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Soil moisture induced yield variability in major crops of Karnataka

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ABSTRACT

South interior Karnataka, being a major rainfed zone contributing to production of pigeonpea, finger millet, groundnut, etc., suffers from severe yield instability due to dependency on rainfall. As the distribution of rainfall (spatial and temporal) is erratic, droughts are becoming a common phenomenon and adversely affecting regional crop production by influencing soil moisture availability. Regression studies on per cent available soil moisture (PASM) and yield were conducted based on long-term field observations in 2014–19 on soil moisture and crop yields in finger millet, pigeonpea and groundnut at UAS-GKVK, Bengaluru. The outcomes indicated large yield variability due to minor soil moisture differences. In finger millet, at 58 PASM, 50% (1500 kg/ha) of normal yield was obtained and at 40 PASM, only 25% of normal yield was obtained. In pigeonpea, the crop yield recorded at 25 PASM was 8–18% (202–347 kg/ha) of the normal yield. In groundnut 50 PASM gave 41% of normal yield. The outcome indicated different soil moisture requirement for different crops, stressed the need for amending existing non-crop specific PASM ranges for drought declaration. Amendments were brought in by considering different PASM levels in these three crops finger millet: 20–40 as severe, 40–60 as moderate, >60 as no drought; in pigeonpea, 25–30 as severe, 30–60 as moderate, >60 as no drought; in groundnut, 35–50 as severe, 50–70 PASM as moderate, >70 as no drought. Since the practicality of the study was proven, the amendments were given in the drought manual published by ministry of farmers' welfare.

Keywords: Drought, Finger millet, Groundnut, PASM, Pigeonpea

Water availability is a significant cause of variability in crop yields in many conditions (Ritchie 1983). Changes in seasonal precipitation, in-season precipitation, and inter-annual variation of precipitation affect the soil water regime. Precipitation amount and distribution along with dry-spell dynamics affect, in particular, the yield of rainfed crops (Thomson *et al*. 2006, Bal *et al.* 2022). The Indian sub-continent experiences large-scale drought in some part or the other, almost every year (Zhang *et al*. 2016). It has been shown that about 68% of cropped area in India is vulnerable to drought, of which 33% receives less than 750 mm of mean annual rainfall and is classified as chronically drought-prone while 35% which receives mean annual rainfall of 750–1125 mm is classified as drought-prone. The drought-prone areas of the country are confined primarily to the arid, semi-arid, and sub-humid regions of peninsular and western India (Anonymous 2002).

Presently, besides rainfall, number of tools are being used for real time drought declaration. They are extent of area sown, soil moisture-based indices i.e. Per cent available soil moisture (PASM) and moisture adequacy index (MAI), length of growing period (LGP), normalized difference vegetation Index (NDVI) and standardized precipitation index (SPI). Drought prone areas are declared based on rainfall/SPI deficiency as mandatory criteria besides impact criteria, viz. crop area sown, NDVI, PASM, MAI and hydrological indicators. Available soil moisture is a very relevant indicator of drought, especially in rainfed regions. The soil moisture-based indices could be calculated using a simple region wise soil-moisture balance methodology which entails collecting some of the baseline data related to soil properties, climatic parameters and crop growth pattern. Basically, soil moisture balance calculates the amount of rainfall available to crops depending upon crop water requirement, climatic evaporative demand and soil water holding capacity. It is suggested that one of the two soil moisture-based indices, viz. (a) PASM or (b) MAI can be used. These indices may be calculated at weekly intervals and averaged over dominant crop growth stages. These indices should be combined with other indicators for the determination of drought.

Since, finger millet (a cereal), pigeonpea (a pulse) and groundnut (an oilseed) are the prominent field crops of south interior Karnataka, the influence of available soil moisture

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on yield is important to decide the onset and occurrences of drought as impact indicators to provide relief assistance to farmers. Hence, the present study was undertaken to assess the soil moisture induced yield variability in these crops at different phenological phases.

