Indian Journal of Agronomy **68** (1): 54—59 (March 2023)

Research Paper

Effect of integrated rainwater-management practices on soil properties and productivity of groundnut (*Arachis hypogaea*) in arid and semi-arid regions of Andhra Pradesh

A. MALLISWARA REDDY[1], A. PRATAP KUMAR REDDY[2], B. RAVINDRANATHA REDDY[3], M.V.S. NAIDU[4], P. SUDHAKAR[5] AND B. SAHADEVA REDDY[6]

Agricultural Research Station, Acharya N. G. Ranga Agricultural University, Ananthapuramu, Andhra Pradesh 515 001

Received: July 2022; Revised accepted: January 2023

ABSTRACT

A field experiment was conducted during the rainy season (*kharif)* of 2017 and 2018 at Agricultural Research Station of the Acharya N.G. Ranga Agricultural University, Ananthapuramu, Andhra Pradesh, to study the effect of integrated rainwater-management practices on soil properties and groundnut (*Arachis hypogaea* L.) productivity. The experiment was laid out in a randomized block design with 9 rainwater-management practices with 3 replications. Results indicated that, application of shales @ 300 t/ha as surface mulch combined with 2 supplemental irrigations of 10 mm each when dryspell of 10 days occurs after 50% flowering treatment (T_7) increased the porosity, water holding capacity, infiltration rate by 17.8, 41.2 and 24.6%, respectively, and bulk density was reduced by 5.0% compared to dryland groundnut (T_1). Similarly, the same treatment (T_7) enhanced the groundnut pod yield by 39.68% compared to the control (T_1). Thus, application of shales @ 300 t/ha as surface mulch combined with 2 supplemental irrigations of 10 mm each when dryspell of 10 days occurs after 50% flowering proved the best integrated rainwater-management practice to improve soil properties and increase the productivity of groundnut under arid and semi-arid regions of Andhra Pradesh.

Key words: Dryspell, Groundnut, Physical properties, Productivity, Rainwater management, Supplemental irrigation

Groundnut (*Arachis hypogaea* L.) yields are often poor and unstable under rainfed conditions due to irregular rainfall and prolonged dryspells during the crop-growing period. Rainfall is the most important climatic variable impacting groundnut production. Because 70% of the crop area is in semi-arid tropic conditions, which are typified by low and unpredictable rainfall. Drought (moisture stress) is one of the most prominent abiotic factors that affects rainfed groundnut productivity among several extreme climatic events. Moisture stress is a reoccurring chronic problem in India, which has a large amount of its land area in the arid and semi-arid tropics (Sunitha *et al*., 2015).

[1]**Corresponding author's Email:** malliagronomy@gmail.com
[1]Scientist (Agronomy), [6]Principal Scientist and Head, Agricultural Research Station, Acharya N.G. Ranga Agricultural University, Ananthapuramu, Andhra Pradesh 515 001; [2]Dean of Agriculture, [5]Controller of Examinations, Acharya N.G. Ranga Agricultural University, Guntur, Andhra Psradesh 522 034; [3]Associate Dean, [4]Professor, Department of Soil Science and Agricultural Chemistry, S.V. Agricultural College, Acharya N.G. Ranga Agricultural University, Tirupati, Andhra Pradesh 517 502

In dryland areas, rainfall is not only scarce, but also unpredictable and unevenly distributed. Because of the favourable physical and chemical features of soils, rainwater and soil losses in dry regions are also more due to runoff and erosion, respectively. Low soil depth, water-holding capacity, surface-crust formation, and poor fertility status are all major soil constraints of Alfisols. Due to these soil constraints, the productivity of the groundnut crop grown in these soils under rainfed situations was relatively low. In this case, adding amendments to improve soil physical qualities is most advantageous. Applying shales to the soil acts as a surface mulch, increasing soil-moisture availability while also improving soil structure. Shales are fine-grained, laminated, or fissile clastic sedimentary rocks containing a detrital component of clay and silt. Depending on the mineralogical composition and depositional environment, shale colours range from white to red, green, grey and black (Okeke and Okogbue, 2011). Expanded shale improves overall aeration, water and nutrient retention and release capacities, and promotes optimal plant growth by modifying soil physical properties (Dunett and Kingsbury, 2008). The incorporation of big-sized shales into soil is essentially a permanent change in the physical properties of the soil (Sloan *et al*., 2002). Grey shale acts as a soil conditioner, and the combination of soil and shale improves the physico-chemical properties of the soil (Sallam *et al*., 2015). Surface mulches are used to prevent soil from blowing and beating action of rainfall, reduce run-off, increase infiltration, reduce evaporation, keep down weeds, improve soil structure and eventually increase yield. Rainwater-conservation strategies, both *in-situ* and *ex-situ*, have a lot of potential to save rainwater and supplement moisture to crops, especially during dry periods (Venkateswarlu *et al*., 2016).

