Journal of Natural Resource Conservation and Management
Vol. 4, No. 2, pp 139-146, 2023
doi: 10.51396/ANRCM.4.2.2023.139-146

Rainfall pattern affecting mango productivity under rainfed conditions in subtropics

Tarun Adak* and Ashok Kumar

ICAR- Central Institute for Subtropical Horticulture, Lucknow-226101, Uttar Pradesh, India
**Corresponding author email: cishtarunadak@gmail.com; Tarun.Adak@icar.gov.in*

Received : August 17, 2023
Revised : October 13, 2023
Accepted : October 15, 2023
Published : December 31, 2023

ABSTRACT

Scientific analysis of rainfall *vis-à-vis* farm productivity is important, as productivity largely depends on moisture availability. Rainfall is crucial for water conservation, harvesting, and distribution across agroecologies. A standardized precipitation index (Long-term dataset from 1990 to 2021) was developed to characterize fruit productivity. In subtropics, rainfall is a key factor determining economic dependency via its distribution pattern. The financial benefits thus should be harnessed in subtropics through contingency planning and integration of annual crops or intercrops in mango orchards. The scientific analysis showed variable numerical values of the number of rainy days from 29 to 24 to 32 during 2019, 2020, and 2021, respectively. Temporal variation of the total amount of rainfall in the reproductive stage was observed. Monthly average pan evaporation varied between 3.0 to 9.4, 2.8 to 7.3, and 4.5 to 9.7 mm/day in 2019, 2020, and 2021, respectively. Dynamics of standardized precipitation index in the mango growing belts of Lucknow, UP was noted, and lower mango productivity (6000 to 10,000 kg/ha) was linked with scarce rainfall and moisture conservation in these subtropical belts. Rainfall water use efficiency differed from 12.7 to 21.4 kg/mm of rainfall water across subtropics in the 2019 to 2021 mango growing season.

Keywords: Environmental analysis, subtropics, standardized precipitation index, mango orchards, productivity

INTRODUCTION

In the modern era of science, nutritional security is becoming a new challenge, and it is very much pertinent as the calorific intake variability was shown across various sections of society. Sendhil *et al.* (2020) scientifically analyzed lower nutrient consumption levels in the human population of different Indian states. The role of the atmosphere on human behavior, food requirements, and tree productivity has significantly impacted over recent decades. Rainfall, the crucial factor in orchard productivity, was also highly variable and scanty. It creates water stress and has implications for growing crops. Adak and Babu (2022) scientifically assessed the weather indicators *vis-à-vis* water application to improve water productivity and fruit yield in Amrapali mango under a dry, hot, subtropical climate. Luvaha *et al.* (2008) assessed mango physiological and morphological characteristics under water deficit conditions. Maseko *et al.* (2019) calculated yield reduction (6.14 and 6.30 t ha^{-1} to 5.70 and 5.12 t ha$^{-1,}$ respectively) in leafy vegetables in Hutton clay loam soil when there was a reduction of irrigation water use (912 mm to 550 mm). The number of fruits per tree also differed in environmental situations. Zunzunegui *et al.* (2010) noted 3575 in Mediterranean, 666 in Mountain, 539 in Coastal browsing, and 100038 in Coastal hydrological cycles. Stresses and all these indicators severely impacted the crop performances and need to be quantified systematically.

Evaluation of one or more environmental and soil indicators was thus given the highest priority in any country dealing with food security. Adak *et al.* (2022) emphasized resource conservation practices in mango germplasms for better resource use efficiency. Petsakos *et al.* (2019) nicely explained the increase in food availability over 2050 in Asia (6.8%) and the world (16.4%) as a consequence of the calorific contribution. Ferrer *et al.* (2017) opined the quality composition of fruit was also influenced by the meteorological regime. Zarch *et al.* (2015) scientifically analyzed world climates, showing the tendency of more dryness with a prediction of increasing trends of standardized precipitation index values of 12.1, 6.3, 7.1, and 14.5 in Arid, Semi-arid, Sub-humid, and Humid regions. Thus, precipitation indexing was thought of, and it will suggest understanding the scientific management of growers' orchards or farmers' fields. The need to develop a crop cafeteria and to plan for contingency crops along with the main fruit crop was re-designed.