MATERIALS AND METHODS

Experimental location and data collection: Long term crop-weather relationship and moisture depletion pattern in finger millet, pigeon pea and groundnut experiment were carried out during 2014–19 at AICRP on Agrometeorology field unit, Zonal Agricultural Research Station (ZARS), University of Agricultural Sciences, Gandhi Krishi Vigyan Kendra (GKVK), Bengaluru, Karnataka, India. The area receives an average 928 mm of rainfall in two peaks, in May and in September (bimodal type).

The Alditols of the study location were characterized for variations in soil texture, water holding capacity and bulk density according to three depths (0–15, 15–30 and 30–45 cm from top). Depletion of soil moisture from field capacity to wilting point were studied at different phenophases of the crops and its effect on yield was recorded. The available soil moisture in the particular volume of soil was calculated as follows.

$$SMW=\left(\frac{SMD_1}{15}\times 100\right)+\left(\frac{SMD_2}{15}\times 100\right)+\left(\frac{SMD_3}{15}\times 100\right)$$

where SMD_1, SMD_2, SMD_3 gravimetric soil moisture at first three layers (0–15, 15–30 and 30–45, respectively); the numerator 15 indicates the depth of soil layer.

Estimation of per cent available soil moisture (PASM): The values of PASM at different phenological phases were tabulated and correlations worked out with biomass accumulation during growth phases and yield of the crop. The PASM was derived from observed moisture data or soil-water balance model following the ‘bucket approach’ and it was calculated using the given formula.

$$PASM=\left(\frac{SMW\text{-}PWP}{FC\text{-}PWP}\right)\times 100 \quad (1)$$

where SMW, Weekly calculated volumetric soil moisture (vol/vol) for the current week; PWP, Permanent wilting point of the soil (vol/vol); FC, Field capacity of soil (vol/vol)

Further, this PASM is used as a one of the triggers in declaration of agricultural drought. In the drought manual published by ministry of farmers’ welfare, the range of PASM for classification of drought is given as 0–25%, severe drought; 25–50%, moderate drought; 50–75%, mild drought; 75–100%, no drought.

Development of relationship between crop yield and PASM: Regression equations were developed using yield of crop as dependent parameter and PASM as independent. The developed regression equations were used to calculate the yield at existing PASM ranges for drought declaration (0, 25, 50 and 100% PASM). Further, the calculated yield was compared with the normal yield of the crop (average yield of the crop under farmers’ practice and yield of the crop obtained under unlimited resources at experimental fields of a university or institute) and also the PASM required for getting 50% of the optimal yield. The hypothesis behind estimating PASM requirement for 50% of optimal yield is that, if a farmer gets at least 50% of yield, he would be able to meet the expenses of cost of cultivation, thereby able to get rid of farm debt related financial crisis.

RESULTS AND DISCUSSION

Weather during the crop growth

The crops were sown soon before onset of monsoon (May) in the experimental plots. The pigeonpea crop had three different sowing dates (May second fortnight, June first fortnight and June second fortnight). Finger millet crop was sown soon after onset of monsoon (June first fortnight) i.e. soon after the receipt of enough rainfall to bring up the soil moisture necessary for seed germination. Groundnut

Table 1 Rainfall deviation from normal during different phases of crops

Sowing window	Year	Early vegetative	Late vegetative	Flowering	Pod filling
May	2014	D	E	N -ve	D
	2015	E	E	N +ve	E
	2016	N +ve	E	D	S
	2017	E	S	D	D
	2018	N -ve	S	N +ve	S
	2019	N -ve	E	D	E
June	2014	D	N -ve	D	E
	2015	N +ve	D	E	D
	2016	E	D	S	S
	2017	S	D	D	D
	2018	S	D	S	D
	2019	E	D	E	D
July	2014	N -ve	D	E	D
	2015	D	E	D	E
	2016	D	S	S	NR
	2017	D	S	D	D
	2018	D	S	D	E
	2019	D	E	D	D
August	2014	D	E	D	S
	2015	E	D	E	S
	2016	S	S	NR	E
	2017	D	D	D	S
	2018	S	D	E	N -ve
	2019	E	D	D	NR

