Research Findings

Photo 1. Crop growth at 30 DAS at the experimental plot; activities of rabi-summer 2014-2015. Photo by H.K. Patro.

Effects of Potassium Application Regime on Productivity and Drought Tolerance Parameters of Groundnut (*Arachis hypogaea* L.) in Odisha, India

Patro, H.K.,[(1)]*, G. Sahoo[(1)], B. Behera[(1)], A.K. Senapati[(1)], N.K. Awasthi[(2)], S.K. Bansal[(3)], S.N. Jena[(1)], N. Prusty[(1)], and A. Panda[(1)]

Abstract

Groundnut (*Arachis hypogaea* L.) is an important oilseed crop in India but its productivity is poor due to factors such as high soil acidity, low fertilizer use, imbalanced fertilizer practices, and frequent crop failures due to recurrent low soil moisture. Groundnut farmers in India, and Odisha in particular, often ignore the high potassium (K) requirements of this crop, which results in low yield and quality, as well as declining soil fertility. Appropriate K application management, therefore, needs to be addressed in order to meet groundnut K demands throughout the season.

The objectives of the present study were: to determine an appropriate K dose for rabi groundnut crops to suit the growing conditions in Odisha; to compare between basal and split K application; and to establish a well-founded fertilization

[(1)]College of Agriculture, Orissa University of Agriculture & Technology, Bhubaneswar, Odisha, India
[(2)]Former IPI Coordinator East India, Bangladesh & Sri Lanka, International Potash Institute (IPI), Zug, Switzerland
[(3)]Potash Research Institute of India (PRII), Gurgaon, India
*Corresponding author: hrusikesh.patro1@gmail.com

Note: IPI acknowledges Mr. Neeraj Kumar Awasthi, former IPI Coordinator for East India, Bangladesh & Sri Lanka, for his contribution to this project

recommendation for Odisha groundnut farmers. Three K doses (40, 60, and 80 kg K_2O ha^{-1}) were examined through basal and split application (basal and at bloom) versus unfertilized control and farmers' practice (18; 48; 36 kg ha^{-1} of N; P_2O_5; K_2O, respectively) altogether comprising eight treatments. Physiological indicators of water stress, drought resistance, and yield components were determined during crop development over two growing seasons in 2014 and 2015.

In most parameters studied, there was a significant advantage to the split K application at the highest dose tested. Due to an increased number of fertile pods per plant, pod yield was 30% higher than under control conditions, in addition to greater kernel weight and higher shelling rates. It may be concluded that split K application is far better for groundnut crops. Nevertheless, further research is required to determine K uptake rates, K agronomic efficiency, and consequently, the appropriate K dose under the conditions characterizing the groundnut production system in Odisha.

Keywords: *Arachis hypogaea* L.; K rate; nitrate reductase (NR) activity; relative water deficit (RWD); split K application; stem water potential (SWP).

Introduction

Among the nine important oilseed crops grown in India, groundnut (*Arachis hypogaea* L.) is of most importance, as it contains 43-55% oil and 25-28% protein. In 2012, groundnut consumption was about 3.28 and 4.52 kg capita^{-1} yr^{-1} in rural and urban areas, respectively (NSSO, 2012). However, the productivity is low in India due to rain dependency (85%), monoculture (60%) and cultivation on marginal land (Jat *et al.*, 2011). Yields fluctuated among years from 554 to 1,163 kg ha^{-1} and consequently, groundnut total production in India varied from 3.48 to 9.67 million Mg, during the period from 1950-51 to 2013-14, from an area of about 5 million ha (India Ministry of Agriculture, 2014).

In India, Gujurat was ranked first in area under cultivation (1.84 million ha), production (4.92 million Mg), and productivity (2,670 kg ha^{-1}), in 2013-14. At the same time, in Odisha, where the present study took place, the groundnut growing area was 0.07 million ha with production of 0.08 million Mg, and productivity of 1,231 kg ha^{-1} (India Ministry of Agriculture, 2014). Here, winter (rabi) groundnut crops are concentrated in river beds and banks, relying on residual soil moisture, while spring (rabi-summer) groundnut crops usually follow rice crops, also relying on residual soil moisture, but with partial irrigation. The current groundnut productivity in Odisha is low, mainly due to high soil acidity, low fertilizer application, imbalanced fertilizer use, and frequent crop failures due to recurrent low soil moisture and incidences of disease.

Potassium (K) is an essential nutrient involved in most of the biochemical and physiological processes that influence plant growth and metabolism (Zörb *et al.*, 2014). It also contributes to the survival of plants exposed to various biotic and abiotic stresses, such as diseases, pests, drought, salinity, cold, frost and waterlogging (Wang *et al.*, 2013). Potassium availability significantly affects plant growth, anatomy, morphology, and metabolism, and is involved in many physiological and molecular mechanisms related to its stress resistance. Potassium is the "plant-preferred" ion for maintaining its water status (Reddy *et al.*, 2003). It facilitates root expansion, thus increasing root-to-shoot ratio and hence, water and nutrient uptake (Cakmak *et al.*, 1994; Rengel and Damon, 2008). Potassium governs plant turgor and is involved in stomatal conductance (Marschner, 2012),

Photos 2. From left to right: Layout preparation; groundnut seeds; groundnut germinating at 6 DAS; view of the field at 35 DAS. Photos by H.K. Patro.

occupying a central role in plant growth and carbon exchange rate. Consequently, K availability must be maintained in order to obtain reasonable crop yields.