Ballester *et al.* (2018) assessed the performance of spectral indices to identify water stress in five fruit trees. Shah *et al.* (2015) successfully explained using a standardized precipitation index for the Surat region, Gujarat, for agricultural planning and actual draught monitoring. In contrast, Dutta *et al.* (2015) observed spatio-temporal variations in the standardized precipitation index in Rajasthan, with negative values suggesting moderately to extremely dry conditions existed. In 2014, AghaKouchak developed a standardized soil moisture index to forecast droughts *vis-à-vis* food production effectively. Irrigation practices based on rainfall indicators also alter the microclimate in fruit farms. Blanco *et al.* (2018) quantified water stress indicators in sweet cherry and found that maximum daily branch shrinkage was the indicator that first detected water stress, followed by soil matric potential. The tree indicators like stomatal conductance and mid-day stem water potential are sensitive to water conditions; the signal intensity of 1.52 to 1.29 and 1.63 to 1.55 were noted in water deficits to normal practices, respectively. Elkollaly *et al.* (2017) applied **a** standardized precipitation index for drought analysis in the Eastern Nile basin. Poschlod *et al.* (2020) scientifically demonstrated the frequency and spatial distribution of heavy rainfall on saturated soil during summer and concurrent heavy rain and snowmelt as a function of climatic change. It was forecasted that there was a probability of a 38 percent increase in heavy rainfall on saturated soil from 1980 to 2070-2099. Thus, the changing precipitation pattern should be considered when analyzing farm productivity. Intercrops, if grown, would be highly beneficial for strategies and water maintenance criteria. The scientific evaluation also provides a means for improving water productivity. In subtropics, fruit orchards have lower productivity, for which sincere efforts were put in place to overcome the barrier of yield stagnation—the lack of scientific information rendered this study for improving farm efficiency.

MATERIALS AND METHODS

The present study was conducted in the subtropical zone of Uttar Pradesh, India. Fruit belts of famous Malihabad were considered for this study. The location of the study was at 26°54′N Latitude, 80°45′E Longitude, and 127 m above mean sea level. Day-to-day weather data of the meteorological observatory was compiled. Rainy days were calculated in each month during monsoon seasons. The total rainfall of historical data was tabulated (1990-2021). Pan evaporation of three consecutive 3 years (2019, 2020, and 2021) was incorporated for analysis. Rainfall events and each month's rainfall were also discussed. A standardized precipitation index was estimated. The value of SPI was used as a referral purpose to indicate moistness or dryness. Standardized precipitation index values of extremely dry, severely dry, and moderately dry were considered for the ranges between -1.00 to -1.49, -1.50 to -1.99, and -2.00 and less. Regarding wetness, 2.00 and above, 1.50 to 1.99, and 1.00 to 1.49 were recognized as extremely wet, very wet, and moderately wet. The SPI value of -0.99 to 0.99 is considered normal. Productivity *vis-à-vis* rainfall water use efficiency was estimated in trees of >30 years of age. Scientific indices were incorporated across food production agroecologies. MS Excel software was used for graphical and tabulation presentations. A recent dataset was used to generate scientific information on mango growing belts.

RESULTS AND DISCUSSION

Analysis of rainfall distribution *vis-à-vis* production pattern

Rainfall is an eminent natural resource that is an efficient indicator in any production system. Moisture conservation in-situ or ex-situ conditions mostly depends on the rainfall in many parts of the country. In rainfed areas, it is a major source of groundwater recharge and conservation. Thus, whatever rainfall comes to the farm should be conserved for farm productivity. The amount should

Table 1. Analysis of rainy days and pan evaporation in mango growing belt of Lucknow, UP

	2019		2020		2021	
	Number of rainy days	Pan evaporation	Number of rainy days	Pan evaporation	Number of rainy days	Pan evaporation
Jan	0	3.9	3	2.8	0	4.5
Feb	2	4.3	0	4.0	0	6.1
Mar	0	6.1	2	4.8	0	8.2
Apr	1	8.1	1	7.2	0	9.7
May	0	9.4	3	7.3	5	7.6
Jun	1	9.0	3	7.0	7	6.4
Jul	10	7.4	5	5.5	6	6.9
Aug	8	6.2	6	6.1	6	5.9
Sep	6	5.2	0	6.7	4	5.9
Oct	0	4.5	0	6.4	4	5.4
Nov	0	4.0	1	4.6	0	5.5
Dec	1	3.0	0	4.1	0	5.6

be used concisely to improve fruit, vegetables, and other food sources. It has been observed that the rainfall pattern is highly dynamic, scattered in many seasons of food growing. Recent information suggests high temporal variability of the number of rainy days in mango growing belts of Lucknow, UP (Table 1). 2019 29 rainy days were recorded, with the highest course in July (10 days). In the next two consecutive seasons (2020 and 2021), 24 and 32 rainy days were noted. It is interesting to note that rainfall was almost absent or its contribution was nil towards the reproductive stages of mango. In March and April, wherein fruit set to development are taking place, absent rainfall relies on groundwater or irrigation channels for watering in the orchards or farms. When Dashehari mostly started harvesting in June, 1 to 7 rainy days were observed. Late-maturing mango varieties like Mallika and Langra may get moisture retention benefits in orchard soil through smaller or heavier showers. The harvesting of Mallika goes up to August; therefore, water management in rainfed or subtropical belts becomes crucial for getting higher yields.