D, deficit (–20 to –59% of normal); E, excess (>20% of normal); S, scanty (–60 to –99% of normal); N +ve, Normal positive (0 to +20 of normal); N –ve, Normal Negative (0 to 20% of normal); NR, No Rain (–100% of normal rainfall).

crop was also sown under two dates of sowing i.e. first and second fortnight of June, looking into the availability of soil moisture.

Daily mean temperature during the crop growth was higher during early growth stages i.e. May second fortnight (Supplementary Fig 1) and decreased during end of the crop growth December second fortnight. As the fingermillet and groundnut are short duration crops, they complete their lifecycle before onset of winter season. But, pigeonpea being long duration crop, gets affected due to lower temperatures of January-February.

The rainfall in the region is of bimodal type, attains two peaks in a year (Supplementary Fig 2) i.e. one at May-June month and another peak at September month. In between the crop suffers due to moisture scarcity, during July-August, November-December months. This necessitates us to study impact of rainfall vis-à-vis soil moisture on crop growth. The variability being uncertain between year to year (Table 1), needs to be studied further. Relative humidity, being a parameter affected by temperature and rainfall, attained maximum up to 75% during the monsoon period (35–40 SMW). Lower relative humidity was observed during initial duration of the crop growth (18 SMW), when the rainfall was meagre to support enough surface evaporation and addition of vapor to the atmosphere (Supplementary Fig 3).

Relationship between crop yield and PASM

Finger millet: Finger millet is a drought resistant staple food crop of South India, widely grown in Alfisols of Karnataka and southern Andhra Pradesh (Sahadeva *et al*. 2019). Even after being drought tolerant crop, its yield is affected by the variation in the available soil moisture. The relationship established between grain yield and PASM is depicted in Fig 1. As it can be clearly observed that the yield and soil moisture follow a linear relationship, yield of the crop is estimated by fitting a trend line to the observed data of past years. The results of six years showed that at 58 PASM, the yield was reduced by 50% (1500 kg/ha). At 40 PASM, 25% of normal yield (800 kg/ha) was obtained. The interpolation of the curve depicts that the threshold PASM of 22% or less will lead to complete crop failure. Crop production interventions like adjusting the date of sowing may help in establishing a proper crop stand, but the occurrence of drought at active growth period of the crop reduces the yield drastically (Sahadeva *et al*. 2019) leading to see through the possibility of compensating the farmers. In cereals, drought induced reduction in yield is due to reduced rate of photosynthesis (Flexas *et al*. 2004), disturbed assimilate partitioning and poor flag leaf development (Farooq *et al*. 2009). Drought conditions at the tasseling stage resulted in a significant yield loss in maize (Anjum *et al*. 2011). In barley, drought resulted in a smaller number of fertile tillers and grains along with less 1000 grain weight (Samarah 2005).

Pigeonpea: Among various pulses cultivated in India, pigeonpea consists of 18% of share (Reddy *et al*. 2013) next to chickpea (40.2%). In long duration crops like pigeonpea, diseases like Fusarium wilt along with the moisture deficit paves way to crop loss (Singh *et al*. 2011). This necessitates proper management and also methodology of compensating the farmer for the loss. The correlation of PASM and yield in all sowing windows clearly shows that PASM and yield have positive significant correlation. PASM and yield relationship in Fig 2 indicates that the per cent increase in

