rainfall (mm)	13.094**	11.999**	14.182**	14.817**	12.248**	8.345**	9.08*	-	-
Rainy days	-9.253	57.599	-	-	-	-	-	-	-
Bright sunshine hours	30.904**	32.604**	35.276**	35.018**	30.385**	22.487**	10.15	1.721	-8.78**
Growing degree Days	-12.336**	-12.733	-12.274**	-13.203**	-8.845**	-	-5.466	-	-
Evaporation (mm)	-26.493*	-20.24	-27.734**	-25.195**	-27.75**	-25.512**	-	-16.77**	-
Potential evapo transpiration (mm)	6.574	-	-	-	-	-	-	-	-
Length of growing period (days)	124.601**	124.344**	136.726**	137.085**	114.089**	62.738**	53.114	30.61**	5.71
Leaf area duration	-0.774	-0.546	-0.929	-	-	-	-	-	-
Total dry matter (g/plant)	10.97*	12.378**	13.581**	14.316**	-	-	20.837*	-	-
a	-7630.53	-9711.22**	-9584.22**	-9762.22**	-7917.89*	-10703.98**	-6142.07	6461.57**	8371.06**
S.E. of a	3804.22	2735.51	2724.64	2754.41	3202.56	2926.23	4628.36	1969.71	2113.04
S.E. of Y	430.85	427.88	426.72	431.92	511.08	530.27	736.78	805.41	907.998
Adjusted R^2	0.839**	0.841**	0.842**	0.839**	0.773**	0.756**	0.529**	0.438**	0.286**
R^2	0.880	0.878	0.874	0.866	0.806	0.784	0.597	0.486	0.326

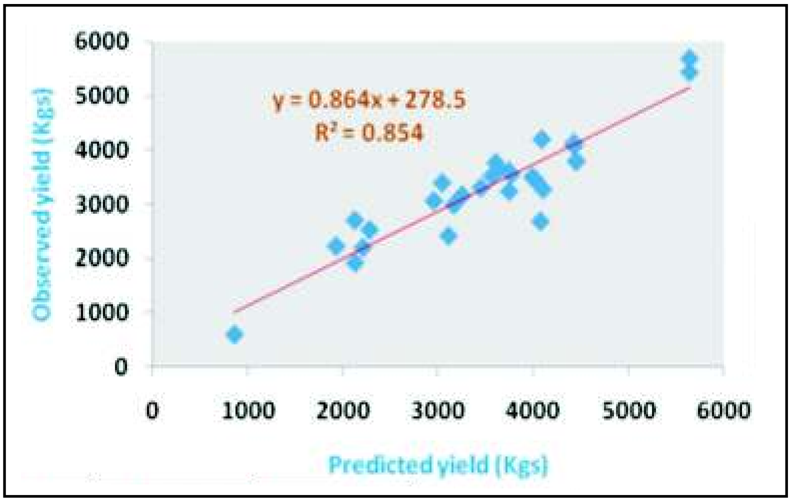

Fig. 3.1: Comparision between observed and predicted yield of finger millet

Table 3.8: Observed and predicted yields of finger millet crop (1992 to1998)

Sl. No.	Year and DOS	Observed yield (kg/ha)	Predicted yield(kg/ha)	Sl. No.	Year and DOS	Observed yield (kg/ha)	Predicted yield(kg/ha)
1.	1992, I DOS	3637	3634	10.	1995, I DOS	3606	3763
2.	1992, II DOS	3451	3307	11.	1995, II DOS	2206	2200
3.	1992, III DOS	3566	3523	12.	1995, III DOS	2122	1925
4.	1993, I DOS	3163	2988	13.	1996, I DOS	3250	3163
5.	1993, II DOS	1922	2225	14.	1996, II DOS	3992	3502
6.	1993, III DOS	2276	2525	15.	1997, I DOS	3768	3549
7.	1994, I DOS	3748	3238	16.	1997. II DOS	2953	3060
8.	1994, II DOS	4092	4198	17.	1998, I DOS	2119	2700
9.	1994, III DOS	3742	3607	18.	1998, II DOS	851	600

Table 3.9: Validation of predicted yield with observed yield for the years 1999 to 2001

Sl. No.	Year and DOS	Observed yield (kg/ha)	Predicted yield (kg/ha)	% Deviation
1	1999, I DOS	4103	3454	15.8
2	1999, II DOS	4022	3275	18.6
3	2000, I DOS	4451	3790	14.9
4	2000, II DOS	4077	2680	34.3
5	2001, I DOS	3108	3393	-9.2
6	2001, II DOS	3041	2415	20.6

IV Operational Agrometeorology

a. Weather Based Agromet Advisory Services for Finger Millet Crop

Weather conditions during the crop period plays a major role in success or failure of crop production. The fluctuations in weather encountered during the crop duration often create instability in food production. Sustainable agricultural production calls for minimizing the adverse impact of weather hazards. It is the fact that weather cannot be altered, except on limited scale but agricultural operations can be advanced or delayed with the help of advance weather forecasts from three to ten days. The utility of weather forecast further depends upon their reliability and applicability at micro level. An estimate made by agribusiness community in western countries indicates that the forecast can be put to an economical use if it is 50-60 per cent accurate. An agriculturally relevant forecast is not only useful for efficient management of farm inputs but also leads to precise impact assessment. Ravindrababu *et al.,* 2007 attempted to verify the suitability of the medium range weather forecast and its impact on economic returns for few crops in Eastern Dry Zone of Karnataka state.

Considering the agro meteorological observatory located at the Gandhi Krishi Vignana Kendra, UAS campus, Bangalore (12° 58' N latitude and 77° 35' E longitude, altitude 930 m above MSL) as the reference centre of the Eastern Dry zone of the State, Medium Range Weather Forecast was issued to the zone. Rainfall amount, cloud amount, maximum and minimum temperature forecasts issued for the period from 1995 to 2005 for this centre was compared with the observed values. To assess the reliability of weather parameters, different verification methods were used. The forecasts of rainfall, temperature and cloud covers have been verified by calculating the error structure. The correct and usable cases summed up and the combined values indicate the percent usability of the forecasts. Ratio score (R score) describes the success rate of correct forecasts of occurrence of rainfall to the total events. It varies from 0 to 1, 1 indicating perfect forecast and Hanssen and Kuipers' score (HK score) indicating the ability to discriminate between rainy and non rainy days. It ranges between -1 and +1 through the 0, the zero indicating no skill. The verification of weather forecasts was done for four seasons *viz.,* Pre-monsoon (March-May), Southwest monsoon (June-September), Northeast monsoon (October-December) and Winter Season (January-February) as defined by India Meteorological Department.

Error structure,

Rainfall	Correct Usable	± 10% ±20%
Temperature	Correct Usable	± 1 .0°C ± 1 .0 to ±2.0°C
Cloud cover	Correct Usable	± 1 Okta ± 1 to ±2.Okta

i) Ratio Score and Hanssen and Kuipers' score.

Forecast	Observed		
		Rain (Y)	No rain (N)
	Rain (Y)	YY	NY
	No rain (N)	YN	NN

Ratio score = (YY+NN)/ N *100

where, N = YY+NN+YN+NY is the total number of days

Hanssen and Kuipers score = [(YY x NN) – (YN x NY)]/[(YY+NN) – (NY+YN)]

Rainfall

The ratio scores and their respective HK scores are presented in Table (4.1). The Southwest monsoon, which is the main rainfall-producing season recorded lowest percentage of usability and it varied from 25 to 69 per cent (Table 4.2). The forecast on rainfall during northeast monsoon, winter and pre monsoon period showed usability percentage between 56 and 98 per cent, 81 and 100 per cent and 57 and 87 per cent, respectively. The mean values were more than 76 per cent in all the seasons except in South west monsoon, which registered the lowest accuracy of 54 per cent and mean value for the entire year is 69.1 per cent. The higher values are indicative of higher reliability of forecast. The lower values during southwest monsoon period varied between 48.5 and 61 per cent over different years. The HK score varied from 0.08 to 0.57 in different seasons over the years. The mean HK score was higher in north east and south west monsoon seasons compared to other seasons. Considering the quantitative data, the overall usability of rainfall, temperature (Maximum & Minimum) and Cloud amount parameters have been worked out and given in Table 4.2.