Interestingly, in the post-harvest season of October to January, 1 or 3 rainy days were found. In the vegetative stage, the absence of rainfall was noted from 2019 to 2021, and during flowering months, February only 2 rainy days in 2019 were recorded. For flowering, induced dryness is needed. However, for greater yields, rainfall is beneficial at the reproductive stage. The pan evaporation during March, April, and May moths were recorded as 6.1 to 9.4, 4.8 to 7.3, and 7.6 to 9.7 mm/day (Table 1). In conjunction with the absence of rainfall, higher pan evaporation makes the environment drier, and very high atmospheric demand is the ultimate result. Under such a situation, soil evaporation and tree transpiration rates could be greater. Water at these stages would be essential to retain fruits on the branches and for greater development; rain may be a boon for farmers. In the later months of September to January, 3.0 to 5.2, 2.8 to 6.7, and 4.5 to 5.9 mm/day pan evaporation was recorded. During flowering to fruit set, a light irrigation is always beneficial for the conducive conditions in the soil. The harvesting of Mallika may be completed in the 5.5 to 7.4 mm/day during the 2019 to 2021 years. Interestingly, the total amount of rainfall was highly variable temporarily. From January to June, 98.2, 209.2, and 319.6 mm of rainfall was received in 2019, 2020 and 2021 (Fig. 1).

Dashehari yields varied between 6000 to 10,000 kg/ha. The rainfall water use efficiency was estimated to range between 61.1 to 101.8, 28.7 to 47.8, and 18.8 to 31.3 kg/mm of rainfall water in 2019, 2020, and 2021. From July to December, 976.8, 588.2, and 816.4 mm of rainfall were received in the subtropical mango belts of Lucknow, UP. This rainfall must be conserved for future use. Greater rainfall was highly localized from July to September in three consecutive seasons. In Mallika, 10 to 15 t ha^{-1} could be harvested. The rainfall water use efficiency lies in 12.7 to 19.1, 14.2 to 21.4, and 13.4 to 20.1 kg/mm of rainfall water in 2019, 2020, and 2021, respectively (Fig. 2). Researchers across food production system recommended precise farm management to enhance productivity. Parmar *et al.* (2012) quantified the impacts of weather parameters on mango flowering in south Gujarat, while Chavan (2020) inferred the occurrence time of vegetative