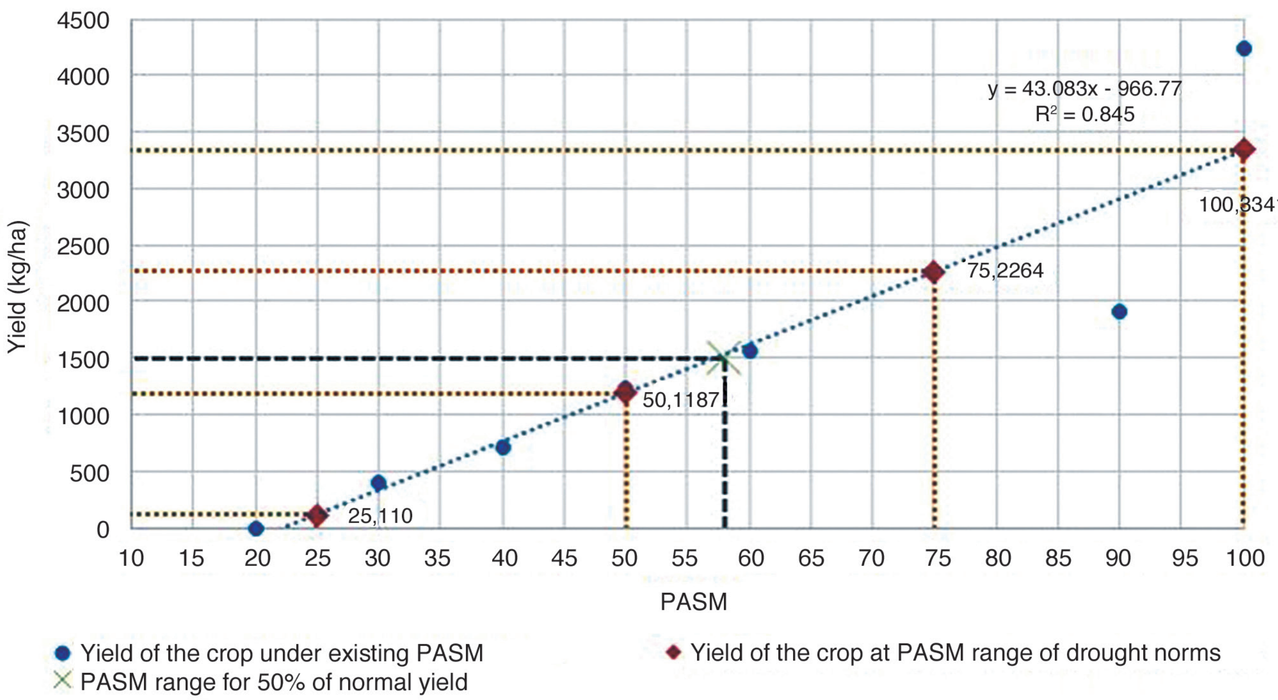

Fig 1 Relationship of finger millet grain yield (kg/ha) with PASM.