The present research was carried out to address all of the aforementioned problems and to develop efficient *in-situ* and *ex-situ* rainwater-management strategies in order to ameliorates soil physical properties and to achieve sustainable groundnut production under sparse, sporadic and unpredictable rainfall conditions in Alfisols of semi-arid regions.

MATERIALS AND METHODS

The current study was carried out during the rainy season (*kharif*) of 2017 and 2018 at dryland farm of Agricultural Research Station of the Acharya N.G. Ranga Agricultural University, Ananthapuramu, Andhra Pradesh (14º 41'104" N, 77º 40'281" E, 350 m above mean-sea level). The experimental site falls under Semi-Arid Tropics (SAT). The experiment was laid out in a randomized block design with 9 rainwater-management practices with 3 replications. The treatments comprised different combinations of *in-situ* and *ex-situ* rainwater-management practices, viz*.*, T_1, Dryland groundnut (without *in-situ* and *ex-situ* rainwater management); T_2, formation of conservation furrows at every 1.2 m width at sowing; T_3, T_2 + 1 supplemental irrigation of 10 mm when dryspell of 10 days occurs after 50% flowering; T_4, T_2 + 2 supplemental irrigations of 10 mm each when dryspell of 10 days occurs after 50% flowering; T_5, shales application @ 300 t/ha as surface mulch (only in the first year of experimentation); T_6, T_5 + 1 supplemental irrigation of 10 mm when dryspell of 10 days occurs after 50% flowering; T_7, T_5 + 2 supplemental irrigations of 10 mm each when dryspell of 10 days occurs after 50% flowering; T_8, 1 supplemental irrigation of 10mm when dryspell of 10 days occurs after 50% flowering; and T_9, 2 supplemental irrigations of 10 mm each when dryspell of 10 days occurs after 50% flowering.

The soil of the experimental site was red sandy loam (taxonomically Ustic Haplogrids according to USDA classification and Luvic yermosols according to FAO classification) in texture, near neutral in reaction, low in organic carbon and available nitrogen, medium in available phosphorus and potassium. Low fertility status, shallow depth, and 1–3% slopy and rocky soils were the major soil constraints in the experimental site, while low and uneven rainfall distribution, early monsoon cessation, late monsoon onset, and prolonged dryspells during crop-growing season were the major climatic constraints. The annual precipitation at the experimental site was 590 mm in 36 rainy days, with the south-west monsoon, accounting for the largest share around 64%. At the experimental site, the mean maximum temperature is 34˚C, the mean minimum temperature is 21.3˚C, and there are 8.2 hours of sunlight per day. The growing period lasts approximately 130–135 days. During the groundnut crop-growing period in 2017 and 2018, a total rainfall of 537.2 mm and 226 mm was received in 34 and 11 rainy days respectively. Before start of the experiment, a composite soil sample was randomly taken from 0–30 cm soil depth and analysed for physico-chemical properties. The characteristics of physical and physico-chemical properties by adopting standard procedures are summarized in Table 1. Post-harvest soil samples were collected at 0–30 cm depth from all the treatments for estimation of soil physical and physico-chemical parameters by adopting standard procedures.