Table 4.1: Qualitative analysis of rainfall forecast and realization

Season	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Mean (1996-2005)
Ratio Score (%)											
Winter season	100.0	95.0	100.0	95.1	80.4	97.8	95.0	98.0	93.0	81.8	93.6
Pre monsoon	80.9	67.3	68.0	78.7	73.9	86.3	83.3	81.3	70.8	65.5	75.6
South West monsoon	50.0	50.0	56.7	48.5	54.6	54.6	59.0	61.0	56.6	49.1	54.0
North East monsoon	86.4	73.0	74.0	76.7	93.2	66.7	80.0	87.0	88.8	63.5	78.9
Annual	68.7	62.7	67.6	68.1	69.6	70.4	74.6	75.5	71.5	62.3	69.1
Hanssen and Kuipers Score (HK score)											
Winter season	0	0	0.35	0	0.57	0	0	0	0.04	0.15	0.11
Pre monsoon	0.36	0.21	0.25	0.13	0.40	0.48	0.32	0.35	0.32	0.17	0.30
South West monsoon	0.16	0.16	0.24	0.26	0.17	0.14	0.26	0.17	0.19	0.08	0.18
North East monsoon	0.14	0.35	0.29	0.13	0.63	0.19	0.14	0.11	0.34	0.36	0.27
Annual	0.36	0.38	0.35	0.15	0.26	0.42	0.35	0.32	0.34	0.31	0.32

Table 4.2: Overall usability (%) analysis of the forecasted parameters

Season	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Mean (1996-2005)
Rainfall											
Winter season	100	95	100	95	81	98	95	98	96	100	95.8
Pre monsoon	67	62	60	74	69	80	84	87	57	86	72.6
South West monsoon	28	45	30	45	26	25	42	69	33	50	39.3
North East monsoon	95	81	65	74	85	62	80	98	85	56	78.1
Annual	54	58	48	64	55	57	68	83	58	72	61.7
Maximum temperature											
Winter season	100	85	92	83	82	84	88	96	93	74	87.7
Pre monsoon	70	76	78	82	82	88	87	77	88	72	80.0
South West monsoon	83	74	74	77	74	91	83	78	86	71	79.1
North East monsoon	95	86	71	88	73	91	89	87	87	72	83.9
Annual	85	74	67	83	70	89	86	82	88	72	79.6

Table 4.2: ***(contd...)***

Season	Rainfall										
	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Mean (1996-2005)
Minimum temperature											
Winter season	75	55	92	66	71	78	68	74	82	60	72.1
Pre monsoon	70	86	72	64	73	82	83	58	93	64	74.5
South West monsoon	77	72	86	81	73	96	90	95	92	93	85.5
North East monsoon	68	62	84	72	73	82	64	72	68	76	72.1
Annual	78	58	74	79	71	88	80	84	88	76	77.6
Cloud amount											
Winter season	66	90	98	97	80	98	85	85	93	84	87.6
Pre monsoon	50	77	52	99	73	93	83	84	72	67	75.0
South West monsoon	61	72	92	86	95	65	58	52	40	40	66.1
North East monsoon	68	85	86	48	95	60	76	89	91	52	75.0
Annual	69	63	68	68	70	70	75	76	71	62	69.1

Benefits of Weather Forecast to Farming Community

The village survey conducted to assess the overall utility of forecasts revealed that medium range weather forecasting for undertaking all farm activities was excellent in 35 per cent cases; very good in 12 per cent; good in 26 per cent and 28 per cent cases were satisfactory in the region, 76 per cent farmers rated the usefulness of forecast between good to excellent. More than 75 per cent of the farmers believed that the MRWF was beneficial for land preparation /sowing, pest and disease control/sprays, fertilizer and manure application, weed control, protective irrigation and harvesting.

Table 4.3: Economic impacts of agromet advisory in finger millet

Crops	AAS Farmers (per acre)				Non-AAS Farmers (per acre)				Additional Income to AAS farmers (Rs)
	Yield (kg)	Total cost (Rs)	Net return (Rs)	B:C	Yield (kg)	Total cost (Rs)	Net return (Rs)	B:C	
Finger millet (*kharif*)	850	4550	3500	1.78	750	4956	1869	1.53	1631

The economic benefit gained by the identified farmers by following the Agromet advisories was also evaluated during the cropping season of the year 2004. The crop yield, total cost of cultivation, net returns and the B:C ratio for finger Millet (seed purpose) grown by the AAS and non-AAS farmers during *Kharif* and Rabi seasons of 2004 are presented in Table 4.3. The cost of cultivation was found to be lower in case of AAS farmers who have effectively adopted the advisory compared to the non-AAS farmers. Further, the crop yield is also higher with low investment by the AAS farmers resulted in higher B:C ratio. The net profit per acre realized by the farmers adopting the medium range weather forecast is Rs.1631 for finger millet (seed purpose).

b. Studies on the Influence of Agromet Advisory Services on Economic Impact of Finger Millet Crop

Weather being an important influencing component in the field of agriculture, the crop growth and yield are regulated by its influence in the region. The advance (3-5 days) information on the likelihood of weather leads to the proper management of resources for agricultural operations to minimize the risk and facilitate the growth and realize the optimum crop yield. Agromet Advisories issued twice a week and adopted by the selected farmers has helped them in maintaining the crop in good condition, thereby achieving higher yield and higher economic returns.

Study was conducted between 2004-05 and 2006-07 at Bangalore rural district of Eastern dry zone of Karnataka. In view of comparing the impact of Agromet Advisories on economic benefits, two groups of farmers namely a group adopting the Agromet Advisories regularly in their operations and the other group of farmers not aware of Agromet Advisories were selected. For this purpose, about 80 farmers from four villages of Doddaballapur taluk, Bangalore rural district, in eastern dry zone were selected. Out of the farmers, different categories such as big, small and marginal, have been identified and Agromet Advisories have been issued to only forty farmers in two AAS villages namely Seethakempanahalli and Shanabhoganahalli during *Kharif* and *Rabi* seasons and care was taken to implement the advisories by this group. Non AAS villages namely Dibburahalli and Itgalpura and AAS villages are about 35 km away from the AAS unit Bangalore. The medium range weather forecast received from NCMRWF centre was given in AAS villages to the identified farmers during *Kharif* season of the year in order to plan and execute various operations according to the services.

Regular observations were made on the situation and constantly compared with nearby fields having the same crops where forecast is not adopted by Non AAS farmers. Further, Economic impact was also assessed based on the input incurred for all cultural operations from sowing to harvest. Adoption of forecast is critically evaluated, including the yield differences and comparing prices in both AAS and Non AAS farmers based on our Agromet advisory services. Expenditure incurred by the farmers at every crop stage from land preparation till the harvest has been worked out and crop growth and yields were monitored regularly in the farmer's field belonging to both the groups.

Economic benefit obtained by farmers following the agromet advisory has been evaluated for *kharif* season of the years 2004-2006. The total cost of cultivation, crop yield and net returns for finger millet grown by the AAS and Non AAS farmers during Kharif season are presented in Table 4.4. The total cost of cultivation was found to be lower in the case of AAS farmers who have effectively adopted the agromet advisory compared to non AAS farmers. Further, the grain yield, straw yield and net returns are 2323 kg/ha, 1551 kg/ha and 8728.5 Rs. / acre respectively in case of AAS farmers and 2148 kg/ha, 1295 kg/ha and 5981.3 Rs/acre in case of non-AAS farmers for finger millet crop. The farmers who have adopted the agromet advisories in their day to day operation have realized an average additional benefit of 31.45 per cent, with respect to finger millet. This clearly indicated that the agromet advisory helps in efficient management practices and can enhance the productivity of the crops.