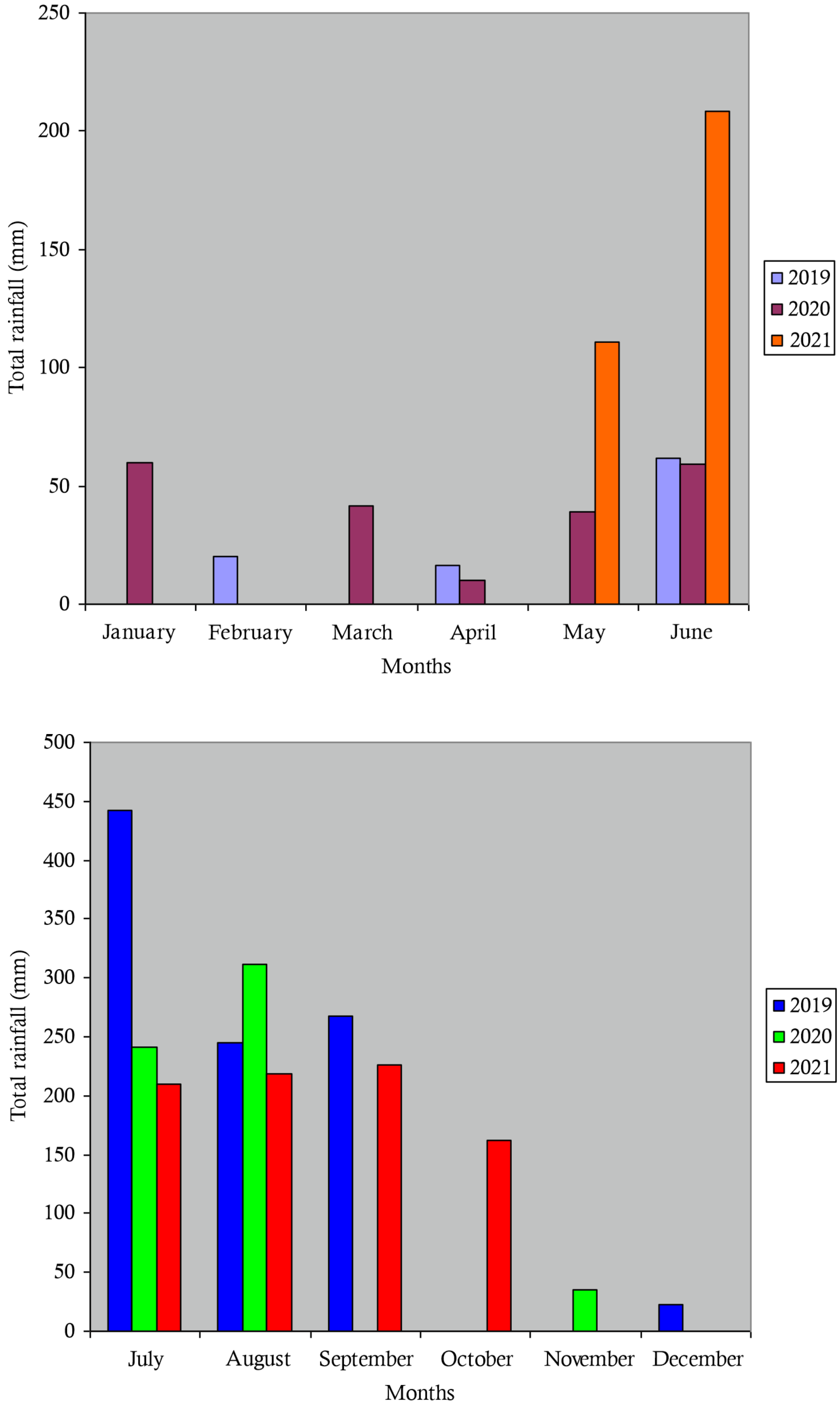

Fig. 1. Recent variations of total rainfall received in three consecutive year of mango growing belt of Lucknow, UP