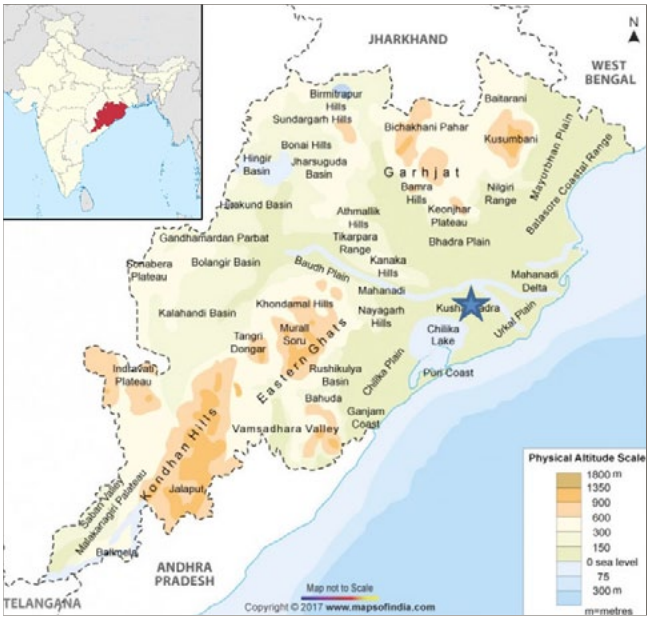
Optimization of mineral nutrition is key to successful groundnut production, as the nutrient demand of this species is very high. Modern high-yielding groundnut varieties remove more nutrients from the soil than traditional varieties. Unfortunately, groundnut growers in Odisha use very low quantities of fertilizer, and when they do, K application is often ignored. This has brought about an exhaustion of the native soil K, leading to a severe reduction in soil fertility. Soil K availability, in the short and long term, is an outcome of complex dynamics between four distinct K phases: soluble, exchangeable, non-exchangeable, and mineral. The dynamics are mainly determined by the bedrock type, but are also substantially affected by temperature and soil moisture fluctuations, the nature of the crop species, and by the farming practice. Under monsoon climates, heavy rainfall often causes rapid nutrient leaching from the soluble and exchangeable phases. On the other hand, certain clay minerals tend to exhibit strong K fixation (Zörb *et al*., 2014). Therefore, recommendations of appropriate fertilizer application must be founded on recent soil testing. Moreover, beyond the establishment of total crop K requirement per season, the timing of application must be considered.

Many studies have been carried out on groundnut fertilization in India. Mandal *et al*. (2002) reported that on average, groundnut requires yearly 160-180 kg nitrogen (N), 20-25 kg of phosphorus (P) and 80-100 kg of K to produce 2.0 to 2.5 Mg ha^{-1} of economic yield. Other studies focused also on the appropriate timing of fertilizer application (Rao *et al*., 2000; Ghosh *et al*., 2003; Chitdeshwari *et al*., 2007). These studies demonstrated that during the intensive growth period of groundnut from 30 to 70 days after sowing (DAS), which also includes the initiation of the reproductive phase, namely bloom, pegging, and pod set, nutrient requirements upsurge. To ensure sufficient nutrient availability during this critical period, fertilizer application at the required quantity seems essential. In particular, split K application has been addressed by several studies (such as CSM, 1990; Chinnasamy, 1993; Ponnuswamy *et al*., 1996), all of which reported significantly higher yields compared to a single, basal application. Nevertheless, the doses and splitting modes were considerably different from each other, leaving just the principal lesson, split K application, to be adopted and quantitatively adjusted according to local conditions.

The objectives of the present study were, therefore, to determine an appropriate K dose for rabi groundnut crops under Odisha's environmental conditions; to compare between basal and split K application; and to establish a well-founded fertilization recommendation for Odisha groundnut farmers.

Materials and methods

The experiment was conducted at the main agronomy research farm of the College of Agriculture at the Orissa University of Agriculture and Technology, Bhubaneswar, Odisha, India. The location has a latitude and longitude of 20°15'N and 85°52'E, an altitude of 25.9 m above sea level, and is situated about 64 km away from the Bay of Bengal (Map 1). The soil is sandy loam, slightly acidic, medium in organic carbon, low in available N, high in available P_2O_5 and low in available K_2O content.



Map. 1. The location of the experiment site in Odisha district (marked with a star). *Source:* Maps were downloaded from: https://store.mapsofindia.com/digital-maps/country-maps-1-2-3/india/state-maps-1-2-3-4/odisha-physical-map (Odisha), and https://simple.wikipedia.org/wiki/Odisha (India).

Odisha is characterized by a sub-tropical climate with a hot and humid summer (March-June), hot and wet monsoon season (late June-mid October), and a mild and dry winter (November-February). Broadly, the climate falls in the group of moist hot type (Lenka, 1976). The mean annual rainfall is 1,527 mm, which is received over 99 days, 74% of which occur from June to September. May is the warmest month (37.7°C) and January is the coldest (15.0°C). The highest evaporation occurs in May and the lowest in September, with 8.0 and 3.3 mm day^{-1}, respectively. These climate conditions restrict the groundnut growing season to the period between December and June, about 180-210 days (Svoboda and Fuchs, 2016). The 2015 season was much warmer than 2014, excluding April (Fig. 1). Also, 2015 was generally wetter, excluding May, when compared to 2014.

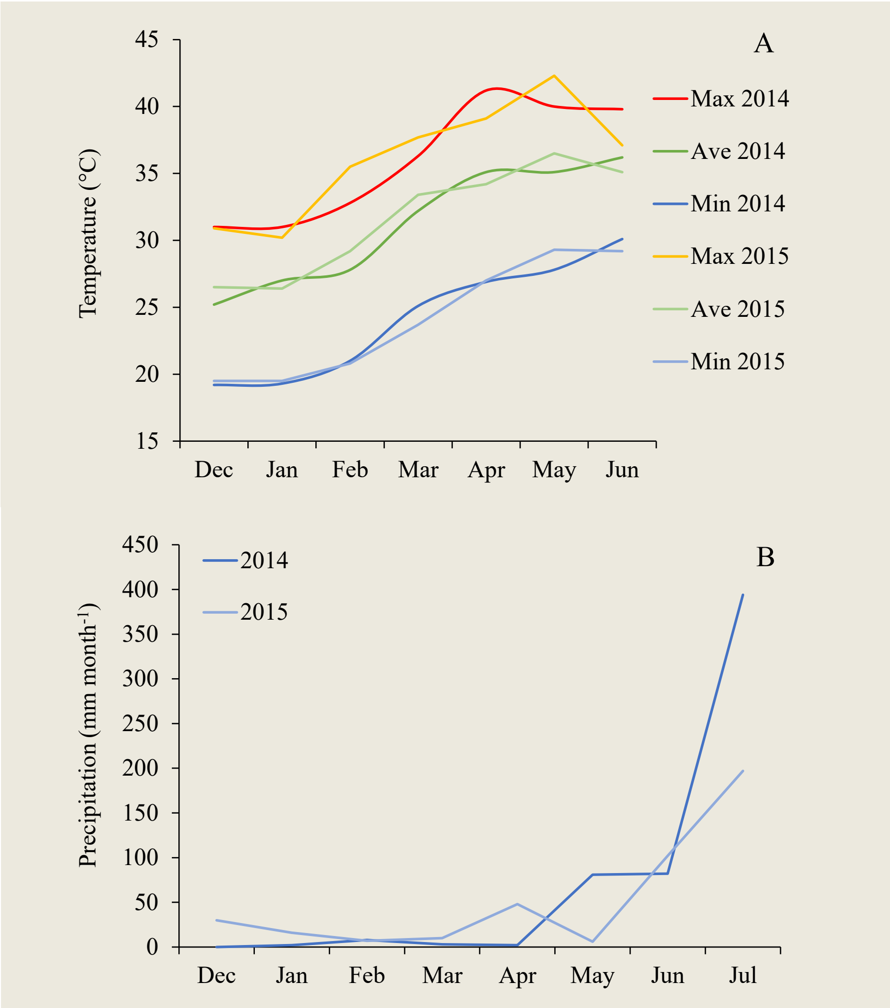


Fig. 1. Monthly maximum, average, and minimum temperatures (A), and monthly precipitation (B) during the 2014 and 2015 groundnut seasons in Odisha, India. *Source:* https://www.worldweatheronline.com/bhubaneswar-weather-averages/orissa/in.aspx.