Table 4.4: Grain yield of finger millet, production costs and economic returns as influenced by AAS during *kharif* season (mean of three years (2004-2006)

Sl. No.	Particulars	Finger millet crop		
		AAS Farmers	Non AAS Farmers	Per cent increase over Non AAS
1	Seed (Rs / ha)	87.46	102.89	-
2	FYM (Rs / ha)	978.06	1079.30	
3	Fertilizer (Rs /ha)	572.2	599.95	
4	Human labour (Rs / ha)	1251.27	1512.30	
5	Bullock labour (Rs / ha)	300	267.50	
6	Machine labour (Rs / ha)	991.70	995.00	
7	Total cost of cultivation (per acre) (Sum of 1-7)	4180.71	4556.78	8.99
8	Grain / pod yield (kg/ha)	2323	2148	7.50
9	Straw yield (kg / ha)	1551	1295	16.50
10	Gross return (Rs / ha)	19180.00	17372.50	9.42
11	Net return (Rs / ha)	8728.5	5981.3	31.45

c. Contingent Crop Planning

Varied monsoon situation and rainfall affects the normal cropping systems and causes negative impact on productivity. Adaptation and mitigation strategies are to be devised to reduce the negative impacts of aberrant weather situation on agriculture. Use of alternative crops or cultivars adapted to climate change, alteration in the planting date, and management of plant spacing and input supply might help in reducing the adverse impact. Use of resource-conservation technologies and a shift from sole cropping to diversified farming system is highly warranted. Contingency crop planning will require greater attention. Water-conservation practices will become economically feasible when nutrient deficiencies are also corrected. Late onset of monsoon rains often leads to delayed planting and specific crop contingency plans have been provided for different sowing periods (Table-4.5).

Table 4.5: Weather based contingent crop plan for season drought condition

Sowing period	Soil type	Normal Crop/ cropping system	Suggested contingency measures	
			Change in crop/ cropping system	Agronomic measures
1st June to 30th June	Red soil and Sandy loam	Finger millet+ Pigeonpea / Field bean (8:2) or (8:1)	Finger millet + Pigeonpea /Field bean (8:2) or (8:1)	Follow deep ploughing, *insitu* moisture conservation practices & opening of conservation furrow
1st July to 31st July	Red soil/Red sandy loam	Finger millet + Pigeonpea / Field bean (8:2) or (8:1)	Finger millet + Pigeonpea Finger millet: MR-1, MR-2, MR-6 & L-5. Pigeonpea: BRG-1, BRG-2	Seed hardening, staggered nursery, contour cultivation, small sectional bunds, dry sowing 8-10 days before rains with 15-20% higher seed rate
1st August to 14th August	Red soil, sandy loam, sandy soil	Finger millet mixed cropping Pigeonpea and Field bean mixed cropping and nursery preparation	Prefer long to medium duration varieties in Finger millet: GPU-28, HR-911, L-5, Indaf-5	Staggered nursery, seed hardening, contour cultivation, small sectional bunds, dry sowing 8-10 days before rain with 15-20% higher seed rate
15th August to 31st August	Red soil, sandy loam, sandy soil	Finger millet sole crop with short duration varieties and nursery preparation	Prefer medium to short duration varieties in Finger millet: GPU-45, GPU-46, GPU-48, Indaf-5, PR-202, GPU-26	Seed hardening and sowing, staggered nursery, contour cultivation, small sectional bunds

Sowing period	Soil type	Normal Crop/ cropping system	Suggested contingency measures	
			Change in crop/ cropping system	Agronomic measures
15th August to 31st August	Red soil, sandy loam, sandy soil	Finger millet sole crop with short duration varieties and nursery preparation	Prefer medium to short duration varieties in Finger millet: GPU-45, GPU-46, GPU-48, Indaf-5, PR-202, GPU-26	Seed hardening and sowing, staggered nursery, contour cultivation, small sectional bunds
From 1st September	Red soil, sandy loam, sandy soil	Finger millet sole crop with short duration varieties nursery transplantation	Prefer short duration varieties in Finger millet: GPU-26, GPU-45, GPU-66, Indaf-5, PR-202,GPU-26	Seed hardening and sowing, contour cultivation, small sectional bunds, transplanting of Finger millet

Crop yield not only depends on the magnitude of weather but also on distribution pattern of weather during cropping season. Not just delayed sowings but also drought conditions during different stages of crop growth period like early, mid season and terminal drought affect the productivity of crops. Contingent plans for these three types of droughts are outlined in tables 4.6 to 4.8. Besides drought, heavy and untimely rains play havoc to crops. Contingency measures for such conditions are provided in Table 4.9.

Table 4.6: Weather based contingent crop plan for normal onset with early season drought

Early season drought	Normal crop/ cropping system	Suggested contingency measures	
		Change in crop/ cropping system	Agronomic measures
Normal onset followed by 15-20 days dry spell after sowing leading to poor germination/ crop stand etc. delay by 2 weeks	Finger millet mixed cropping Pigeonpea and Field bean mixed cropping	Gap filling and thinning, dibbling of Cowpea seeds in borders and gaps, Resowing	Repeated inter cultivation, small section bunds, thinning and gap filling with Cowpea, top dressing after stress alleviation

Table 4.7: Weather based contingent crop plan for mid season drought condition

Mid season drought	Soil type	Suggested contingency measures
Long dry spell, consecutive 2 weeks rainless (>2.5 mm) period at seedling stage	Red soil, Sandy loam, Sandy soil	Thinning, postponement of top dressing, small sectional bunds, inter cultivation and mulching
Long dry spell, consecutive 2 weeks rainless (>2.5 mm) period at flowering / fruiting stage	Red soil, Sandy loam, Sandy soil	Weeding and weed mulching, Second top dressing after stress alleviation

Table 4.8: Weather based contingent crop plan for terminal drought condition

Soil type	Suggested contingency measures
	Crop management
Red soil, Sandy loam, Sandy soil	Provide life saving irrigations

Table 4.9: Weather based contingent crop plan for unusual rains (untimely, unseasonal) for both rainfed and irrigation situation

Condition	Suggested contingency measures			
Normal crop/ cropping system	**Seedling stage**	**Flowering stage**	**Crop maturity stage**	**Post harvest**
Finger millet	Drain out excess water	Drain out excess water	Postpone the harvesting, drain out excess water	Make rain proof heaps

d. Weather Based Crop Insurance for Finger Millet

Based on the agrometeorological experiments, the amount of water required in each stage of the crop for comfortable growth and realization of the optimum biomass has been worked out. The growth loss and its impact on the grain yield for the reduction of each millimeter of rainfall has been generated. The economic loss caused due to shortage of every millimeter of rainfall in individual crop growth stages has been worked out and the information has been provided to the Govt. of Karnataka (GOK Experimental Weather based Crop Insurance plan Mungaaru 2030, Govt. Order). The details of the crop water requirement in each crop growth stages, threshold rainfall values, percentage of crop loss due to shortage of rainfall and its impact in the crop density in the subsequent crop stages and the grain yield loss are given in table 4.10. The amount of insurance supposed to be assured is also given in the last column. Taking the minimum supporting prices, the quantum of economic loss and percentage of compensation (% amount) is also indicated. The crop loss due to heavy rains also worked out and the percentage of amount insured amount eligible in each stages of the crop loss is also indicated in Table 4.11.

Table 4.10: Crop weather insurance for crop loss due to dry spell at different stages of finger millet at GKVK centre

	Period I	Period II	Period III	Cumulative	Alter. crop	% yield loss	Assured Insurance
Period	15th July – 25th Aug. 40 days	26th Aug.–4th Oct.40 days (40+days old crop)	5th Oct.- 20th Nov. 45 days(80+days old crop)	125 days			
Dry Period	Normal	15 Days	15 Days	2 spells of 15 days		No loss	
I (a)	>25 days (suggested for sowing alternate crop)	Normal (Only 50% crop will be leftover)	Normal (50% crop will continue)	(50% crop will continue)	Sowing can not be taken up but can go for legume crops	50%	50%
I (b)	Normal	>15 days<25 days (50% crop will be leftover)	Normal (50% crop will continue)	1 spell of 15-25 days	Crop affected at one stage	50%	50%
I (c)	Normal	Normal	>15 days<25 days(50% crop will be leftover)	1 spell of 15-25 days (50% crop will continue)	Crop affected at one stage	50%	50%
I (d)	> 25 days (50% crop will be leftover)	>15 days<25 days (remain ing 50% crop also will be lost)	No crop	Crop affected at two stages		100%	100%
I (e)	> 25 days (50% crop will be leftover)	Normal	>25 days (entire 100% crop will be lost)	2 spells of 15 -25 days (no crop)	Crop affected at two stages	100%	100%
I (f)	Normal	>15 days <25 days (remain-ing 50% crop also will be lost)	>25 days (entire 100% crop will be lost)	2 spells of 15-25 days (no crop)	Crop affected at two stages	100%	100%
I (g)	>30 days	(Entire crop will be dried)	100%	100%			