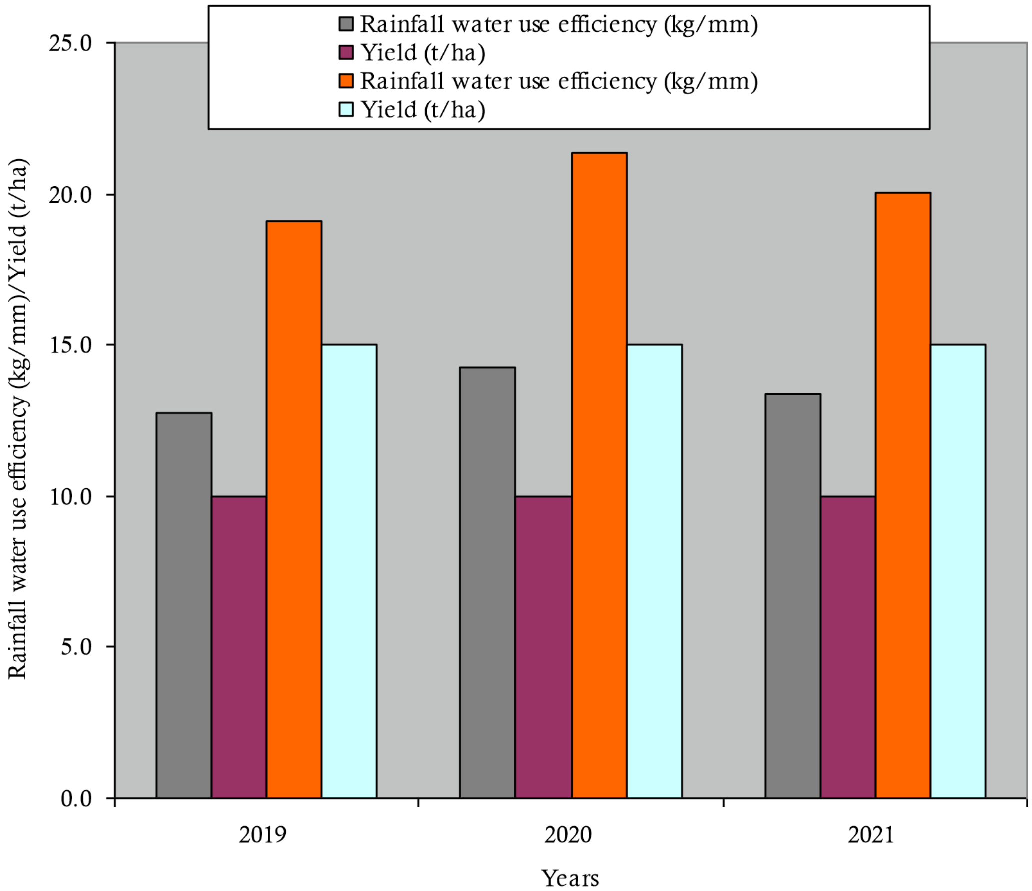

Fig. 2. Rainfall water use efficiency as a function of yields in Lucknow, UP

flush in mango cv—Alphonso for the Konkan region of Maharashtra for further management practices. Precision irrigation management also determines weather mitigation *vis-à-vis* yield in orchards. Therefore, to increase the precision practice, sensor application is a must-have option (Bazzi *et al.*, 2019). Babu *et al.* (2022) demonstrated that drip irrigation is highly useful for growers to conserve water and maintain moisture for producing food crops by interacting with soil-water-climate. In partial soil drying, water relations *vis-à-vis* hydraulic control of stomatal behavior in bell peppers were established for yield harvesting (Yao *et al.*, 2001). For greenhouse production of amaranth in a semi-arid, sub-tropical environment, maintenance of optimum soil water is essential (Masarirambi *et al.,* 2012). Wang *et al.* (2020) assessed the spatio-temporal variations in soil draught under 371.1 to 704.3 mm precipitation conditions. They concluded that the dried soil layer exhibits dryness as a function of land use, topography, and precipitation. Further, for wetness or flooding situations, a satellite-based forewarning system may be useful for rainfall predictions *vis-à-vis* management protocol (Massari *et al.*, 2018). Thus, scientific analyses of rainfall events have immense importance in fruit productivity.

Dynamics of standardized precipitation index in mango growing belts of Lucknow, UP

Statistical analysis of the standardized precipitation index in the mango growing belts of Lucknow, UP, showed high variables and dynamics over the years (Fig. 3). The long-term rainfall could be <1000 mm. From the univariate statistical analysis of the SPI dataset, it was found that the whole dataset had a skewness value of 0.101 and a kurtosis value of 0.317. The maximum SPI value of 2.22 and minimum value of -2.21 was noted. Scientific analysis suggested extremely dry years in 1993, a severely dry year in 1998, and a moderately dry year in 1994 and 1997. In terms of moderate wetness in 1990, very wetness in 2008, and extremely wet year in 2011, Indexing based on the precipitation is useful for future planning regarding probabilistic projections. Of course, we don't have control over