The field of the experiment site was ploughed three times, laddered, and leveled. Nitrogen, P, and K were applied as per treatment specifications in the forms of urea, single super phosphate (SSP), and muriate of potash (MOP), respectively (Table 1). Gypsum and Chlorodust®, at 250 and 25 kg ha^{-1}, respectively, were uniformly applied. The farmers' practice (FP) included a dose of N-P_2O_5-K_2O at a ratio of 18:46:30 kg ha^{-1} and farm yard manure (FYM) at 5 Mg ha^{-1}, applied 15 days before sowing. Sowing took place on 23 and 14 January in 2014 and 2015, respectively. Seed rate was 175 kg pods ha^{-1}, with 30 cm between plant rows, and 10 cm between plants within a row. Surface irrigation was provided during the crop season whenever required. Prophylactic measures were undertaken to protect the crop from diseases and pests.

One day before harvest, soil surface was softened with light irrigation. All border plants were removed before the harvest of each experimental plot. The pods were plucked by hand and cleaned. The pod and haulm were sundried and their weights were recorded separately for each experimental plot.

The experiment comprised eight treatments in three replications, in a randomized block design (RBD). Details of the treatments and the corresponding symbols used for the experiment are given in Table 1. Treatments T3-T8 were basally applied with the full recommended N dose of 20 kg ha^{-1}. The basal dose of fertilizers was placed in furrows at the time of sowing as per treatment specifications and the subsequent splits of K were placed beside the rows.

A groundnut variety known as Devi (originally, ICGV 91114) was used in the experiment. ICGV 91114 is a Spanish variety and has an erect growth habit with sequential flowering and medium elliptic, green to light-green leaves. It is a high-yielding variety, which matures within 110-120 days in the dry winter (rabi) season and is tolerant of mid-season and end-of-season droughts. Due to its early and uniform maturity, attractive pod and seed shape and high shelling turnover, ICGV 91114 is a very popular variety in many parts of India, including Odisha.

During crop development, several indicators of plant drought damage or tolerance were measured, including SPAD, chlorophyll stability index (CSI), membrane stability index (MSI), proline content, nitrate reductase (NR) activity, relative water deficit (RWD), and stem water potential (SWP). SPAD values, commonly used to estimate chlorophyll content, N, and the general physiological status of the plant (Rodriguez and Miller, 2000), were determined in the field at 30, 45, 60, and 75 DAS using a SPAD 502 Plus Chlorophyll Meter (Spectrum Technologies Inc.). To determine CSI, fresh leaves were collected from each treatment plot at 45 and 60 DAS. In two glass test tubes, 0.25 g of representative leaf sample and 10 ml of distilled water were added. One tube was then subjected to heat in a water bath at 56^{0}C for 30 minutes, while the other served as control. Total chlorophyll in the two samples was extracted with 80% acetone and determined using a colorimeter at 652 nm (Lichtenthaler, 1987). CSI, which is directly proportional to drought stress (Blum and Ebercon, 1981; Rahbarian *et al*., 2011), was calculated as the percentage of the total chlorophyll content of the thermally treated as related to the control sample. MSI was determined by the ion leakage method (Deshmuukh *et al*., 1991). Proline content, as a measure of plant resistance to stress, was determined after Bates *et al*. (1973) on leaves collected from each treatment at 45 and 60 DAS. NR activity was determined in leaves collected from each treatment at 45 and 60 DAS, following methods described by Nair and Abrol (1977).

Water stress parameters were determined with fresh leaves which were collected and brought to the lab at 45 and 60 DAS. After leaf fresh weight (FW) was determined, the leaves were immersed in water for an hour. Excess water was then gently removed from the leaves' surface and they were weighed again to determine turgid weight (TW). The leaves were dried in a hot air oven at 80°C for 48-72 h, following which their dry weight (DW) was determined. RWD was calculated as the ratio between the current leaf water content and the maximum leaf water content under full turgidity, as follows: RWD=[(FW-DW)/(TW-DW)]·100. For the determination of SWP, a fully expanded young leaf was wrapped in a damp paper towel and aluminum foil for an hour to allow equilibrium with the plant water potential, and then detached and measured using a Scholander pressure bomb (Model 1000, PMS Instrument Co., Albany, OR, USA) (Tyree and Hammel, 1972).

Five plants were randomly sampled from the middle of each plot to determine the number of pods per plant. At harvest, the pods of each plot were sundried for 3-4 days, weighed, and pod yield was calculated in kg ha^{-1}. A sample of about 1 kg pods was taken from each plot, decorticated, and the shells and kernels were weighed

Table 1. A detailed description of the fertilization treatments.

Symbols	Treatment details	Abbreviation used in text
T_1	Control (no NPK)	T_1; Control
T_2	Farmers' practice (18:46:30 kg NPK ha^{-1}).	T_2; FP
T_3	Full (100%) recommended PK dose: 40 kg P_2O_5 ha^{-1}; 40 kg K_2O ha^{-1}, all at sowing (basal).	T_3; RDF, K_b
T_4	Full (100%) recommended P dose+150% RD of K: 60 kg K_2O ha^{-1}, basal.	T_4; RDF+50% K, K_b
T_5	150% P: 60 kg P_2O_5 ha^{-1}+200% K: 80 kg K_2O ha^{-1}, basal.	T_5; RDF+50% P+100% K, K_b
T_6	Full (100%) recommended PK dose: 40 kg P_2O_5 ha^{-1}; 40 kg K_2O ha^{-1}. K dose split between basal and bloom (30 DAS) applications, 20 kg K_2O ha^{-1} each, respectively.	T_6; RDF, K_s
T_7	100% P: 40 kg P_2O_5 ha^{-1}+150% K: 60 kg K_2O ha^{-1}. K dose split between basal and bloom (30 DAS) applications, 30 kg K_2O ha^{-1} each, respectively.	T_7; RDF+50% P+50% K, K_s
T_8	150% P: 60 kg P_2O_5 ha^{-1}+200% K: 80 kg K_2O ha^{-1}. K dose split between basal and bloom (30 DAS) applications, 40 kg K_2O ha^{-1} each, respectively.	T_8: RDF+50% P+100% K, K_s