In low and sporadic rainfall regions, shales are used as a surface mulch to conserve soil moisture. Shales are fine-grained, laminated or fissile clastic sedimentary rocks with

Table 1. Physico-chemical properties of soil of the experimental field

Particulars	Value
Physical characteristics	
Sand (%)	72.84
Silt (%)	04.12
Clay (%)	23.04
Textural class	Sandy loam
Field capacity (%)	16.0
Permanent wilting point (%)	03.7
Available soil moisture (%)	12.3
Bulk density (Mg/m^3)	01.41
Pore space (%)	40.82
Maximum water-holding capacity (%)	21.25
Infiltration rate (mm/hr)	09.69
Chemical characteristics	
Soil *p*H (1 : 2.5 soil water suspension)	6.02
Electrical conductivity (dS/m)	0.138
Organic carbon (%)	0.37
Available N (kg/ha)	138
Available P_2O_5 (kg/ha)	52
Available K_2O (kg/ha)	202
Micronutrients	
Available copper (mg/kg)	0.41
Available iron (mg/kg)	1.38
Available manganese (mg/kg)	4.92
Available zinc (mg/kg)	0.47

predominance of clay and silt as the detrital components. Characteristic properties of shales are breaks along thin laminae or parallel layering or bedding called fissility. As per treatments, shales @ 300 t/ha were applied during the first year of experimentation (*kharif*, 2017) only, as its efficiency as a mulch on the surface of soil will continue up to 5 years. The shale material was analysed for its physical and chemical composition by adopting standard procedures and presented in Table 2. Groundnut crop was raised at a spacing of 30 cm × 10 cm. The recommended dose of fertilizers (20, 40 and 50 N, P and K kg/ha) was applied basal uniformly to the experimental field. Conservation furrows were formed at the time of sowing itself with an innovative technique of attaching shovels to the tractor-drawn blade, so that sowing, covering the seed and formation of moisture-conservation furrows could be done simultaneously. Conservation furrows were formed at every 1.2-m interval at a depth of 30 cm in the respective treatments. Supplemental irrigation was given from harvested rainwater stored in the farm pond, which is nearer to experimental field. Supplemental irrigation at 10 mm depth was given through micro-irrigation (sprinkler irrigation) in the respective treatments during 2017 and 2018. Rainout shelters were also constructed with transparent white polythene sheet on the top and 2 sides of the frame, to prevent rainwater entry into the plots. The manually operated rainout shelters are used for imposing drought stress in respective treatments. Pod yield obtained from net plot area was sun-dried to obtain a constant weight and expressed as pod yield in kg/ha. The data collected for all the parameters in the present experiment were subjected to statistical analysis by the method of analysis of variance for randomized block design. Statistical significance was tested with 'F' test at 5% level of probability and compared the treatmental means with critical difference. Treatmental differences that were non-significant were denoted as 'NS'.

Table 2. Physical and chemical composition of shales

Physical composition	Value
Sand (%)	67.84
Silt (%)	8.00
Clay (%)	24.16
Bulk density (Mg/m^3)	1.41
Particle density (Mg/m^3)	2.32
Porosity (%)	39.47
Maximum water-holding capacity (%)	
Chemical composition	18.89
*p*H	8.72
Electrical conductivity (dS/m)	0.179
Organic carbon (%)	0.40
Nitrogen (%)	0.006
Phosphorus (%)	0.000446
Potassium (%)	0.008036
Calcium (%)	0.1948
Magnesium (%)	0.04
Sulphur (%)	0.00074
Boron (%)	0.000078
Zinc (%)	0.000032
Iron (%)	0.000356
Manganese (%)	0.000216
Copper (%)	0.000064

RESULTS AND DISCUSSION

Effect of integrated rainwater management practices on post-harvest soil properties

The effect of rainwater-management practices on soil properties is given in Table 3. The soil-bulk density ranged from 1.33 (T_7) to 1.40 (T_1), with mean of 1.37. Among the various rainwater-management techniques investigated, significantly lower bulk density was recorded with application of shales @ 300 t/ha combined with 2 supplemental irrigations of 10 mm each when dryspell of 10 days occurs after 50% flowering (T_7), which was statistically comparable with application of shales @ 300 t/ha combined with 1 supplemental irrigation of 10 mm (T_6), and shales application @ 300 t/ha as surface mulch (T_5). Integrated rainwater-management practices, viz. T_7, T_6 and T_5 treatments, reduced the bulk density by 5, 5 and 4.3%, respectively, compared with the control (T_1). Shale-mulched plots recorded slightly lower bulk density which could be owing to redistribution of soil particles, increased volume of soil and the binding activity of shales as soil conditioner, all of resulted in improved soil structure and thereby reduced the bulk density. The reduction in bulk density is related to an increase in dissolved carbon, water-holding capacity, more surface area, pore space and good soil aggregation (Mishra *et al*., 2017; Zewide *et al*., 2021). On the other hand, dryland groundnut (T_1) had higher bulk density than all the other rainwater-management practices.