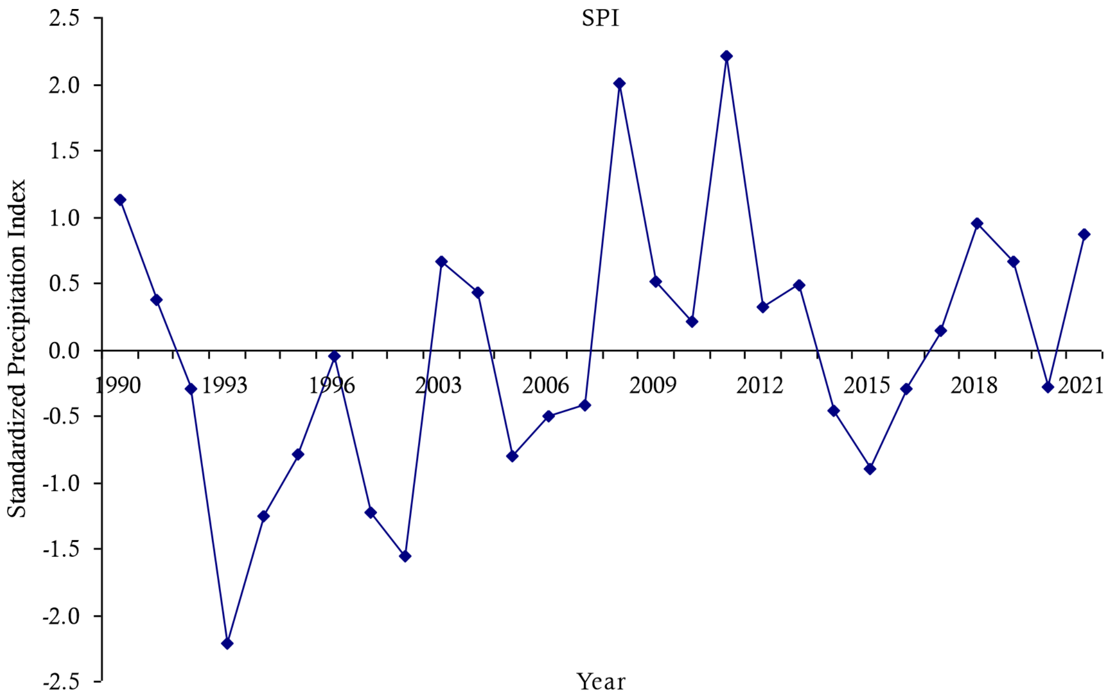

Fig. 3. Temporal variations of standardized precipitation index in mango growing belt of Lucknow, UP (1990 to 2021)

rainfall events, but ground wells or farm pond can be dug to prepare for water harvesting. In-situ rainfall may be conserved in orchards using ground mulching. In furrow or nallas, water can also be conserved. All these rainfall harvesting structures could benefit growers who want to apply water at dry stages. Recently, Singh *et al.* (2023) documented the perception of growers on changes in temperature patterns, change in rainfall patterns, change in frequency of rainfall, intermittent drought spells, and so on under the sodic environment of Uttar Pradesh to adopt the mitigation strategies for future food security purpose. Guenang and Kamga (2014) explained the variability of the standardized precipitation index across Cameroon places.

In contrast, Kostopoulou *et al.* (2017) authenticated the temporal and spatial trends of the standardized precipitation index in Greece from observational datasets. All this Indexing is needed to characterize farm productivity. McCarthy and Li (2019) opined that global food security should be secured through sustainable food production systems and healthy human diets. Adak *et al.* (2020) scientifically explained soil moisture and tree water variability *vis-à-vis* productivity in fruit orchards. Abdelkhalik *et al.* (2019) also emphasized that 75 to 50 percent of recommended irrigation requirements should be practiced at farmers' fields for watermelon if water is limited. Of course, a significant yield reduction was recorded from 293 to 155 mm of irrigating water application in loam to silt loam and clay loam soils in the subtropical Mediterranean zone. Mamrutha *et al.* (2020) developed the heat stress intensity index as an ecological indicator for wheat germplasms in India across different locations with greater values of 0.45 (Ludhiana) to 0.81 (Dharwad) and lower values of 0.11 (Kanpur) to 0.31 (Karnal) were recorded. Babu et al. (2021) suggested root zone moisture conservation practices to produce a considerable amount of mango to ensure fruit production in dry, hot summers in the absence of rainfall. Rangare *et al.* (2022) observed that environmental conditions were responsible for differential fruit set and yield variations in Langra (49 to 72 kg/tree) and Amrapali (53 to 54 kg/tree), having 459 and 624 mm total rainfall in Central India. All such analysis is pivotal for climate change studies *vis-à-vis* productivity analysis.

CONCLUSION

Since there was a lack of authentic information on the broad aspect of dryness and draught-related issues and policy practices, the present study broadly described the temporal variability in rainfall amount in mango growing belts of Subtropical Lucknow, UP conditions. The variations in rainy days from

2019 to 2022 were significant and influence the tree phenology. The total rainfall amount also varied across mangoes' flowering, fruit set, and developmental periods. The vegetative stage also experienced a peculiar absence of rainfall. Pan evaporation varied temporally at the reproductive phase, suggesting the need for moisture conservation at orchards. Standardized precipitation index values varied across long-term events in extremely dry to extremely wet categories. Low fruit yield in mango (<10 to 15 t ha^{-1}) may be attributed to rainfall and soil dryness. Rainfall water use efficiency was estimated and showed variation across subtropical zones during 2019, 2020, and 2021. Thus, the present study emphasized the need for precision soil and water management to maintain moisture *vis-à-vis* greater productivity in subtropical zones.

ACKNOWLEDGEMENT

The Director, ICAR-CISH, Lucknow, is kindly acknowledged for the smooth functioning of the field study and other staff for cooperation in the laboratory and fields. The present study was the output of ICAR project on "Evaluation of soil, tree and climatic indicators in Mango orchards" and has also been duly acknowledged.

REFERENCES

Adak, T., Babu, N. and Singh, V.K. (2022). Mango Biodiversity Conservation: Management Needs for Better Sustainability. In: *Soil and Water Conservation Bulletin* (Mandal, D., Kaushal, R., Kumar, G., Singh, R.J. and Roy, T. (eds.), Indian Association of Soil and Water Conservationists, Dehradun, Uttarakhand, No. *7*, 29-36.