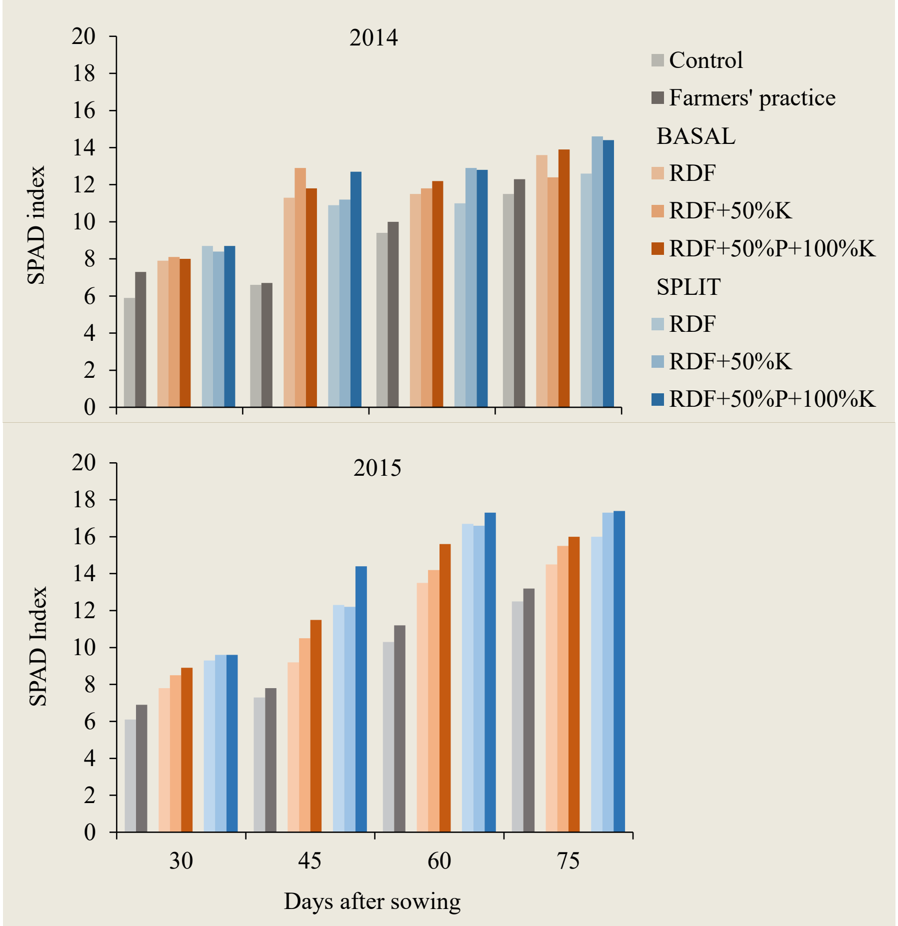


Fig. 2. Effects of elevated K rates, and of basal versus split K application on SPAD values of groundnut crop measured in the two experimental years at 30, 45, 60, and 75 DAS. A detailed explanation of treatments is given in Table 1.

separately to determine the shelling percentage, as follows: shelling (%)=[(kernels wt./(kernels+shells wt.)]·100. The weight of 100 kernels was determined by a random sampling and weighing of 100 kernels of each plot.

All data were subjected to statistical analyses suitable to the experimental design, following Panse and Sukhatme (1985). The treatment variations were tested for significance using an F test and the critical difference (CD) was calculated at P=0.05 and presented.

SPAD values increased with plant age from 45 to 75 DAS (Fig. 2). While K application rate had slight and inconsistent effects on SPAD in 2014, SPAD values displayed a much clearer response in 2015, increasing with the rise in K application rate in most cases. SPAD response to split K dose was also stronger in 2015, being significantly higher than at the basal application.

In 2014, RWD was extremely high in the control plants compared to other treatments, but no significant difference occurred between the measurements taken at 45 and 60 DAS (Fig. 3). In the other treatments, RWD was significantly higher at 60 than at 45 DAS. While no significant influence occurred for K dose at 45 DAS, a clear trend of decreasing RWD in response to K rate was observed at 60 DAS. Furthermore, this trend was much stronger under the split, compared to the basal K application (Fig. 3).

In 2015, RWD was significantly high at control and FP treatments, slightly less at the basal treatments, and further declined to significantly lower levels under the split K application (Fig. 3). The effect of K rate on RWD was obvious only at the split K group, decreasing with the elevated K rate at both measurement days. The control plants SWP was significantly lower than in the other treatments in both years. SWP steadily increased with the rising K rate at the basal applications (Fig. 3). Under split K application, SWP was generally at the highest range, however, it responded to the rising K rate only in 2015. Noteworthy was the significantly lower SWP at 60, compared to 45 DAS in 2014, but not in 2015.

Since the values and response patterns for CSI, MSI, NR activity and proline concentration were similar in both experimental years in the groundnut leaves, they were pooled and averaged (Fig. 4). No significant effects of K rate, application mode or the timing of measurement on CSI were found, although slight trends