The porosity of soil ranged from 41.09 (T_1) to 48.42 (T_7), with mean of 44.81. In the pooled mean, the highest porosity of soil was recorded under T_7 treatment, which was at par with T_6 and T_5 treatments. When compared to the control (T_1), integrated rainwater- management strategies such as T_7, T_6 and T_5 treatments enhanced the porosity by 17.8, 16.3, and 16.1%, respectively, in pooled mean. Shale-amended treatments showed lower bulk density, higher water-holding capacity, higher infiltration rate, and more soil aggregates than un-amended treatments, resulting in improved soil structure and increased porosity (Sloan *et al*., 2011). Dryland groundnut (T_1) had the lowest soil porosity, which was on a par with 1 supplemental irrigation of 10 mm when a dryspell of 10 days occurs after 50% flowering (T_8).

The water-holding capacity of soil ranged from 21.91% (T_1) to 30.94% (T_7), with mean of 26.45%. Among the several rainwater-management techniques that have been tested, significantly higher water-holding capacity was registered with T_7 treatment, which was at par with T_6 and T_5 treatments and these rainwater-management strategies outperformed the rest of the treatments (Table 3). In pooled mean, integrated rainwater-management practices such as T_7, T_6 and T_5 treatments enhanced the water-holding capacity by 41.2, 38.3 and 34.0%, respectively, compared to dryland groundnut (T_1). The maximum water-holding capacity of soil was found in shale-amended soil, owing to the maximum dispersion of micropores, which function as a water moderator, allowing for more moisture to be available. Application of soil-shale deposits improves the soil-moisture retention in top soil (Sallam *et al*., 1995). Dryland groundnut (T_1) registered the lowest water-retention capacity of all the rainwater-management practices, which was on a par with 1 supplemental irrigation of 10 mm after 50% flowering (T_8). This could be attributed to a smaller distribution of micropores and inadequate aeration.

The infiltration rate of soil ranged from 21.91% (T_1) to 30.94% (T_7), with mean of 26.45%. The highest infiltration rate was registered with T_7 treatment, which was at par with T_6 and T_5 treatments, which were significantly superior to rest of the treatments (Table 3). The pooled data revealed that, integrated-rainwater management practices such as T_7, T_6, and T_5 treatments increased the infiltration rate by 24.6%, 23.8%, and 22.9% respectively, compared to the control (T_1). Shale-mulched treatments improved infiltration, reduced raindrop effect on soil, and extended the time availability for water to enter the soil profile (Li *et al.,* 2000). The incorporation of large-sized shales into soil results in a permanent modification property of the soil, notably the rate of infiltration (Sloan *et al.,* 2002). Due to increased bulk density and reduced porosity, dryland groundnut (T_1) had a lower infiltration rate, which was on a par with the formation of conservation furrows at every 1.2 m width at sowing (T_2).

The *p*H of the soil did not alter significantly due to different rainwater-management practices in groundnut. However, shale-mulched treatments recorded numerically higher soil *p*H values than the rest of the treatments (Fig. 1). This could be due to the fact that, shale mulch worked

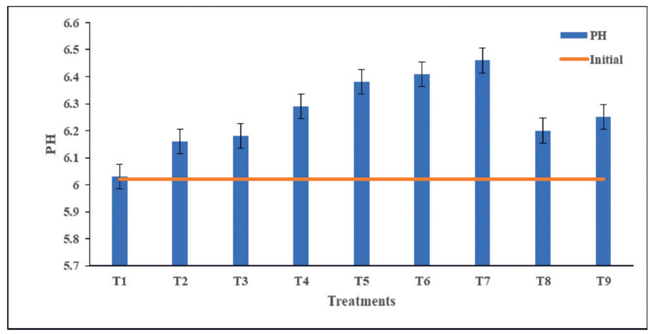

Fig. 1. Soil *p*H as influenced by different rainwater-management practices in groundnut (Pooled mean of 2 years) (Bars represent standard error mean).

