Commentary

Smart Rain Simulators for Rain-Starved Districts of the Indian Subcontinent

Peeyush Khare[1,*], Tushar Agarwal[2] and Satyajit Ghosh[3,4]

[1]Laboratory of Atmospheric Chemistry, Paul Scherrer Institute, Villigen Switzerland

[2]Environmental Resources Management, Gurugram India

[3]School of Mechanical Engineering, Vellore Institute of Technology, Vellore India

[4]School of Earth and Environment, University of Leeds U.K.

*Corresponding author: peeyush.khare@psi.ch

Key points:

- A newly patented and economical rain simulator for crop hydration during failed monsoons.
- Closely matches the kinetic energy fluxes and dropsize distributions of natural rain.
- Very suitable for small to medium-scale farmers in drought-hit developing countries.

Abstract

To help tackle drought-related farmer suicides, a new design of a rain simulator, recently patented is presented (Patent no. 351688, Govt. of India Patent Office). This is versatile and yields showers with near-identical drop-size distributions when compared to natural showers. It is useful for many applications requiring controlled hydration from showers instead of relying on root hydration alone. The apparatus is soon to be rolled out to farmers in the Indian State of Tamil Nadu. It is portable, and with a cost of under USD 1000 a piece, can alter patterns of cropland hydration even when a monsoon fails.

Keywords: droughts, farmer suicides, rain simulator, dropsize distribution, kinetic energy flux

Need for innovative irrigation techniques in India

Variability in agricultural income is a major driver of suicides in India. [1–3] Since 1980, more than 60,000 farmer suicides have been reported This variability is largely linked to rising temperatures and the increasing frequency of droughts.[3] Droughts are a major driver of deaths especially in Southern India that substantially reduce agricultural production of owners of both large and small croplands and increase their financial debts.[4,5] Leaders from All India Kisan Sabha discussed in 2019 how droughts affected farmers in their areas in many parts of the country. They also noted that “rainfall was low, but even in areas where the deficit may not be high, the rain had come late, affecting the sowing and growing of crops". Arupathy S. Kalyanam, President of the Thanjavur Delta farmers reported in 2015 that persistent droughts had resulted in many farmers in Tamil Nadu giving up on farming and moving to cities to look for better opportunities for their survival. With the ground water drying, the farmers were in a dilemma as to how to face the situation. He also reported that agro-climatic zonal cropping, judicious water management and supporting irrigational needs, were needed to be addressed to save the plight of the farmers.[6,7]

In fact, water scarcity has been a consistent challenge for much of Indian agriculture, largely rain fed and thereby seasonal. Manmade water bodies in the form of tanks, lakes, ponds and dug wells, have either dismally fallen into disrepair or have been built over by other structures in expanding urban landscape.[8] This has aggravated the problem of water availability for farmers. Future drought-related impacts could be even more severe due to a predicted 1-3°C rise in average temperatures over India by 2050 with the potential to jeopardize the livelihood of millions of farmers.[9] Whilst big farmers owing to their economic assets are financially cushioned to an extent from the onslaught of droughts, small farmers entirely depend on monsoons to sustain their families and are most gravely affected.[10,11] It is imperative that sustainable and economical irrigation practices are developed for these small land owners in order to enhance their resilience to droughts and protect their livelihoods.

Unique aspects of the newly patented artificial rainfall simulator

The recently patented design of this novel and economical rainfall simulator (Figure 1) irrigates small patches of land efficiently with limited water resources while maintaining the dropsize spectrum and kinetic energy fluxes similar to Indian monsoon showers (Government of India Patent Office, Patent no. 351688).[12] This was achieved via a set of upward-titled nozzles whose height, orientation and spacing were carefully calibrated using computational models to produce desired rainfall characteristics for different simulated rainfall intensities.[13]