Season: Kharif (Number of years considered is 37 years)

Payouts recommendations:

Phases	15th July-25 th August	26th August -4th Oct	5th Oct-20th Nov
Index	Water requirement 64 mm	Water requirement 141 mm	Water requirement 107 mm
Strike 1	64-21 mm (25% loss)	141-47 mm (25% loss)	107-36 mm (25% loss)
Strike 2	21-10 mm (25% loss)	47-20 mm (25% loss)	36-20 mm (25% loss)
Exit	10mm	10 mm (50% loss)	10 mm (50% loss)
	S1=64 Rs/mm/ha	S1=29 Rs/mm/ha	S1=39 Rs/mm/ha
	S2=250 Rs/mm/ha -	S2=102Rs/mm/ha Exit=550 Rs/mm/ha	S2=172 Rs/mm/ha Exit=550 Rs/mm/ha
Maximum payout (Rs.)	5500/-	5500/-	11000
No.of events S1	1	9	9
S2	0	1	1

Note: If crop is affected in two stages 100% payout is recommended (Based on farmers average yield of the crop)

Table 4.11: Crop weather insurance for crop loss due to heavy rains at different stages of finger millet

	Period I	Period II	Period III	Cumulative	% of yield loss	Assured Insurance
Periods	15th July – 25th Aug. 40 days	26th Aug.– 4th Oct.40 days (40 + days old crop)	5th Oct.-20th Nov. 45 days (80+days old crop)	125 days		
Water requirement	100 mm	160 mm	100 mm	360 mm	No loss	00
I (a)	> 100 mm / day or >150 in two consecutive days	Normal (>55mm)	Normal (>35 mm)	Crop is affected at one stage	50 %	50 %
I (b)	Normal	> 150 mm / day or >250 in two consecutive days	Normal	Crop is affected at one stage	50 %	50 %
I (c)	Normal	Normal	>150 mm / day or >250 in two consecutive days	Crop is affected at one stage	50 %	50 %
I (d)	> 100 mm / day or >150 in two consecutive days	> 150 mm / day or >250 in two consecutive days	Normal	Crop is affected at two stages	100 %	100 %
I (e)	> 100 mm / day or >150 in two consecutive days	Normal	> 150 mm / day or >250 in two consecutive days	Crop is affected at two stages	100 %	100 %
I (f)	Normal	> 150 mm / day or >250 in two consecutive days	> 150 mm / day or >250 in two consecutive days	Crop is affected at two stages	100 %	100 %

Payouts recommendations

Phases	15th July - 25th August	26th August-4th Oct.	5th Oct.-20th Nov
Index	Water requirement 64 mm	Water requirement 141 mm	Water requirement 107 mm
Strike1-Daily Rainfall	100-150mm (50% loss)	150-200 mm (50% loss)	150-200 mm (50% loss)
Exit	150 mm* (if >150mm in two consecutive days 50% crop loss)	200 mm* (if >250 mm in two consecutive days (50% crop loss))	200 mm* (if >250mm in two consecutive days (50% crop loss))
	S1=110Rs/mm/ha	S1=110 Rs/mm/ha	S1=110 Rs/mm/ha
	*110Rs/mm/ha	*110 Rs/mm/ha	*110 Rs/mm/ha
Maximum payout (Rs.)	5500/-	5500/-	5500/-
No.of events in a day S1 (>100)	0	2	1
Exit (>150)	0	1	0

Note: If crop is affected in two stages 100% payouts is recommended (Based on farmers average yield of the crop).

e. Crop Weather Calendar

Crop weather calendar consists of the weekly normal weather data during crop growing periods, sowing window of different crops and their phenological stages. For normal and varied rainfall situations, crops of different durations and varieties are also included. Information contained in the calendars guides the planners, agricultural administrators, plant breeders and the farmers in formulating the policy matters regarding plant breeding, crop adoption, drought proofing, supplemental irrigation and thus maximizing the yield. Figure 4.1 to 4.6 provides mean weather factors and crop weather calendar for major Finger millet growing districts of Karnataka.

Bengaluru rural / urban district

Months	APRIL				MAY				JUNE					JULY			
Std Weeks	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
RF (mm)	3.1 a	11.5	17.6	12.0	20.4	17.8	21.8	28.3	29.2	25.3	21.3	10.3	7.8	17.7	25.2	24.2	27.5
Rainy days	0	1	1	1	1	1	1	2	2	2	1	1	1	1	2	2	2
Max. Temp	33.4	33.8	33.7	33.8	33.7	33.4	33.2	32.7	31.6	30.3	29.1	29.1	29.0	28.8	28.3	28.1	27.7
Min. Temp	19.8	20.3	20.5	20.6	20.7	20.8	20.4	20.4	19.9	19.6	19.5	19.3	19.2	19.1	19.0	19.1	19.0
PET (mm)	37.5	38.4	38.4	38.0	36.7	37.6	38.5	37.2	34.5	34.2	32.0	33.1	32.6	31.0	30.2	29.8	28.5
SSH (Hrs)	8.7	8.7	8.8	8.7	8.3	8.1	8.3	8.4	7.5	6.5	5.1	5.2	5.3	4.8	4.3	4.5	3.9
WS (Km/Hr)	6.9	6.6	6.8	6.9	7.3	7.8	8.8	9.2	9.7	11.5	12.6	14.3	14.1	13.2	12.5	12.7	11.7
EVP (mm)	7.7	7.7	7.3	7.4	7.5	7.0	7.0	7.1	6.6	6.2	5.8	5.8	6.0	5.8	5.3	5.2	4.9
RH I hr(%)	78	79	79	78	80	81	80	81	83	85	86	87	87	87	87	88	89
RH II hr (%)	33	33	36	35	36	39	39	41	45	50	53	53	53	53	55	56	58
AET	3.7	14.0	20.7	10.7	19.1	16.3	16.9	29.7	30.7	29.4	22.0	9.1	8.7	18.0	24.3	22.9	27.4

Months	AUGUST					SEPTEMBER				OCTOBER				NOVEMBER				DECEMBER				
Std Weeks	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
RF (mm)	32.2	24.1	27.8	35.3	31.8	42.0	48.0	55.6	45.8	62.7	35.2	30.0	25.8	23.5	16.4	13.4	10.7	4.3	4.6	3.1	2.8	2.0
Rainy days	2	2	2	3	2	2	2	2	2	3	2	2	2	1	1	1	1	0	0	0	0	0
Max. Temp	27.5	27.5	27.5	27.7	27.9	28.1	28.2	28.1	28.0	27.8	28.1	27.6	27.7	27.0	26.8	26.6	26.6	26.4	26.0	26.1	26.1	26.3
Min. Temp	18.8	18.9	18.9	18.8	18.7	18.8	18.8	18.9	18.8	18.7	18.6	18.2	17.9	17.5	17.5	16.5	16.3	15.2	14.8	14.5	14.1	14.1
PET (mm)	28.2	28.6	28.1	28.1	28.8	27.3	28.6	27.3	26.9	25.8	25.7	25.2	24.5	23.6	23.1	22.4	22.3	22.6	21.4	21.7	21.8	25.4
SSH (Hrs)	3.9	4.3	4.7	5.1	5.6	5.6	5.8	5.8	5.8	5.9	6.3	6.4	6.2	5.6	5.8	6.9	6.8	7.4	6.9	7.2	7.5	7.6
WS (Km/Hr)	11.5	11.8	10.5	9.5	9.2	8.0	7.6	7.0	6.2	6.1	5.4	5.3	5.6	6.1	6.5	6.3	6.2	6.8	7.0	7.0	7.6	6.9
EVP (mm)	4.6	4.9	4.8	4.9	5.0	5.0	4.9	5.1	4.8	4.6	4.6	4.6	4.8	4.6	4.3	4.3	4.6	4.6	4.4	4.5	4.5	4.5
RH I hr(%)	89	89	89	89	88	88	88	88	89	89	88	87	87	87	87	87	88	85	86	86	87	87
RH II hr (%)	58	58	57	58	56	57	56	57	59	58	56	57	57	56	57	56	56	51	54	51	50	48
AET	28.2	20.8	28.1	28.2	28.8	27.3	28.6	27.3	26.9	25.8	25.7	25.2	27.1	27.2	31.0	29.0	28.5	28.1	21.1	17.4	14.1	12.3