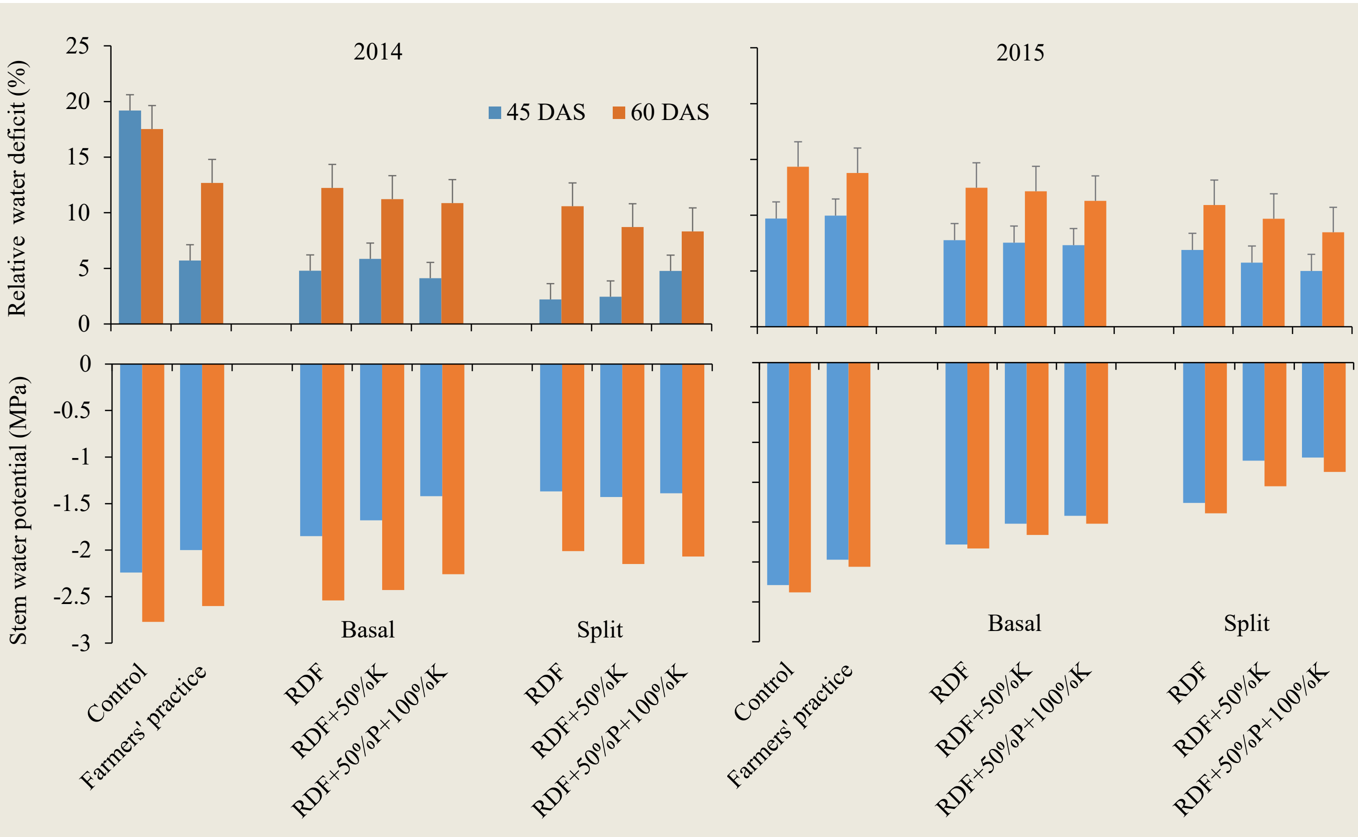


Fig. 3. Effects of elevated K rates and of basal versus split K application on RWD and SWP values of groundnut crop measured in the two experimental years at 45 and 60 DAS. A detailed explanation of treatments is given in Table 1.

of increasing CSI could be observed in response to K rate and split application (Fig. 4A). MSI was significantly lower at 60, compared to 45 DAS (Fig. 4B). MSI response to K treatments was rather weak, particularly at 45 DAS, nevertheless, it gradually increased from the control to the highest K rate under split application, where it was significantly higher (Fig. 4B). In contrast, NR activity exhibited a substantial response to the fertilizer treatments (Fig. 4C). It rose consistently from about 10 to 36 µL NO_2 gFW^{-1} h^{-1}, in control (T_1) and in the higher and split K dose (T_8), respectively. Generally, NR activity was higher at 45 than at 60 DAS. These patterns were similar but much weaker with the response of proline concentration to K fertilization regime (Fig. 4D).

All yield parameters were improved by all fertilization treatments compared to the unfertilized control (Fig. 5). FP displayed a general advantage over control, particularly in 2014, the yield parameters of which were basically lower than those of 2015. Compared to FP, the basal K application had no significant influence on the yield parameters in 2014, including no differences that occurred between K rates. The split K application, however, resulted in significant increases in most yield parameters in 2014, with substantial rises in pod number and pod yield in response to elevated K rates (Fig. 5). In 2015, shelling percentage and kernel weight were significantly higher than in 2014. Also, the basal K application seemed more effective than FP, with a slight but consistent advantage to the higher K rates. As in 2014, the split K application gave rise to further increases in yield parameters, with a similar response pattern to the elevated K rates (Fig. 5). Hence, the higher K rates, split between basal and upon bloom applications resulted in the highest groundnut yields in both years.

Discussion

In Odisha, India, groundnut is grown during the dry season, relying on residual soil moisture remaining in river banks after the wet monsoon season or following rice crops. In the absence of sufficient supplement irrigation, rabi crops are often subjected to drought stress. The early reproductive stages, usually occurring between 35 and 75 DAS, are highly susceptible to drought stress (Reddy *et al.*, 2003). A minimum level of soil moisture is required to allow K uptake by the roots, as well as for successful pegging and early pod development (Smith, 1951; Reddy *et al.*, 2003). The 2014 groundnut season was significantly drier than 2015 during