Table 3. Post-harvest soil physical properties of groundnut as influenced by rainwater-management practices in groundnut (pooled mean of 2 years)

Treatment	Bulk density (Mg/m^3)	Porosity (%)	Maximum water-holding capacity (%)	Infiltration rate (mm/hr)
T_1, Dryland groundnut (without *in-situ* and *ex-situ* rainwater management)	1.40	41.09	21.91	9.72
T_2, Formation of conservation furrows at every 1.2 m width at sowing	1.39	44.34	25.17	9.83
T_3, T_2 + 1 supplemental irrigation of 10 mm when dryspell of 10 days occurs after 50% flowering	1.39	44.55	26.14	10.01
T_4, T_2 + 2 supplemental irrigations of 10 mm each when dryspell of 10 days occurs after 50% flowering	1.38	45.15	26.96	10.07
T_5, Shales (*Beluku* in Telugu) application @ 300 t/ha as surface mulch (first year application only)	1.34	47.70	29.37	11.95
T_6, T_5 + 1 supplemental irrigation of 10 mm when dryspell of 10 days occurs after 50% flowering	1.33	47.77	30.31	12.03
T_7, T_5 + 2 supplemental irrigations of 10 mm each when dryspell of 10 days occurs after 50% flowering	1.33	48.42	30.94	12.11
T_8, Only 1 supplemental irrigation of 10 mm when dryspell of 10 days occurs after 50% flowering	1.40	41.80	23.53	9.86
T_9, 2 supplemental irrigations of 10 mm each when dryspell of 10 days occurs after 50% flowering	1.39	42.46	23.75	9.93
SEm±	0.010	0.971	0.895	0.271
CD (P=0.05)	0.03	2.90	2.71	0.83
Initial	1.41	40.82	21.25	9.69

as a buffering agent, allowing the soil *p*H to remain stable. Filcheva and Tsadilas (2002) reported similar findings with zeolite amended soil.

Various rainwater-management strategies had no significant effect on the electrical conductivity of the soil (Fig. 2). However, marginally higher soil electrical conductivity was recorded with T_7 treatment, followed by T_5 treatment. This could be because of increased soil moisture in the soil profile, which enhanced salt solubility and, as a result, improved electrical conductivity in shale-applied treatments. The physico-chemical properties of the soil were unaffected by the rest of the rainwater-management practices, such as conservation furrows and supplemental irrigation.

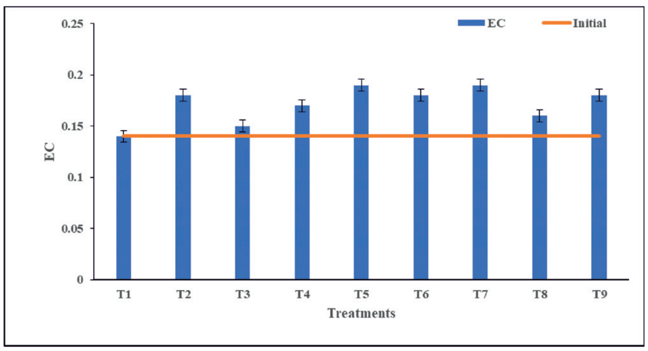

Fig. 2. Soil electrical conductivity (EC) as influenced by different rain water management practices in groundnut (pooled mean of 2 years) (Bars represents standard error mean).

Organic carbon of soil was found to be statistically non-significant due to various rainwater-management practices, (Fig. 3) but numerically higher soil organic carbon was registered with T_7 treatment followed by T_6 and T_5 treatments.

This could be due to a better soil physical environment, viz. water-holding capacity, aeration, which increased soil biota, resulting in faster decomposition of organic material and hence increased soil organic carbon. Due to inadequate water-holding capacity, dryland groundnut (T_1) cultivation had lower soil organic carbon, which resulted in a lower soil microbial load and, as a result, a lower soil organic carbon content.