Normal Sowing
Long duration varieties

SOWING	TILLERING	GROWTH PHASE	E. H. E. & DEV	MATURITY & HARVEST
Sowing, fertilzer application	GAP filling, 2-3 times hoeing at 25 and 35 days after sowing	Nitrogen top dressing, hoeing and intercultivation	plant protection measures - sprays when necessary	Harvest threshing, drying and storage

cropping systems/ Inter cropping

SESAMUM - FINGER MILLET

FINGER MILLET + { PIGEON PEA / GROUNDNUT / FIELD BEAN / NIGER }

FINGER MILLET (Short Duration) + {PIGEON PEA / FIELD BEAN (Local Variety) / NIGER }

Late sowing
medium to short duration varieties

SOWING	TILLERING	GROWTH PHASE	E. H. E. & DEV	MATURITY & HARVEST
Sowing, fertilizer application	GAP filling, 2-3 times hoeing at 25 and 35 days after sowing	Nitrogen top dressing, hoeing and intercultivation	plant protection measures - sprays when necessary	Harvest threshing, drying and storage

Fig 4.1: Mean weather variables and crop calendar of finger millet for Bengaluru rural / urban district

Hassan district

Months	JUN				JUL				AUG					SEP				OCT				NOV					DEC			
Std Weeks	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
RainFall (mm)	27.0	20.0	23.0	36.0	38.0	31.0	26.0	25.0	27.0	22.0	20.0	12.0	8.0	14.0	16.0	39.0	34.0	36.0	44.0	34.0	29.0	14.0	16.0	7.0	7.0	2.0	4.0	4.0	2.0	0.0
Rainy days	2	2	2	3	3	2	2	2	2	2	2	2	1	1	1	3	2	2	2	2	2	1	1	1	1	0	1	0	0	0
Max. Temp	27.1	26.8	26.5	26.1	25.5	24.6	24.2	24.5	24.7	24.8	24.9	25.1	25.2	25.5	26.4	26.8	27.1	27.3	27.1	27.0	26.8	26.8	26.7	26.6	26.6	26.5	26.5	26.4	26.4	26.3
Min. Temp	18.9	18.7	18.6	18.5	18.5	18.3	18.2	18.3	18.4	18.5	18.5	18.4	18.3	18.2	18.3	18.3	18.2	18.2	18.2	18.1	17.9	17.2	16.9	16.7	16.4	16.1	15.8	15.1	14.4	14.1
RH (I)hr	88.6	88.8	89.2	89.4	89.6	89.8	90.1	90.3	90.4	90.2	90.0	89.8	89.6	89.4	89.1	88.9	88.6	88.4	87.9	87.1	86.2	85.4	84.6	83.2	82.8	82.4	82.3	82.1	81.9	81.8
RH (II)hr	78.1	78.3	79.5	79.8	80.5	80.9	81.6	81.2	81.4	81.2	81.0	80.9	80.6	79.5	78.1	76.9	75.8	74.4	72.8	71.1	69.1	67.2	65.8	64.1	62.6	60.4	58.6	57.1	55.4	54.2
VP (I)hr	23.2	23.1	22.9	22.8	22.5	22.3	22.2	22.0	22.1	22.0	21.9	21.9	21.8	21.9	22.1	22.1	21.9	21.9	21.8	21.8	21.6	21.1	20.8	20.4	19.9	19.2	18.6	17.9	17.3	16.9
VP (II)hr	24.1	23.8	23.6	23.1	22.9	22.5	22.3	22.5	22.5	22.6	22.6	22.7	22.8	22.9	23.1	22.9	22.8	22.6	22.4	22.1	21.5	21.1	20.6	20.2	19.8	18.9	18.4	17.6	17.1	16.5

Normal Sowing

Long duration varieties

SOWING	TILLERING	GROWTH PHASE	E. H. E. & DEV	MATURITY & HARVEST
Sowing, fertilizer application	GAP filling, 2-3 times hoeing at 25 and 35 days after sowing	Nitrogen top dressing, hoeing and intercultivation	plant protection measures - sprays when necessary	Harvest threshing, drying and storage

Inter cropping system — **FINGER MILLET + PIGEON PEA**

Fig 4.2: Mean weather variables and crop calendar of finger millet for Hassan district

Kolar district

Months	JUN				JUL				AUG					SEP				OCT				NOV					DEC			
Std. week	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
Rainfall (mm)	35	17	8	11	19	20	23	25	15	17	17	20	22	29	46	67	58	44	39	26	27	25	18	15	15	11	13	6	4	2
Rainy Days	2	1	0	1	1	1	1	2	1	1	1	1	2	1	2	3	3	2		2	1	2	1	1	1	1	2	1	0	0
Max. Temp	31.5	31.1	30.4	30.2	30.1	29.7	29.4	29.3	29.3	29.2	29	28.9	29	29.1	29.2	29.1	28.9	28.3	28.1	27.8	27.5	27.1	26.7	26.1	25.8	25.5	25.4	25.3	24.9	24.8
Min. Temp	21.4	20.8	20.4	20.3	20.3	20.2	20	19.9	19.9	19.8	19.7	19.6	19.6	19.7	19.8	19.6	19.5	19.4	19.4	19.2	18.6	18.3	17.9	17.4	17.2	16.9	16.4	15.9	15.5	15.1
RH (I) hr	74.5	75.2	75.4	75.8	76.3	77.8	78.4	79.1	79	79.5	79.8	80.3	80.5	80.3	80.1	80	80.1	80.3	81.5	81.6	80.8	80.5	79.8	79.6	80.1	80.3	81.4	82.8	83.6	83.8
RH (II) hr	53.9	54.4	55.6	56.1	56.4	57.2	58.1	58.9	59.1	60.2	60.4	60.9	61.9	62.3	62.9	63.5	64.1	65.8	66.7	67.8	67.5	67.4	67.2	67.1	66.8	66.7	64.8	63.6	62.7	62.1
VP (I) hr	22.8	22.4	21.8	21.6	21.7	21.6	21.8	21.7	21.5	21.6	21.7	21.9	22.1	22.3	22.1	22.2	22	22.1	21.9	21.7	21.6	21.1	20.4	19.8	19.4	18.9	18.6	18.1	17.6	17.3
VP (II) hr	21	20.9	20.7	20.6	20.7	20.8	20.9	20.8	20.8	20.9	21.1	21.2	21.2	21.3	21.5	21.6	21.4	21.5	21.3	20.9	20.6	20.3	19.5	19.1	18.6	18.1	17.9	17.3	16.8	16.4
Wind speed	11.5	11.3	11.2	10.9	11.1	10.9	10.9	10.7	10.8	10.5	10.2	9.9	9.5	8.9	7.8	7.1	6.7	6.1	5.6	4.9	4.6	4.7	4.9	5.1	5.4	5.6	5.7	5.9	6.1	6.3

Normal Sowing

Long duration varieties

SOWING	TILLERING	GROWTH PHASE	E. H. E. & DEV	MATURITY & HARVEST
Sowing, fertilizer application	GAP filling, 2-3 times hoeing at 25 and 35 days after sowing	Nitrogen top dressing, hoeing and intercultivation	plant protection measures - sprays when necessary	Harvest threshing, drying and storage

SOWING	TILLERING	GROWTH PHASE	E. H. E. & DEV	MATURITY & HARVEST
Sowing, fertilizer application	GAP filling, 2-3 times hoeing at 25 and 35 days after sowing	Nitrogen top dressing, hoeing and intercultivation	plant protection measures - sprays when necessary	Harvest threshing, drying and storage

Inter cropping system

FINGER MILLET + { PIGEON PEA / FIELD BEAN / NIGER }

FINGER MILLET + { PIGEON PEA / FIELD BEAN / NIGER }

FINGER MILLET (Short Duration) + { PIGEON PEA / FIELD BEAN (Local Variety) / NIGER }

