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Influence of Tillage and Nutrient Management Practices on Peanut Yields, Economics and Resource Efficiency in Thar Desert of South Asia

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Abstract

Arid regions of Rajasthan province of India have very low productivity and due to hungry and thirsty soil it further affected by continuous and inappropriate tillage and fertilizer management practices. A two year study was piloted to explore the efficient tillage and fertilizer management practices and their influence on crop and water productivity and nutrient uptake in peanut. The experiment was planned with three tillage practices in main plots and six fertilizer management options in sub plots, and replicated four times. Deep tillage (DT) (25 cm) contributed significantly higher pod (2.98 Mg ha^{-1}), kernel (2.16 Mg ha^{-1}), protein (0.24 Mg ha^{-1}), and oil (0.91 Mg ha^{-1}) yield which were respectively 13, 26, 26 and 28% higher over the minimum tillage (MT). MT recorded the higher energy use efficiency (EUE) by 10.2% and energy profitability (EP) by 12.5% compared to DT, respectively. Among nutrient management options peanut (20 kg N + 32 kg P + 15 kg K ha^{-1}) (RDF) along with seed inoculation with arbuscular mycorrhizal fungi (AMF) and phosphorus solubilizing bacteria (PSB) recorded significantly higher pod, kernel, protein, and oil yields compared to RDF without seed inoculation. Also recorded the maximum water productivity (8.27 kg ha^{-1}), net return (2708.32), EUE (10.89 MJ ha^{-1}), and EP (0.18 kg MJ^{-1}) over rest of the nutrient management practices. Thus, deep tillage along with RDF + PSB + AMF (2 kg ha^{-1}) enhanced peanut pod, kernel, protein and oil yields as well as peanut water productivity and economic returns under alkaline soils of arid region.

Keywords: Peanut; Tillage; Nutrients; Biofertilizer; Pod yield; Economics; Energy use

Introduction

Peanut (*Arachis hypogaea* L.) is cultivated in more than 100 countries under diverse agro-ecologies and it ranks 5th amongst the oilseeds crop grown in the World. About 80% of the peanut is grown in vulnerable regions (arid and semi-arid) with high variability of drought, temperature, rainfall and land degradation [1]. Peanut covers 29.5 M ha area globally with a production of 48.7 Mt [2]. India is the 2nd largest producer (next to China; 37% contribution) in the World and ranks first in acreage. In India, peanut is grown in the sizable area of 5.56 M ha with a production of 10.1 Mt (agricoop.nic.in) and grown under different agro-climatic zones. Peanut is used for both human and bovine consumption and is an important source of proteins, minerals and vitamins. Geographically, Rajasthan is the largest province of India and faced the problems of land degradation through accelerated wind erosion. The arid zone covers about 12% of the country's total geographical area and out of that Thar Desert shares almost 62% of total hot arid region in India. The gravity of increasing human and animal population on arid land resources has increased manifold in the Thar Desert. Desertification, deterioration in groundwater quality and soil nutrient loss are the common ecology threats in the Thar Desert and these worsen as the desert expanse year by year, risking the ecology of the region and environmental sustainability of the Thar Desert. The desertification is primarily geogenic but induced by human activities and could be overcome using the site specific traditional land management and agricultural practices [3]. The management options like introduction of new crops, applying new agriculture practices, use of ground water etc. making Thar Desert's natural ecosystem more vulnerable to the climate change risks. For the economic development of the region, there are the requirements of current time to introduce the spreading crops like peanut, mungbean, urdbean, cowpea etc. The productivity of peanut is quite low in India when compared to other peanut growing countries [4] mainly due to dependency on rain (80%), monoculture (60%) and cultivation on degraded/marginal lands with low fertility. Like other crops, peanut also needs sufficient amount of nutrients and water for optimum growth and high productivity. Sustainable production of peanut can be attained by diversifying the peanut cropping system and adoption of best nutrient and water management practices [5].

Long term extensive use of improper tillage and chemical fertilizers are posing a serious threat to Thar desert ecosystem and crop productivity in Western Rajasthan. After three to five years of peanut cultivation on virgin arid lands the average productivity starts declining. Though exponential increase in yield obtained with intensive tillage and chemical fertilization under tube-well irrigated eco-systems during initial two to three years. Therefore, it was felt imperative to explore the most effective tillage and fertilizer management practices with combination of bio-inoculants for sustaining the productivity of soil, crop and water under irrigated hot arid eco-system of Rajasthan, India. Appropriate soil tillage is required for optimum crop stand, good growth and yield in all types of soil where human induced erosion and runoff prevails [6]. In soils especially in light (sandy) textured soils excess tillage breaks clods and exposes the soil surface to wind and water erosion. Reduced or minimum tillage is being introduced as a substitute to intensive tillage to minimize the high cost of tillage operations and save time, energy and labour. Besides conserving soil moisture and soil structure reduce tillage also increases crop production [7]. However decrease in yield of cowpea was reported under no tillage in arid regions [8].