Adak, T. and Babu, N. (2022). Innovative approach for enhancing water productivity in Mango cv Amrapali. In: *Proceedings of 3rd International Web-Conference on "Natural Resource Management for Global Food Security and Sustainable Development Goals" organized during* December *2 to 3, 69-70.*

Adak, T., Babu, N. and Pandey, G. (2020). Soil Moisture Variability and Tree Water Status *vis-à-vis* Productivity in Fruit Orchards as Estimated by Unmanned Aerial Vehicle, Drones, RADAR Technologies. *Journal of Agricultural Physics, 20*(2), 185-190.

Abdelkhalik, A., Pascual-Seva, N., Nájera, I., Giner, A., Baixauli, C. and Pascual, B. (2019). Yield response of seedless watermelon to different drip irrigation strategies under Mediterranean conditions. *Agricultural Water Management*, *212*, 99-110.

AghaKouchak, A. (2014). A baseline probabilistic drought forecasting framework using standardized soil moisture index: application to the 2012 United States drought. *Hydrology and Earth System Sciences, 18*, 2485-2492.

Babu, N., Adak, T., Arvind, K. and Singh, V. K. (2021). Scientific analysis of drought assessment and its management strategies for food security. *Current Advances in Agricultural Sciences (An International Journal)*, *13*(1), 1-6.

Babu, N., Adak T. and Kumar, A. (2022). Natural Resource Conservation Technologies in Horticultural Crops for Doubling Farmers' Income under Subtropical Uttar Pradesh. In: *Soil and Water Conservation Bulletin* (Mandal, D., Kaushal, R., Kumar, G., Singh, R.J. and Roy, T. (eds.), Indian Association of Soil and Water Conservationists, Dehradun, Uttarakhand, No. *7*, 17-21.

Ballester, C., Zarco-Tejada, P.J., Nicolas, E., Alarcon, J.J., Fereres, E., Intrigliolo, D.S. and González-Dugo, V. (2018). Evaluating the performance of xanthophyll chlorophyll and structure-sensitive spectral indices to detect water stress in five fruit tree species. *Precision Agriculture, 19*, 178-193.

Bazzi, C. L., Schenatto, K., Upadhyaya, S., Rojo, F., Kizer, E. and Ko-Madden, C. (2019). Optimal placement of proximal sensors for precision irrigation in tree crops. *Precision Agriculture, 20*, 663-674.

Chavan, V.G., Rajemahadik, V.A., More, V.G., Chavan, S.A. and Mahadkar, U.V. (2020). Weather based prediction model for time of occurrence of vegetative flush in mango cv. Alphonso for Konkan region of Maharashtra state. *Journal of Agrometeorology, 22*(4), 531-533.

Dutta, D., Kundu, A., Patel, N.R., Saha, S.K. and Siddiqui, A.R. (2015). Assessment of agricultural drought in Rajasthan (India) using remote sensing derived Vegetation Condition Index (VCI) and Standardized Precipitation Index (SPI). *The Egyptian Journal of Remote Sensing* and *Space* Sciences, *18*(1), 53-63.

Elkollaly, M., Khadr, M. and Zeidan, B. (2017). Drought analysis in the Eastern Nile basin using the standardized precipitation index. *Environmental Science* and *Pollution Research,* 1-15.

Ferrer, M., Echeverría, G. and Mirás-Avalos, J.M. (2017). Meteorological conditions: Influence on yield, sanitary status and grape composition. *International Journal of Environmental & Agriculture Research, 3*(8), 16-27.

Guenang, G.M. and Kamga, F.M. (2014). Computation of the Standardized Precipitation Index (SPI) and Its Use to Assess Drought Occurrences in Cameroon over Recent Decades. *Journal of Applied Meteorology and Climatology*, *53*, 2310-2324.

Kostopoulou, E., Giannakopoulos, C., Krapsiti, D. and Karali, A. (2017). Temporal and spatial trends of the standardized precipitation index (SPI) in Greece using observations and output from regional climate models. In: Karacostas, T., Bais, A., Nastos, P.T. (Eds.), Perspectives on Atmospheric Sciences. Springer International Publishing, Cham, pp. 475-481.

Luvaha, E., Netondo, G.W. and Ouma, G. (2008). Effect of water deficit on the physiological and morphological characteristics of mango (*Mangifera indica*) rootstock seedlings. *American Journal of Plant Physiology*, *3*, 115.