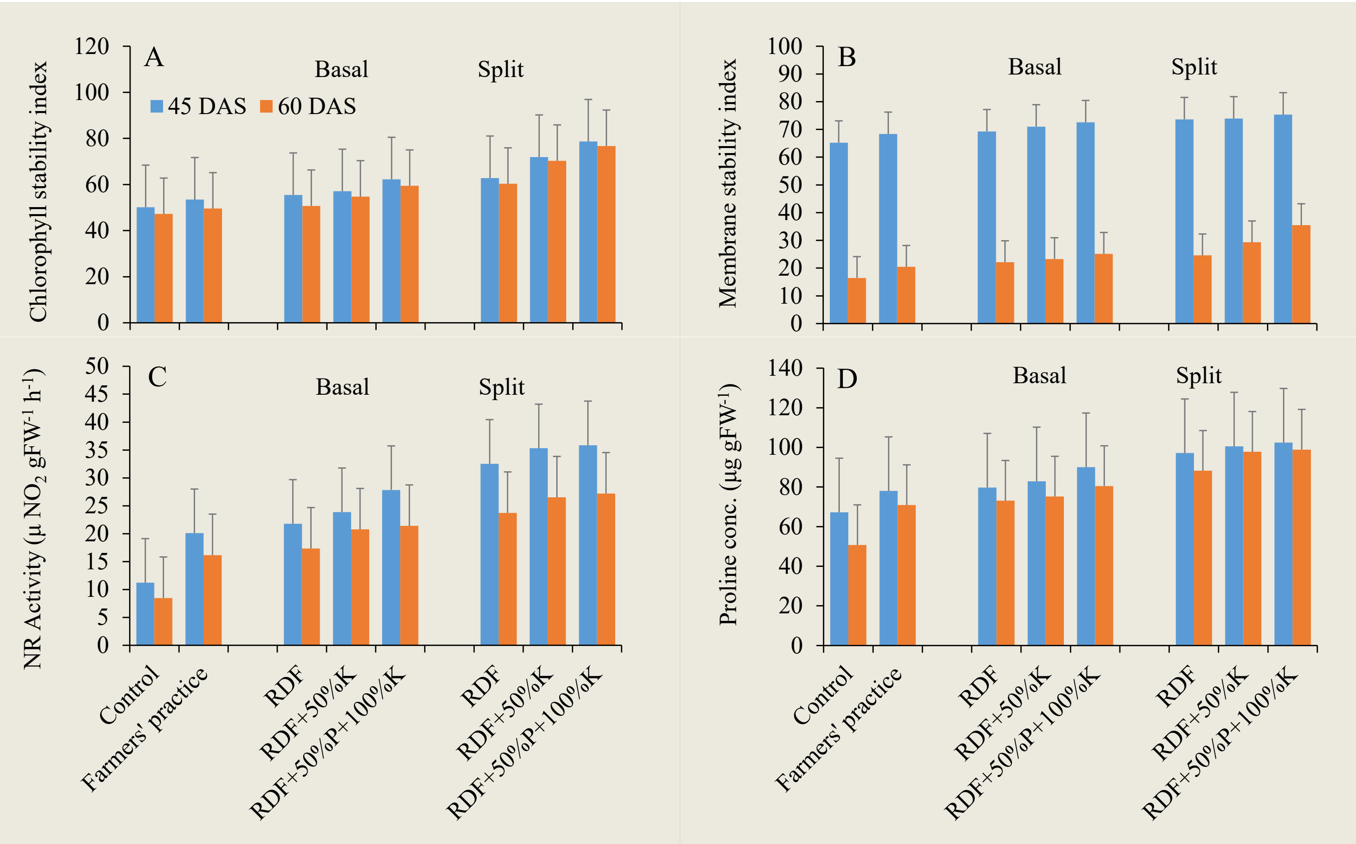


Fig. 4. Effects of elevated K rates, and of basal versus split K application on CSI (A), MSI (B), NR activity (C), and proline concentration in groundnut leaves measured at 45 and 60 DAS. Data for the two years were pooled and averaged. A detailed explanation of treatments is given in Table 1.

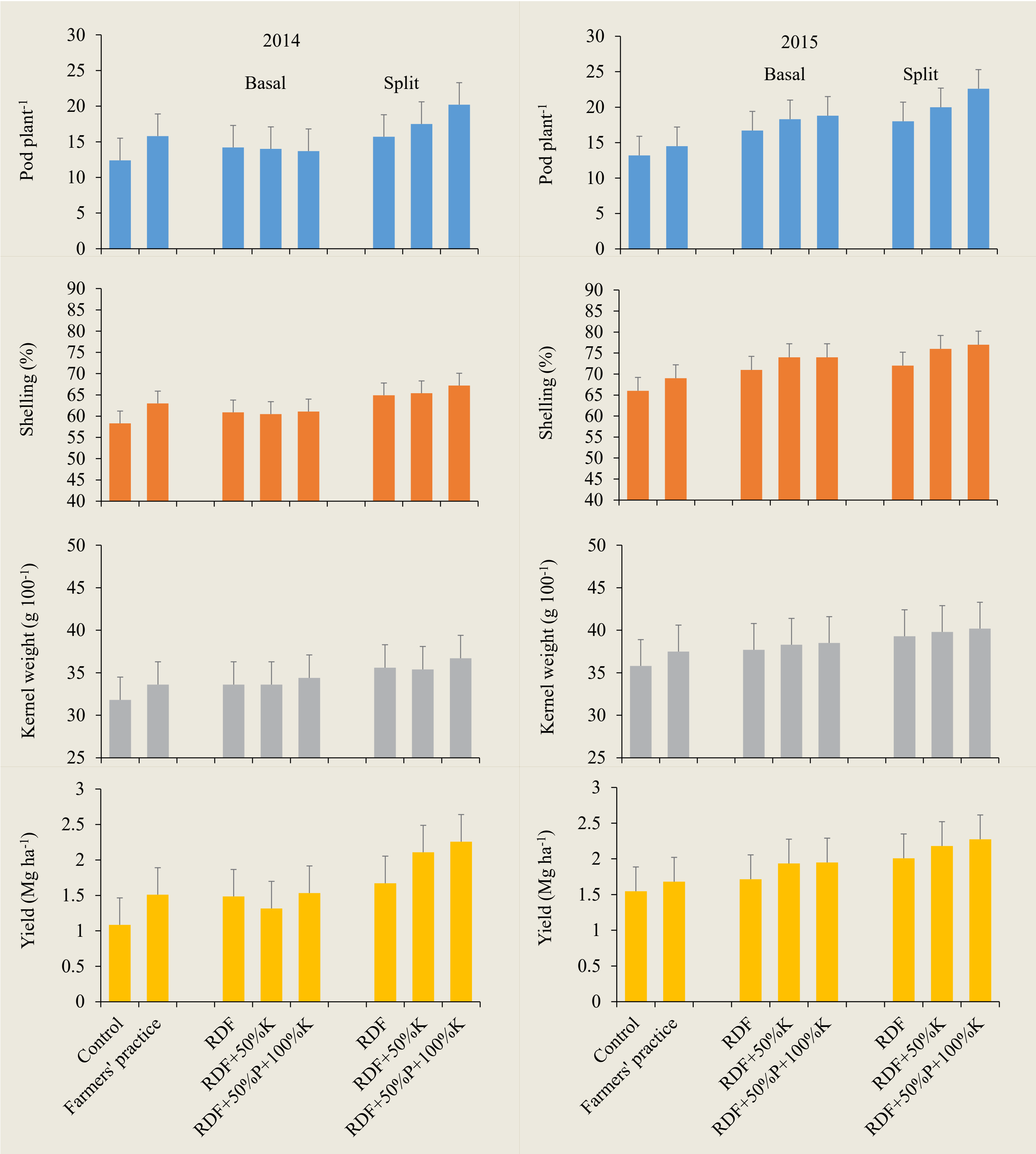


Fig. 5. Effects of elevated K rates, and of basal versus split K application on groundnut yield parameters in 2014 and 2015. A detailed explanation of treatments is given in Table 1.

this critical period (Fig. 1), which might have been the reason for many differences between the two years that occurred in physiological indicators (Figs. 2, 3, and 4), and consequently, in yield parameters (Fig. 5).