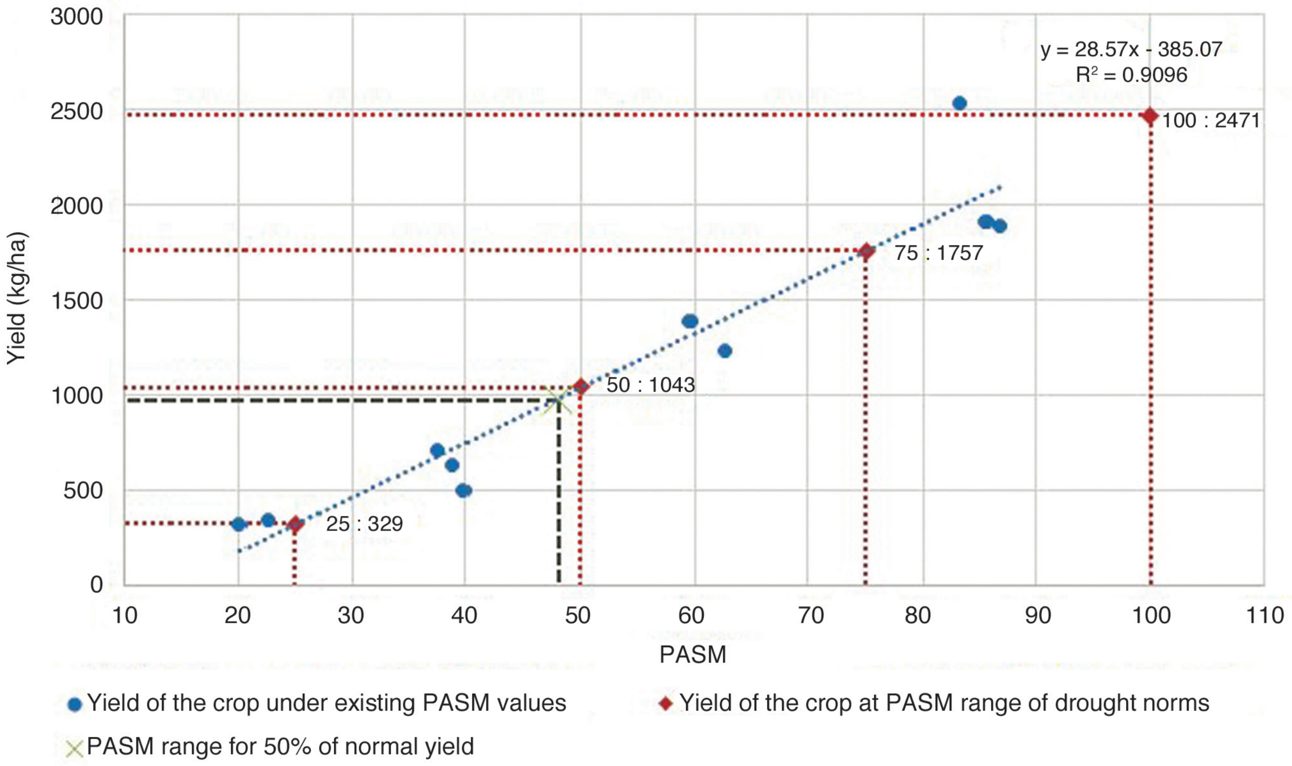

Fig 2 PASM and seed yield (kg/ha) relationship in pigeonpea.

yield is high with the increase in PASM as a single factor above 50% PASM. Hence, PASM values of 45%, the crop can yield only 50% of the normal yield. PASM of less than 15 will lead to complete crop failure. The crop yielded 1043 kg seed yield/ha when the PASM was 50, the yield levels were as low as 329 kg/ha when the PASM was 25.

The PASM values in different stages of pigeonpea crop over all sowing windows indicate that severe drought class (<25 PASM) gave an average of 20% of the yield during pod filling stage, while an average of 43% of the yield was obtained at severe drought during flowering stage. Thus, optimum moisture at these stages are crucial for getting potential yield of the crop. The moisture stress at different growth stages of pigeonpea affected its yield. Earlier researches also reported that the exposure of pigeonpea to drought stress at the flowering stage resulted in over 50% reduction in the seed yield (Nam *et al*. 2001). The seed yield of pigeonpea was higher by 46–66% in 20–40 cm soil depths over other soil depths (Subbareddy *et al*. 2001). Along with the rainfall, the on-field management practices affect the availability of soil moisture to the crop.

Groundnut: In groundnut crop, reduced pod and haulm yields were recorded due to stress during various growth stages. In most of the varieties grown under rainfed situation, pod-development stage and flowering period are most vulnerable to stress. The crop is known for its better performance under rainfed conditions, yet, it lacks the capacity to extract moisture from deeper layers. Gulati *et al*. (2000) proved the negative impact of water table depth on root length of groundnut. This emphasizes the impact of PASM on yield variability. The PASM values in different stages of groundnut crop indicated that moderate drought class (25–50 PASM) gave 41% of yield during pegging/pod formation which is crucial for yield of the crop. The PASM values of more than 50 in all phenological phases of the crop were satisfying ranges and hence there was no negative effect on crop yield. At PASM values of 38–41%, the pod yield was 29% (278 kg/ha) of optimum yield (962 kg/ha) under no drought (PASM 75–100%). The reduction in yield was the result of combined effect of reduced plant growth and severe moisture stress during late pod-filling period (Velu 1998). The crop management practices like application of FYM helps in improvement of yield in crops like groundnut as the FYM incorporation improves the porosity along with the supply of nutrients (Kumar *et al*. 2014).