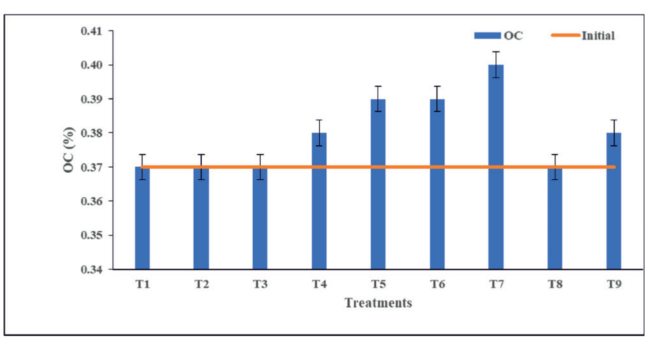

Fig. 3. Soil organic carbon (%) as influenced by different rainwater-management practices in groundnut (pooled mean of 2 years) (Bars represent standard error mean).

Effect of integrated rainwater-management practices on groundnut productivity

In the pooled data over 2 years, the pod yield ranged from 1209 kg/ha (T_1) to 1679 kg/ha (T_7), with mean of 1420 kg/ha (Fig. 4). Among the different rainwater-management practices, higher pod yield of groundnut was registered with treatment T_7, which was on a par with T_6 treatment. Treatment T_7 resulted in increased pod yield by 39.68% compared to dryland groundnut (T_1). Surface mulching with shales resulted in higher yields owing to reduced soil compaction and sufficient moisture availability, which supported improved root development and, as a result, increased groundnut growth parameters and yield attributes. Surface shale-mulched plots had higher pod yields, owing to the fact that mulch prevents water vapour loss from the soil surface to the microclimate, reduces direct evaporation loss of water, and increases soil-moisture availability, which creates a favourable environment for root growth, improves microclimate, and enhances crop growth, yield-attributing characters and ultimately yield (Chhetri and Sinha, 2017). Dryland groundnut (T_1) gave significantly lower pod yields, owing to shallow root production, poor root proliferation, and a lack of soil moisture in the soil profile at different phenophases of groundnut, resulting in lower soil moisture and nutrient uptake and a rapid depletion of moisture in the rooting zone. Moisture stress occurred during the flowering to pegging stages of groundnut, resulting in a significant loss in pod yield. This was attributable to flower drop, non-synchronized flowers, and a lower flower to peg-conversion rate (Reddy *et al*., 2013).

The haulm yield of groundnut was significantly influenced by different rainwater-management practices. The haulm yield ranged from 2,904 kg/ha (T_1) to 3,838 kg/ha

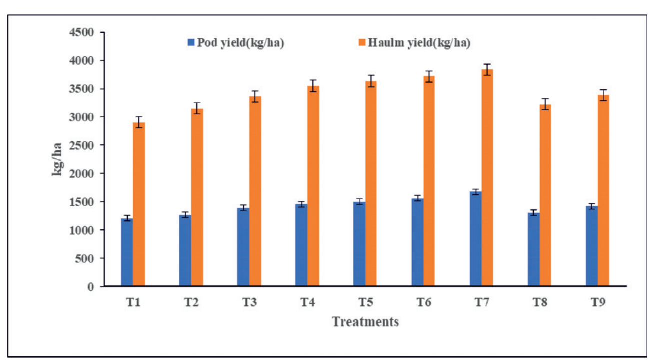

Fig. 4. Pod and haulm yield (kg/ha) as influenced by different rainwater-management practices in groundnut (pooled mean of 2 years) (Bars represent standard error mean).

(T_7), with mean of 3,419 kg/ha. Among different rainwater-management practices, significantly higher haulm yield of groundnut was obtained with treatment T_7, which was at par with T_6, T_5 and T_4 treatments. Higher haulm yield attained with surface mulching was due to beneficial effect of moisture conservation in root zone, which might have resulted in better root growth and nutrient availability and higher growth and yield-attributing characters, resulting in higher haulm yield. Further, supplemental irrigation improved the soil-moisture status in the rootzone, which has helped in the extension of leaf area. Significantly lower haulm yield was attained by dryland groundnut could be due to deficit soil moisture in the root zone at key developmental stages of crop gave reduced leaf-area and dry-matter. These results are in agreement with the findings of Sunitha *et al*. (2015).