SPAD, a general indicator of crop vigor, N content, and chlorophyll status (Srinivasarao *et al*., 2016), demonstrates the differences between the two years (Fig. 2). In 2014, a clear positive effect of K application on SPAD values was observed, but any further influence of K dose or application management was rather poor and inconsistent. In contrast, SPAD responses to these parameters were clear and significant in the wetter groundnut season of 2015. These differences may indicate that the limiting factor in 2014 was insufficient K uptake by the crop due to the dry soil, in spite of adequately supplied fertilizers.

Potassium regulates plant water relations, facilitates water uptake, as well as growth and development. Among other mechanisms and factors, K plays a crucial role governing the osmotic regulation required to draw water into plant roots. Potassium deficient plants have difficulties in withstanding drought because of their failure to adjust the root osmotic potential necessary to absorb water from a drying soil. In the present study, K application reduced leaf RWD and increased SWP under normal and stress conditions (Fig. 3). These two parameters consistently responded to both elevated and split K dose, demonstrating the central role of sufficiently available K in plant water status, as previously discussed by Umar and Moinuddin (2002). Proline accumulation, another osmo-regulator, also facilitates plant drought resistance. Interestingly, proline concentration increased steadily with the rising K dose; moreover, it was higher under the split K management (Fig. 4D). Altogether, it appears that improved K management can significantly raise the drought resistance of groundnut crops, thus improving water uptake and supporting productivity.

CSI and MSI are good measures of plant cell integrity. Low values may indicate stress (Rahbarian *et al*., 2011) but also aging of the sampled leaves. The increasing CSI and MSI values with the rising K availability, through higher dose or under split application (Fig. 4A-B), demonstrate the indirect contribution of better K nutrition to facilitated performance of a groundnut crop. Beyond this general influence of K, the straightforward increasing values of NR activity in response to elevated K readiness (Fig. 4C) help to demonstrate the pivotal role of this nutrient in N uptake and metabolism, which is fundamental to plant growth and development (Hasanuzzaman *et al*., 2018).

Basal K application is necessary for groundnut as it complements N and P uptake at the early stages of crop development. Also, it promotes root proliferation, thus extending plant water acquirement from the soil. Nevertheless, the capacity of the young crop to take up the whole seasonal K dose is very limited. Therefore, most of the K dose, if basally applied, may be lost through leaching or fixation, and will not be available to the crop at later developmental stages, when K demands surge.

Splitting K dose into two applications, basal and upon bloom, provides the groundnut crop with more appropriate K quantities throughout the season, precisely when required. The advantages of split K application, which was demonstrated in several previous studies (CSM, 1990; Mondal and Goswami, 1991; Chinnasamy 1993; Ponnuswamy *et al*., 1996; Rao *et al*., 2000; Ghosh *et al*., 2003; Chitdeshwari *et al*., 2007), has therefore also been confirmed in the present experiment; in both years, the split K application gave rise to greater pod numbers and yields, and to higher kernel weight (Fig. 5). More recent studies on groundnut crops in India (Borah *et al*., 2017; Sanadi *et al*., 2018) also support these results.

A significant increase of the recommended K dose, from 40 to 80 kg K_2O ha^{-1}, and particularly under split K application, brought about a significant increase in yield of 30% (Fig. 5). These results are supported by previous studies that also showed remarkable groundnut yield increases in response to elevated K doses (Jain *et al*., 1990; Jana *et al*., 1990; Mitra and Sahoo, 1998; Truong *et al*., 2017). However, the upper threshold, above which further increase of K dose is not expected to contribute to yield or quality, is still unclear. In addition, the efficiency of K application in the present study is undetermined. Further research into the groundnut cropping systems in Odisha is hence required to quantify K uptake rates and K agronomic efficiency, and to evaluate the economic feasibility of a split K application regime at higher K doses.

Acknowledgement

This project was financially supported by the International Potash Institute (IPI), Switzerland.

References

Bates, L.S., P. Waldren, and I.D. Tare. 1973. Rapid Determination of Free Proline for Water Stress Studies. Plant Soil 103:875-883.

Blum, A., and A. Ebercon. 1981. Cell Membrane Stability as a Measure of Drought and Heat Tolerance in Wheat 1. Crop Sci. 21(1):43-47.

Borah, B., D.S. Patil, and Pawar, R.B. 2017. Enhancing Kharif Groundnut (*Arachis hypogaea* L.) Yield and Quality in Entisol through Potassic Fertilizer Management. Int. J. Curr. Microbiol. App. Sci. 6(11):4068-4074. doi: https://doi.org/10.20546/ijcmas.2017.611.476.

Cakmak, I., C. Hengeler, and H. Marschner. 1994. Partitioning of Shoot and Root Dry Matter and Carbohydrates in Bean Plants Suffering from Phosphorus, Potassium and Magnesium deficiency. J. Exp. Bot. 45:1245-1250.

Chinnasamy, C. 1993. Studies on the Effect of Split Application of Nitrogen and Potassium on the Yield Performance of Irrigated Groundnut (VRI 2) under various Methods and Times of Application. M.Sc. (Ag.). Thesis, Tamil Nadu Agricultural University, Coimbatore.

Chitdeshwari, T., P.K. Selvaraj, and P.M. Shanmugam. 2007. Influence of Levels and Split Application of Fertilizers on the Yield and Nutrient Uptake by Groundnut. Agricultural Science Digest 27(2):91-94.

CSM (Oils seeds). 1990. Crop Scientists Meet on Oilseeds. *In:* Proc. of Crop Scientists Meet on Oilseeds, 25-26 April, Tamil Nadu Agricultural University, Coimbatore.

Deshmuukh, P.S., R.K. Sairam, and D.S. Shukla. 1991. Measurement of Ion Leakage as a Screening Technique for Drought Resistance in Wheat Genotypes. Indian J. Plant Physiol. 34:89-91.

Ghosh, P.K., D. Dayal, K.G. Mandal, R.H. Wanjari, and K.M. Hati. 2003. Optimization of Fertilizer Schedules in Fallow and Groundnut-Based Cropping Systems and an Assessment of System Sustainability. Field Crops Res. 80(2): 83-98.

Hasanuzzaman, M., M.H.M. Bhuyan, K. Nahar, M.S. Hossain, J.A. Mahmud, M.S. Hossen, and M. Fujita. 2018. Potassium: A Vital Regulator of Plant Responses and Tolerance to Abiotic Stresses. Agronomy 8(3):31.