The laboratory setup (Figure 1) illustrates that the assembling of the apparatus is straight forward and a dialogue has already been initiated at the Vellore Institute of Technology's School of Agricultural Innovations and Advanced Learning (VAIAL) to have one day workshops to familiarize farmers of Tamil Nadu to assemble the apparatus under supervision. Additionally, the Institute's Patent Office is in the process of engaging with Tamil Nadu's Startup Companies to commence on the assembly and delivery of the simulator. VAIAL have had a close look at this new patented product. It was felt "that the device will be of much use not just for farmers in the region but also generally could be used as a full scale laboratory equipment". Students here training to become agricultural engineers can easily offer a real time demonstration to the Tamil Nadu farmers familiarizing them with the apparatus who can manually adjust the simple tilting mechanisms to create shower of their choice to irrigate the crops. VAIAL closely engages with farmers from Tamil Nadu who are eager to adapt to new developments and practices to maximize crop yield production.

They have indicated that a device with controlled generation of showers would help the farmers to optimally irrigate their crops particularly when they are at the flowering or newly sprouting-foliage stage; otherwise the strongly impacting drops would damage plants. It proves costly to have all of them to be nurtured indoors in a protected environment as in a glass house. With this device, outdoor controlled irrigation could prove to be very cost effective.

The up-tilted nozzles facilitate artificially created rain-shower to surge upward against gravitational acceleration, and in the process, deplete itself of the excess kinetic energy induced by the initial pressurized release of the spray. In contrast to conventional simulators with downward titled nozzles, this design generates much smaller droplet energy fluxes (~0.1-2 W m^{-2}) similar to natural rain showers. The design also allows for horizontal translational and rotational movement of nozzles granting tri-directional maneuverability to spray geometry for constraining the hydrated land area against cross-winds of different magnitudes that typically accompany rains in India. Specially designed nozzle holders resting on a horizontal plate supported on three columns were used for this purpose (Figure 1). Laboratory experiments have shown that this simulator can be adjusted to alter characteristics of applied rain showers e.g. intensity, dropsize distribution and coverage area, to adjust for diurnal changes in meteorological factors such as temperature, crosswind speed and direction, as well as for crop-type.[13]