FINGER MILLET (Short Duration) + { PIGEON PEA / FIELD BEAN (Local Variety) / NIGER }

FINGER MILLET (Short Duration) + { PIGEON PEA / FIELD BEAN (Local Variety) / NIGER }

Late sowing short duration varieties

SOWING	TILLERING		E. H. E. & DEV	
Sowing, fertilzer application	GAP filling, 2-3 times hoeing at 25 and 35 days after sowing	Nitrogen top dressing, hoeing and intercultivation	Nitrogen top dressing, hoeing and intercultivation	Harvest threshing, drying and storage

Fig 4.3: Mean weather variables and crop calendar of finger millet for Kolar district

Mandya district

Months	JUN				JUL				AUG					SEP				OCT					NOV				DEC			
Std. Week	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
Rainfall (mm)	23	10	9	7	11	11	11	14	13	12	13	15	18	17	38	54	41	44	45	37	26	21	12	6	8	3	7	4	1	1
Rainy Days	0	1	3	0	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	1	1	1	1	0	1	0	0	0
Max.Temp	31.2	30.8	30.6	30.2	30.1	29.6	29.3	29.1	28.7	28.5	29.1	29.2	29.4	29.8	30.8	30.2	29.7	29.6	29.7	29.5	29.4	29.5	29.1	29.3	28.4	28.7	28.5	28.4	28.3	28.1
Min.Temp	20.6	20.4	20.1	19.8	20.2	19.9	20.1	20	19.8	20	19.7	19.5	19.3	19.7	19.5	19.6	19.5	19.6	19.8	19.4	19.3	18.7	18.5	18.6	18.1	17.9	17.1	16.4	15.9	15.6
RH(I)hr	81.8	82.7	83.5	83.8	83.6	83.1	82.7	82.5	82.8	83.6	84.5	84.9	84.1	83.8	84.2	84.7	84	85.9	86.2	85	84.1	84.2	83.9	83.2	82.7	82.3	82.6	82.4	81.6	81.4
RH(II)hr	67.5	68.1	70.4	70.9	72.3	72.9	73.2	73.6	73.9	73.1	72.8	71.4	71.1	69.4	68.1	67.4	67.9	68.6	69.2	70.9	70.1	70.3	69.2	68.3	67.4	64.9	63.6	62.4	61.1	60.2
VP(I)hr	25.1	24.8	24.6	24.5	24.1	24.7	24.1	24.2	24.3	24.1	24	24.2	24.2	24.1	24	24.2	24.1	24.6	24.8	23.5	23.9	23.7	23.2	22.7	22.5	21.6	21.4	20.6	19.2	18.6
VP(II)hr	25.6	25.1	24.8	24.7	24.8	24.6	24.6	24.4	24.5	24.8	24.6	24.8	24.7	24.6	24.8	24.7	24.6	24.8	24.6	24.1	23.9	24.1	23.8	23.4	23.1	22.2	21.8	21.1	20.4	20.1
Wind speed	6.8	6.9	6.7	6.5	6.8	6.9	6.7	6.6	6.5	6.1	5.8	6.4	5.7	5.2	4.9	4.7	4.2	3.9	4.1	3.6	3.4	3.5	3.4	3.2	3.3	3.5	3.4	3.6	3.5	3.7

Normal Sowing

Long duration varieties

SOWING	TILLERING	GROWTH PHASE	E. H. E. & DEV	MATURITY & HARVEST
Sowing, fertilizer application	GAP filling, 2-3 times hoeing at 25 and 35 days after sowing	Nitrogen top dressing, hoeing and intercultivation	plant protection measures - sprays when necessary	Harvest threshing, drying and storage

SOWING	TILLERING	GROWTH PHASE	E. H. E. & DEV	MATURITY & HARVEST
Sowing, fertilizer application	GAP filling, 2-3 times hoeing at 25 and 35 days after sowing	Nitrogen top dressing, hoeing and intercultivation	plant protection measures - sprays when necessary	Harvest threshing, drying and storage

SOWING	TILLERING	GROWTH PHASE	E. H. E. & DEV	MATURITY & HARVEST
Sowing, fertilizer application	GAP filling, 2-3 times hoeing at 25 and 35 days after sowing	Nitrogen top dressing, hoeing and intercultivation	plant protection measures - sprays when necessary	Harvest threshing, drying and storage

Inter cropping system

FINGER MILLET + { PIGEON PEA / FIELD BEAN / SOYABEAN }

FINGER MILLET + { PIGEON PEA / FIELD BEAN / SOYABEAN }

Late sowing

Short duration varieties

SOWING	TILLERING	GROWTH PHASE	E. H. E. & DEV	MATURITY & HARVEST
Sowing, fertilzer application	GAP filling, 2-3 times hoeing at 25 and 35 days after sowing	Nitrogen top dressing, hoeing and intercultivation	plant protection measures - sprays when necessary	Harvest threshing, drying and storage

Fig-4.4: Mean weather variables and crop calendar of finger millet for Mandya district

Mysore district

Months	JUN				JUL				AUG					SEP				OCT					NOV				DEC			
Std.Week	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
Rainfall (mm)	28	16	17	20	27	21	17	20	18	17	16	14	125	12	28	46	42	36	44	38	32	16	15	12	14	3	8	5	1	1
RainyDays	2	2	1	2	2	2	2	2	2	2	1	1	1	1	2	3	2	2	3	2	2	1	1	1	1	1	1	0	0	0
Max.Temp	29.9	29.8	29.4	29.2	28.6	28.3	28.2	28.1	28	27.9	28.1	28.1	28.2	28.5	28.9	29.4	29.2	29.1	29.2	28.9	28.8	28.6	28.6	28.4	28.4	28.3	28.1	27.9	27.7	27.5
Min.Temp	20.4	20.1	19.9	19.7	19.7	19.5	19.5	19.4	19.4	19.5	19.6	19.5	19.5	19.6	19.5	19.5	19.4	19.4	19.5	19.3	19.2	19.1	18.8	18.4	17.9	17.7	17.3	17.1	16.7	16.4
RH (I) hr	83.5	83.6	84.2	84.4	84.6	84.8	85.2	85.4	85.6	85.8	85.9	86.2	86.4	86.2	86.1	85.8	85.6	85.4	85.2	84.8	84.6	84.2	83.6	82.4	81.8	81.1	80.6	80.1	79.9	79.4
RH (II) hr	67.1	68.6	69.8	70.5	70.9	71.8	72.4	72.6	72.4	72.3	72.1	71.8	71.6	70.2	68.8	68.1	67.3	67.8	68.2	68.1	67.6	66.1	64.8	63.5	62.2	61.4	60.1	58.8	57.4	56.2
VP (I) hr	24.5	24.2	23.7	23.4	23.3	23.1	22.9	22.7	22.8	22.9	23	23.1	22.9	22.9	23	23.1	22.9	22.9	22.8	22.9	22.8	22.5	22.1	21.6	21.3	20.9	20.2	19.4	18.6	18.1
VP (II) hr	24.1	23.8	23.6	23.2	23.1	23.1	22.9	22.8	22.9	23.1	23.1	23	22.9	22.8	22.9	23	22.9	22.9	23	23	22.8	22.6	22.2	21.5	21.1	20.7	20.1	19.3	18.6	18.1

Normal Sowing

Long duration varieties

SOWING	TILLERING	GROWTH PHASE	E. H. E. & DEV	MATURITY & HARVEST
Sowing, fertilizer application	GAP filling, 2-3 times hoeing at 25 and 35 days after sowing	Nitrogen top dressing, hoeing and intercultivation	plant protection measures - sprays when necessary	Harvest threshing, drying and storage

SOWING	TILLERING	GROWTH PHASE	E. H. E. & DEV	MATURITY & HARVEST
Sowing, fertilizer application	GAP filling, 2-3 times hoeing at 25 and 35 days after sowing	Nitrogen top dressing, hoeing and intercultivation	plant protection measures - sprays when necessary	Harvest threshing, drying and storage