Consequently, different rainwater-management practices had a significant impact on soil physical and physico-chemical properties. The soil physical properties after harvesting of groundnut crop revealed significance increase in porosity, water-holding capacity and infiltration, while significant reduction in soil bulk density and soil *p*H and organic carbon were numerically increased with application of shales 300 t/ha combined with 2 supplemental irrigations of 10 mm each when dryspell of 10 days occurs after 50% flowering. Hence, among the different rainwater-management practices tested, application of shales @ 300 t/ha combined with 2 supplemental irrigations of 10 mm each when dryspell of 10 days occurs after 50% flowering was found to be best rainwater-management practice for improving the soil physico-chemical properties and groundnut productivity in arid and semi-arid regions of Andhra Pradesh.

REFERENCES

Chhetri, B. and Sinha, A.C. 2017. Impact of moisture conservation and nutrient management practices on performance of maize (*Zea mays*) in tarai region of West Bengal. *Indian Journal of Agronomy* **62**(1): 59–64.

Dunnett, N. and Kingsbury, N. 2008. *Planting Green Roofs and Living Walls.* Timber Press Inc., Portland, O.R. 112 pp.

Filcheva, E.G. and Tsadilas, C.D. 2002. Influence of clinoptilolite and compost on soil properties. *Communications in Soil Science and Plant Analysis* **33**(3–4): 595–607.

Li, X.Y., Gong, J.D. and Wei, X.H. 2000. *In-situ* rain water harvesting and gravel-mulch combination for corn production in the dry semi-arid regions of China. *Journal of Arid Environments* **46**: 371–382.

Mishra, K.N., Patra, A.K., Garnayal, L.M., Mohanty, A.K and Swain, S.K. 2017. Long-term effects of integrated nutrient management on productivity and soil properties of rice–rice cropping system in coastal Odisha. *Indian Journal of Agronomy* **62**(3): 239–246.

Okeke, O.C and Okogbue, C.O. 2011. Shales: A review of their classifications, properties and importance to the petroleum industry. *Global Journal of Geological Sciences* **9**(1): 55–73.

Reddy, B.S., Sankar, G.R.M., Reddy, B.R., Reddy, A.M., Padmalatha, Y., Radhika, P., Bhargavi, K. and Sravani, N.P. 2013. Efficient management of dryspells with supplemental irrigation for maximum productivity of groundnut in arid *Alfisols* of South India. *Journal of Irrigation and Drainage Engineering* **139**(8): 645–654.

Sallam, A.S.H., Elwan, A.A. and Rabi, F.H. 1995. Shale deposits of El-Farafra depression (Egypt) as soil conditioner for sandy soils. *Arid Soil Research and Rehabilitation* **9**: 209–221.

Sloan, J.J., Ampim, P.A.Y., Cabrera, R.I., Mackay, W.A. and George, S.W. 2011. Moisture and nutrient storage capacity of calcined expanded shale. (In) *Principles, Applications and Assessment in Soil Science,* pp. 29–32. Dr. Burcu E. Ozkaraova Gungor (Ed.), ISBN: 978-953-307-740-6, InTech.

Sloan, J.J., George, S.W., Mackay, W.A., Colbaugh, P and Feagley, S. 2002. The suitability of expanded shale as an amendment for clay soils. *Hort Technology* **12**(4): 646–651.

Sunitha, V., Vanaja, M., Sowmya, P., Razak, S.K.A., Kumar, G.V., Anitha, Y. and Lakshmi, N. J. 2015. Variability in response of groundnut (*Arachis hypogaea* L.) genotypes to moisture stress and stress release. *International Journal of Bio-resource and Stress Management* **6**(2): 240–249.

Venkateswarlu, B., Chary, G.R., Singh, G. and Shivay, Y.S. 2016. *Climate Resilient Agronomy*, pp.120–142. The Indian Society of Agronomy, New Delhi.

Zewide, I., Singh, S. and Wogi, L. 2021. Soil physico-chemical properties as affected by integrated use of blended fertilizer, cattle manure, vermicompost and mineral nitrogen and phosphorus in potato in acidic soil of south-western Ethiopia. *Indian Journal of Agronomy* **66**(4): 474–482.