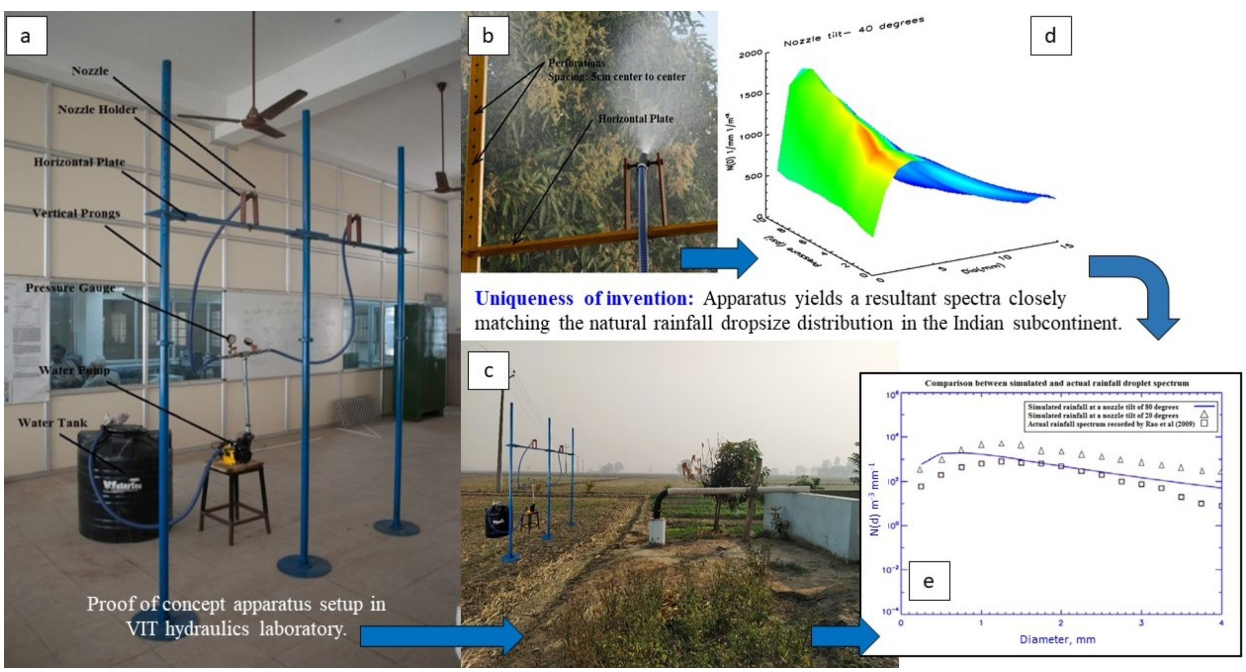

Figure 1: (a) A full-scale assemblage of the artificial rain simulator showing components. Typically, the assembling time is 2 *h*. The component parts weigh

less than 20 kg excluding the weight of the water tank. **(b)** Axi-symmetric nozzle tilted upwards with rapidly decreasing kinetic energy flux so that the descending droplets attain terminal velocity and yield a drop size distribution (DSD) closely matching a real monsoon shower's distribution **(c)** Visualization of a farmland in north India set up with the patented rain simulator to grow spinach on a 20 m^2 plot. Intermittent and controlled showering from above is the preferred choice saving precious ground water which is pumped into a large water tank. Only a fraction of stored water is used to fill up the water tank (see the black cylindrical tank on the left) with a volume of 1000 liters. Note also the two nozzles with a unique tri-directional maneuverability yielding an up-tilting mechanism so that the calibrated sprays lose all of their vertical kinetic energy on their upward surge before falling much like natural shower with a median droplet diameter of ~ 1.5 mm. This arrangement also accounts for the effects of variable cross winds-the design ensures that with a coupled up and down turning a spray shower is always directed onto the foliage thereby saving water (Patent no. 351688, Govt. of India Patent Office). **(d)** Computational analysis of changing dropsize distribution with nozzle pressure at a nozzle tilt of 40° from the vertical and crosswind velocity of 3 ms^{-1} and **(e)** Comparison of simulated rainfall dropsize spectrum with natural rainfall.

Potential environmental and economic benefits

The ability to simulate dropsize distributions as well as droplet kinetics of natural rainfall is the primary novel aspect of this design which separates it from previous rainfall simulators. It could potentially minimize stress response in plants from high-energy droplet impaction from regular sprinklers that affects their growth, and, arrest erosive potential of droplets hitting the soil.[14,15] Moreover, this simulator could regulate water outflow conserving large quantities of water relative to traditional flood irrigation, ebb nutrient erosion caused by runoff, deliver highly oxygenated water to roots and permit thorough foliage hydration for improved photosynthesis activity. Owing to its portability, the especially intended application of this simulator is for parched croplands where it could likely enhance yields of a wide range of crops, e.g. cotton, which requires hydration via monsoon showers and is among the worst drought-hit crops in India's southern black soil plateau region.[16]

Considering the financial limitations of a small scale farmer in the Indian subcontinent, this newly developed rainfall simulator is designed to cost under USD 1000 and could be easily dismantled to allow for convenient transport within and across different patches of land. The device could hydrate 10-20 m^2 of land at a time, which coupled with high mobility could let three devices irrigate 2000-4000 m^2 of land typically owned by a small-scale Indian farmer. It does not require any additional infrastructural investments and could also be comfortably set up for irrigating uneven patches of land e.g. terrace farming. Additionally, the farmers in India possess small pieces of farmlands that sometimes may not be close to each other. In such a situation, they need a design that could be easily dismantled at one field, transported and easily reassembled at another. Here, besides technical differences, the western designs also become too huge and unwieldy, and thus inapplicable on Indian croplands.