Mamrutha, H.M., Khobra, R., Sendhil, R., Munjal, R., Sai Prasad, S.V., Biradar, S., Mavi, G.S., Dhar, T., Bahadur, R., Bhagwan, J.H., Prakash, S., Singh, H., Shukla, R.S., Srivastava, M., Singh, C., Gosavi, A.B., Salunke, V.D., Dhyani, V.C. and Singh, G.P. (2020). Developing stress intensity index and prioritizing hotspot locations for screening wheat genotypes under climate change scenario. *Ecological Indicators*, *118,* 106714.

Masarirambi, M.T., Dlamini, Z., Manyatsi, A.M., Wahome, P.K., Oseni, T.O., Shongwe, V.D. (2012). Soil water requirements of amaranth (*Amaranthus hybridus*) grown in a greenhouse in a semi-arid, sub-tropical environment. *American-Eurasian Journal of Agricultural and Environmental Sciences, 12*, 932-936.

Maseko, I., Ncube, B., Mabhaudhi, T., Tesfay, S., Chimonyo, V.G.P., Araya, H.T., Fessehazion, M. and Du Plooy, C.P. (2019). Moisture stress on physiology and yield of some indigenous leafy vegetables under field conditions. *South African Journal of Botany, 126*, 85-91.

Massari, C., Camici, S., Ciabatta, L. and Brocca, L. (2018). Exploiting satellite-based surface soil moisture for flood forecasting in the Mediterranean area: state update versus rainfall correction. *Remote Sensing, 10*(2), 292.

McCarthy, W.J. and Li, Z. (2019). Healthy diets and sustainable food systems. *The Lancet*, *394,* (10194), 214.

Parmar, V.R., Shrivastava, P.K. and Patel, B.N. (2012). Study on weather parameters affecting mango flowering in south Gujarat. *Journal of Agrometeorology* (*Spl. Issue*), *14*, 351-353.

Petsakos, A., Prager, S.D., Gonzalez, C.E., Gama, A.C., Sulser, T.B., Gbegbelegbe, S., Kikulwe, E.M. and Hareau, G. (2019). Understanding the consequences of changes in the production frontiers for roots, tubers and bananas. *Global Food Security, 20*, 180-188.

Poschlod, B., Zscheischler, J., Sillmann, J., Wood, R.R. and Ludwig, R. (2020). Climate change effects on hydrometeorological compound events over southern Norway. *Weather and Climate Extremes, 28*, 100253.

Rangare, N.R., Bhan M. and Pandey, S.K. (2022). Assessment of weather effect on flower morphogenesis and fruit set in mango varieties in central India. *Journal of Agrometeorology, 24*(1), 33-37.

Sendhil, R., Kiran Kumara, T.M., Ramasundaram, P., Sinha, M. and Kharkwal, S. (2020). Nutrition status in India: Dynamics and determinants. *Global Food Security, 26*, 100455.

Shah, R., Bharadiya, N. and Manekar, V. (2015). Drought Index Computation Using Standardized Precipitation Index (SPI) Method For Surat District, Gujarat. *Aquatic Procedia, 4*, 1243-1249.

Singh, A.K., Arora, S., Verma, C.L., Singh, A., Kiran, R., Jha, S.K., Rizvi, R.H., Damodaran, T. and Singh, R.K. (2023). Farmers perception to climate change under sodic environment of Uttar Pradesh. *Journal of Natural Resource Conservation and Management*, *4*(1), 100-106.

Wang, Y., Shao, M., Sun, H., Fu, Z., Fan, J., Hu, W. and Fang, L. (2020). Response of deep soil drought to precipitation, land use and topography across a semiarid watershed. *Agricultural and Forest Meteorology*, *282-283*, 107866.

Yao C, Moreshet S, Aloni B. (2001). Water relations and hydraulic control of stomatal behaviour in bell pepper plant in partial soil drying. *Plant, Cell and Environment, 24*, 227-235.

Zarch, M.A.A., Sivakumar, B. and Sharma, A. (2015). Droughts in a warming climate: A global assessment of Standardized precipitation index (SPI) and Reconnaissance drought index (RDI). *Journal of Hydrology*, *526*, 183-195.

Zunzunegui, M., Ain-Lhout, F., Jáuregui, J., Díaz Barradas, M.C., Boutaleb, S., Álvarez-Cansinoa, L. and Esquivias, M.P. (2010). Fruit production under different environmental and management conditions of argan, *Argania spinosa* (L.). *Journal of Arid Environments*, *74*, 1138e1145.