Inter cropping system

FINGER MILLET + FIELD BEAN

FINGER MILLET + CASTOR

Late sowing

Short duration varieties

SOWING	TILLERING	GROWTH PHASE	E. H. E. & DEV	MATURITY & HARVEST
Sowing, fertilizer application	GAP filling, 2-3 times hoeing at 25 and 35 days after sowing	Nitrogen top dressing, hoeing and intercultivation	plant protection measures - sprays when necessary	Harvest threshing, drying and storage

Fig-4.5: Mean weather variables and crop calendar of finger millet for Mysore district

Tumkur district

Months	JUN				JUL				AUG					SEP				OCT					NOV				DEC			
Std Weeks	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
Rainfall (mm)	35	18	16	10	13	25	36	32	28	20	22	21	26	28	35	59	46	53	39	28	26	15	13	8	6	4	7	4	1	1
Rainy Days	2	2	1	2	1	2	2	2	2	1	2	2	2	1	2	3	2	2	2	2	1	1	1	1	0	0	1	0	0	0
Max. Temp	30.8	30.5	29.6	30.1	29.2	28.9	28.4	28.5	28.7	28.5	28.1	28.3	28.4	28.6	29.3	29	29.2	29	29.1	28.9	28.3	28.3	28.1	27.9	27.6	27.5	27.4	27.3	27.3	27.2
Min. Temp	20.8	20.4	20	20.1	20.1	19.8	19.6	19.7	19.6	19.5	19.4	19.5	19.3	19.3	19.5	19.4	19.2	19.4	19.5	19.1	19.2	19.1	18.6	18.2	17.9	17.4	17.1	16.8	16.5	15.8
RH (I)hr	77.5	78.3	79.5	80.2	80.8	81.1	80.9	81.3	81.8	82.6	83.5	84.1	83.1	83.5	82.4	81.6	80.5	79.6	78.9	76.4	75.1	74.2	73.5	72.9	71.9	71.6	71.2	70.6	70.2	69.5
RH(II)hr	56.3	58.9	61.2	62.7	63.8	65.2	66.8	67.8	68.5	68.1	67.2	66.5	65.8	64.3	63.1	60.8	61.2	61.3	60.8	61.1	59.7	60.3	59.8	58.8	57.2	56.1	53.8	50.4	47.5	45.8
VP(I)hr	23.1	22.9	22.4	22.6	22.5	22.3	21.9	22.3	22.4	22.1	22.2	21.8	22.4	22.8	22.6	21.9	21.5	21.9	22.1	21.5	21.2	20.8	20.4	19.5	19.1	18.6	17.4	16.8	16.6	16.1
VP(II)hr	20.6	20.9	21.5	21.8	21.9	21.6	21.4	21.5	21.7	21.5	21.6	21.8	21.7	21.9	21.7	21.5	21.2	20.9	21.2	20.2	20.6	20.1	19.5	18.7	17.6	17.2	16.7	15.9	15.1	14.3
Wind Speed	8.1	7.8	7.2	7.4	7.3	7.1	6.8	6.7	6.7	6.3	6.5	6.2	6.3	6.1	5.9	5.8	5.7	5.1	4.6	4.3	4.5	4.9	5.3	5.8	6.2	6.4	6.3	6.4	6.6	6.7

Normal Sowing

Long duration varieties

SOWING	TILLERING	GROWTH PHASE	E. H. E. & DEV	MATURITY & HARVEST
Sowing, fertilizer application	GAP filling, 2-3 times hoeing at 25 and 35 days after sowing	Nitrogen top dressing, hoeing and intercultivation	plant protection measures - sprays when necessary	Harvest threshing, drying and storage

SOWING	TILLERING	GROWTH PHASE	E. H. E. & DEV	MATURITY & HARVEST
Sowing, fertilizer application	GAP filling, 2-3 times hoeing at 25 and 35 days after sowing	Nitrogen top dressing, hoeing and intercultivation	plant protection measures - sprays when necessary	Harvest threshing, drying and storage

Late sowing

Short duration varieties

SOWING	TILLERING	GROWTH PHASE	E. H. E. & DEV	MATURITY & HARVEST
Sowing, fertilizer application	GAP filling, 2-3 times hoeing at 25 and 35 days after sowing	Nitrogen top dressing, hoeing and intercultivation	plant protection measures - sprays when necessary	Harvest threshing, drying and storage

Intercropping systems

FINGER MILLET + FIELD BEAN OR FINGER MILLET + GROUNDNUT

FINGER MILLET + CASTOR

Fig-4.6: Mean weather variables and crop calendar of finger millet for Tumkur district

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ANNEXURE

Finger Millet varieties available under varied sowing windows spread out from June to October

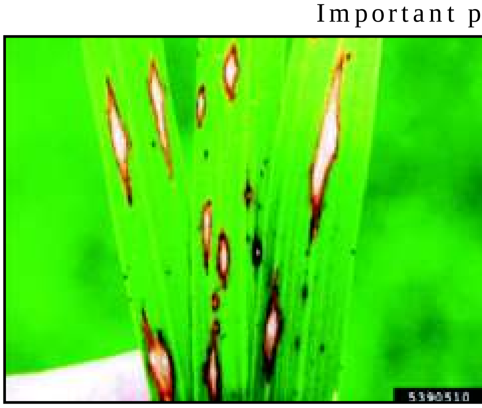
Sl.No.	Varieties	Duration in days	Sowing Season
1.	Indaf-8	120-130	June – July
2.	M.R-1	120-125	June – July
3.	M.R-6	120-125	June – July
4.	L-5	115-120	June – July
5.	KMR-301	120-125	June – July
6.	HR-911	115-120	July
7.	Indaf-5	105-110	July – August
8.	GPU-28	110-115	July – August
9.	Indaf-9	110-115	July – August
10.	KMR-204	100-110	July-August
Varieties Recommended for Late Kharif			
11.	PR-202	115-120	August
12.	GPU-45	95-100	August – October
13.	GPU-48	100-105	August – October
14.	GPU-26	100-105	August – October
15.	GPU-66	100-105	August – October
Varieties Recommended for Winter Season			
16.	Indaf-7	115-120	September-October
17.	KMR-301	120-125	September-October

Major Pests, Diseases and their Management

The important pests in this crop are: stem borer, hairy caterpillars and aphids. Proper Integrated Pest Management (IPM) practices should be followed to keep the pest population below ETL (Economic Threshold Level).

Sl. No.	Name of the Important pest/disease	Phases of incidence	Favourable Weather parameters	Control measures
Pests				
1.	Stem Borer	Tillering and Panicle emergence phase	The optimum temperature 24-29°C for the hatching is with RH 90-100%.	Field Sanitation, Summer Ploughing, crop rotation with non-germinaceous crops, Spray Methyl Parathion 1 ml/ Liter of water at seedling stage and at tillering stage.
2.	Aphids	Seedling to tillering and panicle emergence to milky phase	Requires warm temperature 25-30°C with RH > 85%	Proper Spacing, Remove weeds, Intercultivation, Spray Phosphamidon 100 EC(0.5 ml/Lit) or Dimethoate 30 EC(0.7 ml/lit) or Confidor 0.6ml ltr
3.	Ear head Webber	Panicle emergence to maturity	Requires warm temperature 25-30°C with RH > 90 %	Use Malathion 5% dust or Carbaryl 10 % dust at ear head stage.
Diseases				
1.	Leaf Blast and Neck Blast ***Pyricularia grisea***	Seedling –tillering, panicle emergence-maturity	Low night temp. (<24°C) coupled with high RH helps in rapid spread of the disease.	*Use resistant Varities like: GPU-28, GPU-48, C-5. Avoid excess application of N. Maintain proper row spacing, Timely weeding. *Spray Tricyclozole (0.6 g/l) -Beam or Edifenphos-1ml/lit or Carbendazim 1.0 gm/ liter of water at seedling stage, tillering and after opening of flowers.
2.	**Cercospora leaf spot** ***Cercospora penniseti***	Disease occurs at Tillering, panicle emergence stage	Temp-28.7°CRH->92% with cloudy helps in spread of the disease.	Use resistant varieties -GPU-28, GPU-48Spray Mancozeb-1 gm and Carbendazim 1.0 gm at the time of symptoms