India Ministry of Agriculture. 2014. Agricultural Statistics at a Glance, 2014. Published in India by Oxford University Press. ISBN-13: 978-0-19-945965-0. https://eands.dacnet.nic.in/PDF/Agricultural-Statistics-At-Glance2014.pdf

Jain, R.C., D.P. Nema, R. Khandwe, and R. Thakur. 1990. Effect of Phosphorus and Potassium on Yield, Nutrients Uptake, Protein, and Oil Contents of Groundnut (*Arachis hypogaea*). Indian J. Agric. Sci. 60(8):559-561.

Jana, P.K., S. Ghatak, A. Barik, and B.C. Biswas. 1990. Response of Summer Groundnut to Nitrogen and Potassium. Indian J. Agron. 35:137-143.

Jat, R.S., H.N. Meena, A.L. Singh, J.N. Surya, and J.B. Misra. 2011. Weed Management in Groundnut (*Arachis hypogaea* L.) in India - A Review. Agricultural Reviews 32(3).

Lenka, D. 1976. Classification of Rainfall Zones and Drought Prone Areas (in) Water Requirement of Crops in Orissa. Publisher Directorate of Agriculture, Govt. of Orissa 1976: 4-5.

Lichtenthaler, H.K. 1987. Chlorophylls and Carotenoids: Pigments of Photosynthetic Membranes. Method Enzymol. 148:350-382.

Mandal, K.G., P.K. Ghosh, R.H. Wanjari, K.M. Hati, K.K. Bandyopadhyay, and A.K. Misra. 2002. Practical Implication of Nutrient x Nutrient Interaction to Boost Oilseeds Productivity in India. Fertilizer Research 47(7):13-18 & 21-26.

Marschner, P. 2012. Marschner's Mineral Nutrition of Higher Plants, 3rd ed. Academic Press: London, UK, 2012. p. 178-189.

Mitra, G.N., and D. Sahoo. 1998. Nitrogen - Potassium Interaction on Yield and Quality Development for Rice - Legume Sequence in Orissa. Final Report. IPI/PRII sponsored research project. Department of Agril. Chemistry, Soil Science and Bio Chemistry. OUAT.

Mondal, S.S., and S.B. Goswami. 1991. Effect of Split Application of Potassium on Rainfed Groundnut. J. Potassium Research 7(4):304-308.

Nair, T.V.R., and Y.P. Abrol. 1977. Studies of Nitrate Reducing Systems in Developing Wheat Ears. Crop Sci. 17:428-442.

NSSO (National Sample Survey Office, India). 2012. Report No. 558: Household Consumption of Various Goods and Services in India, 2011-12.

Panse, V.G., and P.V. Sukhatme. 1985. Statistical Methods for Agricultural Research. ICAR, New Delhi.

Ponnuswamy, K., V.K. Balakrishnan, and P. Santhi. 1996. Exploiting the Production Potential of Groundnut by Improved Nutrient Management in the Lower Bhavani Project Area, Tamil Nadu, India. International Arachis Newsletter 16:50-52.

Rahbarian, R., R. Khavari-Nejad, A. Ganjeali, A. Bagheri, and F. Najafi. 2011. Drought Stress Effects on Photosynthesis, Chlorophyll Fluorescence and Water Relations in Tolerant and Susceptible Chickpea (*Cicer arietinum* L.) Genotypes. Acta Biologica Cracoviensia Series Botanica 53(1):47-56.

Rao, M.M.V.S., G. Bheemaiah, and M.V.R. Subrahmanyam. 2000. Growth and Yield of Rainfed Groundnut (*Arachis hypogaea*) Alley Cropped with Albizia Lebbeck under Integrated Nutrient Management. Indian J. Agric. Sci. 70(11):786-790.

Reddy, T.Y., V.R. Reddy, and V. Anbumozhi. 2003. Physiological Responses of Groundnut (*Arachis hypogea* L.) to Drought Stress and its Amelioration: A Critical Review. Plant Growth Regulation 41(1):75-88.

Rengel, Z., and P.M. Damon. 2008. Crops and Genotypes Differ in Efficiency of Potassium Uptake and Use. Physiol. Plant. 133:624-636.

Rodriguez, I.R., and G.L. Miller. 2000. Using a Chlorophyll Meter to Determine the Chlorophyll Concentration, Nitrogen Concentration, and Visual Quality of St. Augustinegrass. HortScience 35(4):751-754.

Sanadi, U., K.K. Math, B.I. Bidari, and B.S. Yenagi. 2018. Effect of Potassium Nutrition on Yield, Quality and Economics in Groundnut (*Arachis hpogaea* L.) in a Vertisol. J. Pharmacognosy and Phytochemistry 7(2):220-222.

Smith, B.W. 1951. *Arachis hypogaea* - Aerial Flowers and Subterranean Fruit. Amer. J. Botany 37:802-815.

Srinivasarao, C., A.K., Shanker, S. Kundu, and S. Reddy. 2016. Chlorophyll Fluorescence Induction Kinetics and Yield Responses in Rainfed Crops with Variable Potassium Nutrition in K Deficient Semi-Arid Alfisols. J. Photochemistry and Photobiology B: Biology 160:86-95.

Svoboda, M., B. Fuchs. 2016. Handbook of Drought Indicators and Indices. https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1118&context=droughtfacpub.

Truong, T.T., M.M. Duong, V.B. Pham, H.C. Ho, M.T. Hoang, and Q.D. Tran. 2017. Effect of Potassium Fertilizer Types and Rates on Peanut Growth and Productivity on Coastal Sandy Soil in South Central Vietnam. International Potash Institute *e-ifc* 48:20-26.

Tyree, M.T., and H.T. Hammel. 1972. The Measurement of the Turgor Pressure and the Water Relations of Plants by the Pressure-bomb Technique. J. Experimental Botany 23:267-282. https://doi.org/10.1093/jxb/23.1.267.

Umar, S., and Moinuddin. 2002. Genotypic Differences in Yield and Quality of Groundnut as Affected by Potassium Nutrition under Erratic Rainfall Conditions. J. Plant Nutr. 25:1549-1562.

Wang, M., Q. Zheng, Q. Shen, and S. Guo. 2013. The Critical Role of Potassium in Plant Stress Response. Int. J. Molecular Sciences 14(4):7370-7390.

Zörb, C., M. Senbayram, and E. Peiter. 2014. Potassium in Agriculture-Status and Perspectives. J. Plant Physiol. 171:656-669.

The paper "Effects of Potassium Application Regime on Productivity and Drought Tolerance Parameters of Groundnut (*Arachis hypogaea* L.) in Odisha, India" also appears on the IPI website at:

Regional activities/India