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References

1. Sharma, S. & Mujumdar, P. Increasing frequency and spatial extent of concurrent meteorological droughts and heatwaves in India. *Sci. Rep.* **7**, (2017).2. Kar, S. & Das, N. Climate change, agricultural production, and poverty in India. in *Economic Studies in Inequality, Social Exclusion and Well-Being* 55–76 (Springer, 2015). doi:10.1007/978-981-287-420-7_43. Carleton, T. A. Crop-damaging temperatures increase suicide rates in India. *Proc. Natl. Acad. Sci. U. S. A.* **114**, 8746–8751 (2017).4. On India's Farms, a Plague of Suicide . *New York Times, Section A p.1* (2006). Available at: https://www.nytimes.com/2006/09/19/world/asia/19india.html. (Accessed: 1st January 2021)5. Singh, A., Phadke, V. S. & Patwardhan, A. Impact of Drought and Flood on Indian Food Grain Production. in *Challenges and Opportunities in Agrometeorology* 421–433 (Springer Berlin Heidelberg, 2011). doi:10.1007/978-3-642-19360-6_326. Farmers group wants drought norms revised - The Hindu. Available at: https://www.thehindu.com/sci-tech/agriculture/farmers-group-wants-drought-norms-revised/article28492870.ece. (Accessed: 15th May 2021)7. Tamil Nadu farmers in dilemma over drought situation. Available at: https://www.deccanchronicle.com/nation/politics/280617/farmers-in-dilemma-over-drought-situation.html. (Accessed: 15th May 2021)8. Brinkmann, K., Hoffmann, E. & Buerkert, A. Spatial and Temporal Dynamics of Urban Wetlands in an Indian Megacity over the Past 50 Years. *Remote Sens.* **12**, 662 (2020).9. Mani, M., Bandyopadhyay, S., Chonabayashi, S., Markandya, A. & Mosier, T. *South Asia's Hotspots: The Impact of Temperature and Precipitation Changes on Living Standards. South Asia's Hotspots: The Impact of Temperature and Precipitation Changes on Living Standards* (Washington, DC: World Bank, 2018). doi:10.1596/978-1-4648-1155-510. Indian farmers faced with debt and drought turn to suicide, leaving families helpless in the fields. *The Associated Press* (2009). Available at: https://www.nydailynews.com/news/world/indian-farmers-faced-debt-drought-turn-suicide-leaving-families-helpless-fields-article-1.401001. (Accessed: 2nd January 2021)11. Udmale, P., Ichikawa, Y., Manandhar,

S., Ishidaira, H. & Kiem, A. S. Farmers' perception of drought impacts, local adaptation and administrative mitigation measures in Maharashtra State, India. *Int. J. Disaster Risk Reduct.* **10**, 250–269 (2014).12. Journal of the Intellectual Property Office, India. (2020). Available at: https://ipindia.gov.in/writereaddata/Portal/IPOJournal/1_4927_1/Part-2.pdf13. Khare, P., Agarwal, T. & Ghosh, S. Droplet spectrum analysis from artificially generated rain showers. *J. Irrig. Drain. Eng.* **140**, (2014).14. van Moerkercke, A. *et al.* A MYC2/MYC3/MYC4-dependent transcription factor network regulates water spray-responsive gene expression and jasmonate levels. *Proc. Natl. Acad. Sci. U. S. A.* **116**, 23345–23356 (2019).15. Furbish, D. J., Hamner, K. K., Schmeeckle, M., Borosund, M. N. & Mudd, S. M. Rain splash of dry sand revealed by high-speed imaging and sticky paper splash targets. *J. Geophys. Res.* **112**, F01001 (2007).16. Times of India. Drought hits North Maha's cotton production by 40% . (2019). Available at: https://timesofindia.indiatimes.com/city/nashik/drought-hits-north-mahas-cotton-production-by-40/articleshow/67492708.cms. (Accessed: 3rd January 2021)