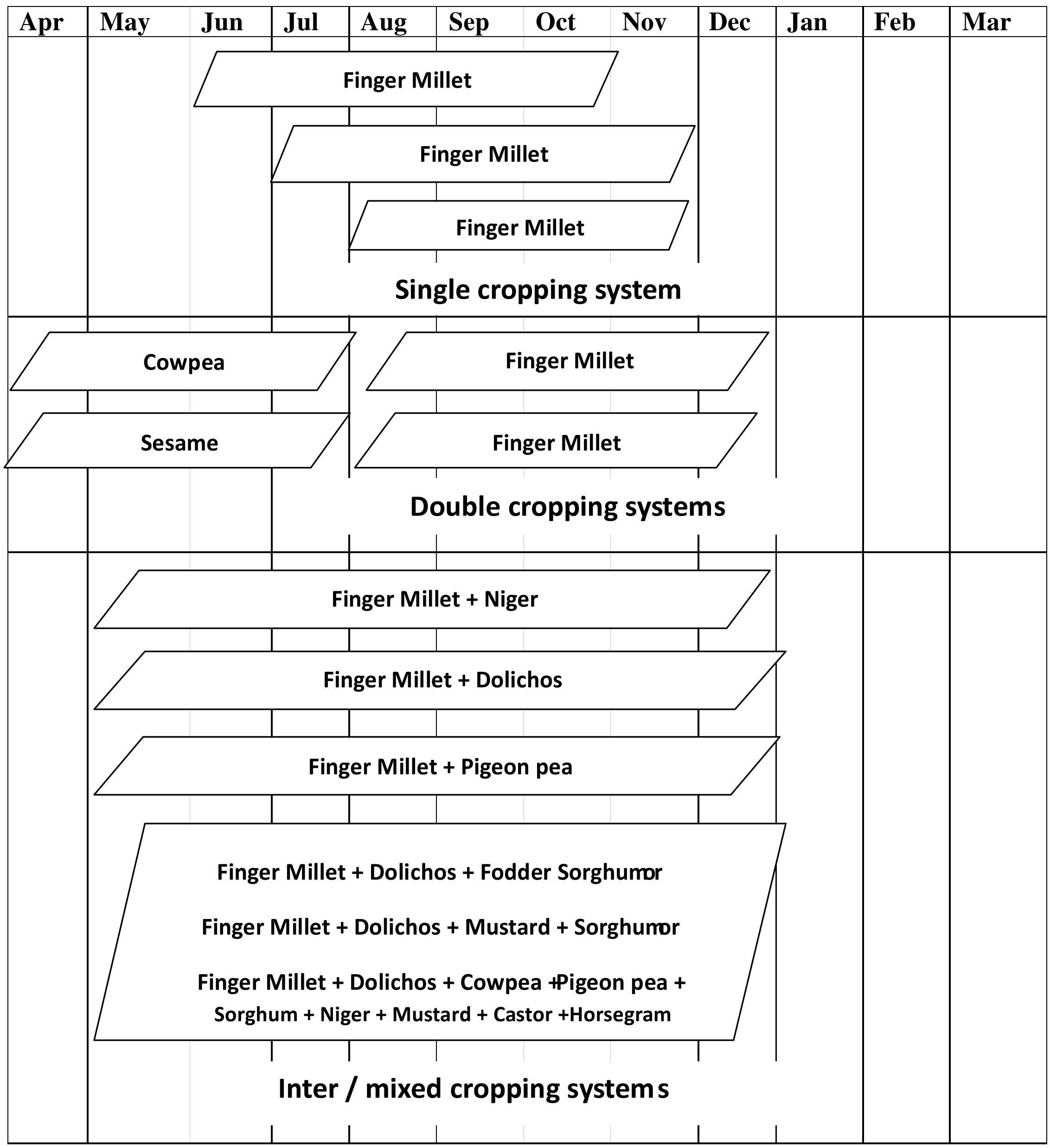
Important pests of Finger millet



Leaf blast

Leaf blast

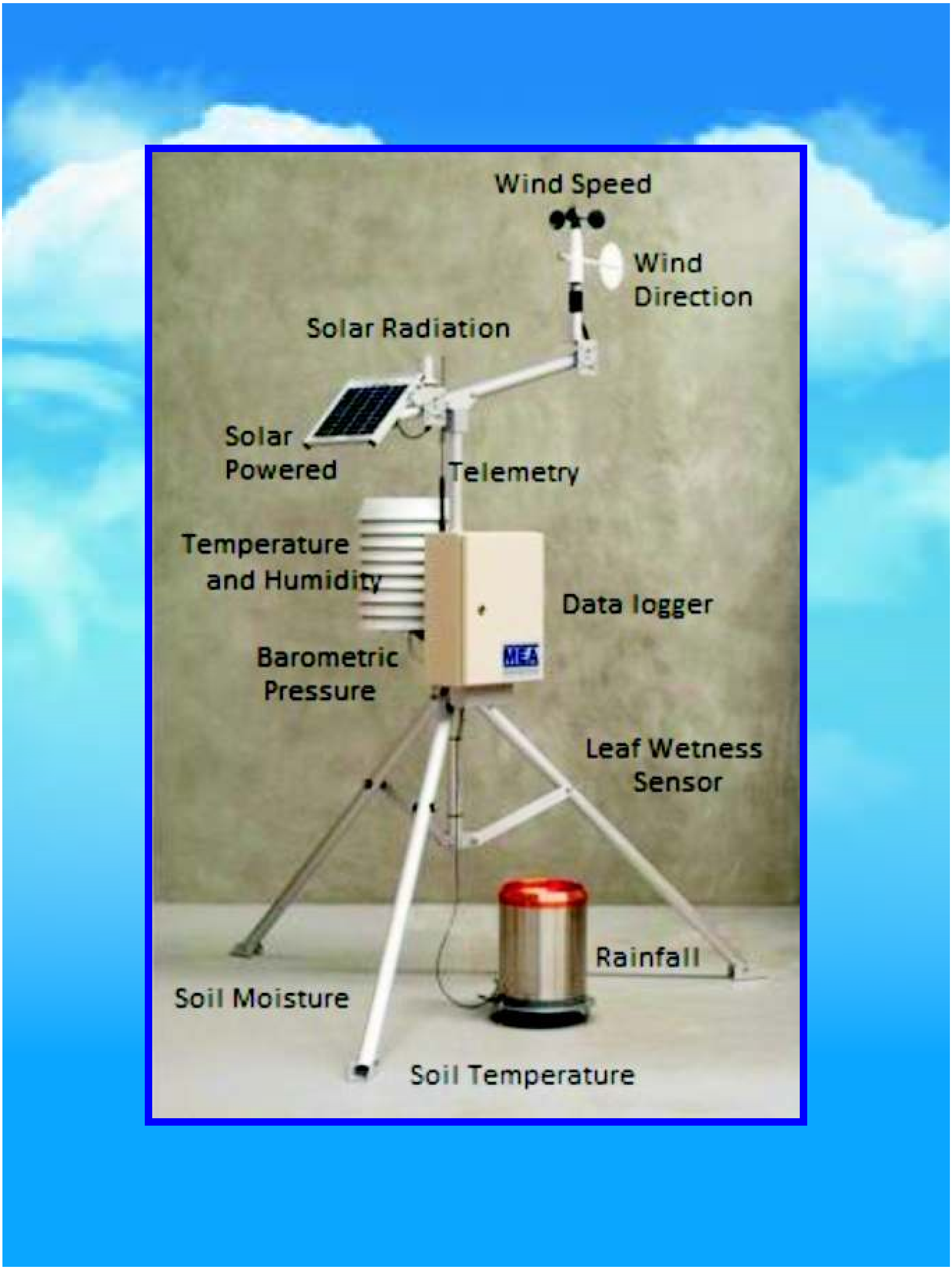
Important Diseases of Finger millet



Important Rainfed Finger Millet Cropping Systems

Agri-Horti system (Finger millet and Mango), climate resilient system for yield and income stability against drought

Agro-Forestry System (Finger millet with Silver oak/Melia dubia), climate resilient system for yield and income stability against drought


Wind Speed
Wind Direction
Solar Radiation
Solar Powered
Telemetry
Temperature and Humidity
Data logger
Barometric Pressure
MEA
Leaf Wetness Sensor
Rainfall
Soil Moisture
Soil Temperature