PASM and yield relationship in Supplementary Fig 4 indicates that the per cent increase in yield is high with the increase in PASM as a single factor above 50% PASM. Hence, any PASM < 35 will lead to crop failure. Even though management practices like mulches influence the yield of the crop by reducing the evaporation loss of moisture from the soil (Chakravarti *et al*. 2010), in large rainfed crop production areas such options are not cost effective and unavailability of mulching makes them impractical. As per earlier PASM ranges for drought declaration, the crop yield was 0, 297, 1214 and 2131 kg/ha at PASM levels of 25, 50, 75 and 100, respectively (Supplementary Fig 4). Even though it's not possible to reach PASM level of 0 and 100, the crop performed best under the PASM range of 75–100. Further, the crop necessarily needs 56 PASM in order to produce at least half of the normal yield (479 kg/ha).

Majority of the rainfed crops in the semiarid tropics reach the wilting point below 33.3% of PASM (Richard *et al.* 1977). Below 50–33.3% of PASM, the Actual Evapo-transpiration by the crops is very low, and hence crops just survive but do not grow. This leads to the drastic reduction of grain or pod yield (Guled *et al*. 2013). When the PASM drops below 33.3%, crops start drying and withering of leaves begins, as no soil moisture is available to the crop root zone. Thereby, crops do not flower or grain formation does not take place, grain filling and maturity are severely affected, even if the grain formation stage is reached, leading to the zero grain or pod yield (Sahu *et al.* 2018). However, for declaration of drought in India, PASM value suggested is 0 to 25 (severe drought) as an impact of criteria irrespective of the crop (Anonymous 2016). Estimated yield of crops according to existing drought norms is depicted in Table 2 and the recommended modifications based on the study are indicated in Table 3. From this table, it can be clearly observed that the range of severe drought was extended up to 50 PASM using the outcome of the long-term experiments.

In a nutshell, for declaration of drought in India, the given PASM values may be followed as an impact criterion after the mandatory criteria of rainfall/SPI deficiencies are triggered : 20–40 PASM as severe, 40–60 PASM as moderate, >60 PASM as no drought for finger millet. 25–30 PASM as severe, 30–60 PASM as moderate, >60 PASM as no drought for pigeon pea. 35–50 PASM as severe, 50–70 PASM as moderate, >70 PASM as no drought for groundnut. Thus, the threshold value of 50% may be kept to differentiate drought and non-drought areas irrespective of crops. Ten years research in Agrometeorology section lead to redefining of the criteria for drought declaration. Long term Crop-weather and moisture depletion pattern in finger millet, pigeonpea and groundnut shown that the Per cent Available Soil Moisture (PASM) should not go below 50% for normal crop growth. If PASM goes below 50%, then the Taluk has to be declared drought affected. This criterion developed by AICRP on Agrometeorology, University of Agricultural Sciences, Bangalore was considered for modifying the National level guidelines of Drought Manual (Table 3) released by Ministry of Agriculture and Farmers Welfare, Government of India.

Table 2 Estimated yield of crops according to existing drought norms

	Estimated yield (kg/ha)		
PASM (%)	Finger millet	Pigeonpea	Groundnut
0–25	0	329	0
25–50	110	1043	297
50–75	1187	1757	1214
75–100	2264	2471	2131

Table 3 Existing and redefined ranges of PASM for drought declaration

Existing		Amended	
PASM range	Category	PASM range	Category
76–100	No drought	76–100	No drought
51–75	Mild drought	51–75	Mild drought
26–50	Moderate drought	0–50	Severe drought
< 25	Severe drought		

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