Energy use is one of the utmost significant variables of crop performance. For the well planning of sustainable systems the net energy and economic returns of a cropping system can be enumerated [9]. Energy is required for every operation related to soil and crop management like preparation of land, sowing of seeds, multiple irrigation and fertilization, harvesting and post-harvest processing. Minimum tillage has gained attention of farmers as it reduces cultivation cost by minimizing energy utilization for preparation of field and establishment of crop [10]. The no-till method of sowing is cost effective, energy efficient and advantageous to environment by reducing fuel consumption as compared to conventional tillage practices [11,12]. The energy (input-output) analysis provides the opportunity for the policy makers and farm planners to assess economical intersection of energy use. Energy efficient system could be achieved by reducing the energy use adheres with fertilizers inputs or tillage operations or by enhancing the outputs i.e.

crop yields.

Integrated nutrient management practices played a great role in enhancing pod, haulm, kernel and oil yields, and also net economic returns in peanut production [13]. Combined application of organics with inorganics nutrients recorded the significantly higher peanut-equivalent yield, economic return and cost: benefit ratio of the peanut-wheat crop rotation [14]. Bio-fertilizers containing useful micro-organisms are known to enhance plant growth by stimulating the supply of plant nutrients and may help to enhance soil productivity. Inoculation of legumes with biofertilizer (rhizobium bacteria) increased the nodule and nitrogen-fixing activity of the plants and the application of biofertilizers can be a probable approach to improve soil microbial status that stimulates the natural soil microbiota therefore influencing nutrient accessibility and decomposition of organic matter as compared to chemical fertilizers, biofertilizers are an economical, ecologically benign, and sustainable source of plant nutrients, and as a result, they are gaining worldwide acceptance and value in agricultural production [15-17]. Results from a study showed that higher peanut yield can achieved with tillage + 2-inter-cultivations and integrated fertilizer application comprising of both organics (50%) and inorganics (50%) as compared to 100% inorganics [18].

In degraded soils, to mitigate the negative effects of desertification, it is felt needed to identify viable management options to maintain the ecosystem at sustainable level [19]. The climatic condition, soil types, topography and unscientific management practices are the main causes of soil desertification. Thus, potential use of adaptable cereals/legumes/oilseeds with appropriate practices is a key to restore the problems of desertification and soil alkalinity. There is meagre information available on the different tillage options under alkaline soils in peanut and their interactions with the nutrient management practices under arid ecosystem of Rajasthan in Indian subcontinent. Hence, this research was commenced to study the direct and interaction effects of tillage, chemical fertilizers and bio-inoculants on peanut yield, root nodulation, water productivity, nutrient uptake and energy use in arid ecosystem.

Materials and Method

Experimental site characteristics

These research was carried out for two consecutive years in Kharif season (2019 & 2020) at experimental farm, College of Agriculture, Swami Keshwanand Rajasthan Agricultural University (SKRAU) Bikaner, India (28.01°N latitude, 73.22°E longitude, and at elevation of 234.7 m above msl). Hyper arid partially irrigated western plain zone, receives an average annual rainfall is about 274 mm, 70–80% of which occurs during monsoon season (June to September) through south-west monsoon.

A total rainfall of 241.0 and 157.9 mm was occurred during the crop season in 2019 and 2020, respectively. During 2019 crop season, rainfall received in July, August, September and October was 40.6 mm, 101.8 mm, 42.6 mm and 28.8 mm, respectively. The corresponding rainfall in second year (2020) was 13.4, 82.5, 62.2 and 0.0 mm, respectively. The temperature (maximum and minimum) was almost same during both the cropping seasons (Figure 1).

Experimental details and description of treatments

The experiment was designed in split-plot with four replications. The total treatment combinations were 18; three tillage practices viz., (i) minimum tillage by tractor drawn rotavator (MT), (ii) shallow tillage by tractor operated disc plough followed by rotavator (ST) and (iii) deep tillage by tractor operated disc harrow followed by rotavator (DT) in the main plots (120.96 m^2) (Table 2). Six fertilizer management interventions namely F0: No NPK fertilization (control), F1: recommended dose of N and K fertilizers (20 and 15 kg ha^{-1}), F2: recommended dose of NPK fertilizer (RDF) @ 20:32:15 kg ha^{-1} , F3: RDF + inoculation with P solubilizing bacteria (PSB) @ 2.5 kg ha^{-1}, F4: RDF + PSB @ 2.5 kg ha^{-1} + arbuscular mycorrhizal fungi (AMF) @ 2 kg ha^{-1} and F5: RDF + PSB @ 2.5 kg ha^{-1} + AMF @ 4 kg ha^{-1} as soil application in sub plots of 20.16 m^2 (4.8×4.2 m). After reaching optimum moisture condition (about 75% of field capacity) in field, the three main plot treatment operations were performed. The sub plots fertilizer treatments were applied at sowing as per standard procedure. Fertilizer sources namely urea, di-ammonium phosphate (DAP) and muriate of potash (MOP) were used with calculated dose of N, P and K of respective fertilizer. Thereafter, before sowing a light irrigation (40 mm) was given to maintain the optimum moisture for proper germination. All the experimental plots were received 10 Mg ha^{-1} of well decomposed sheep manure (0.50-0.52% N, 0.26-0.27% P_2O_5 and 0.56-0.59% K_2O) which was broad casted uniformly with concomitant tillage operations.

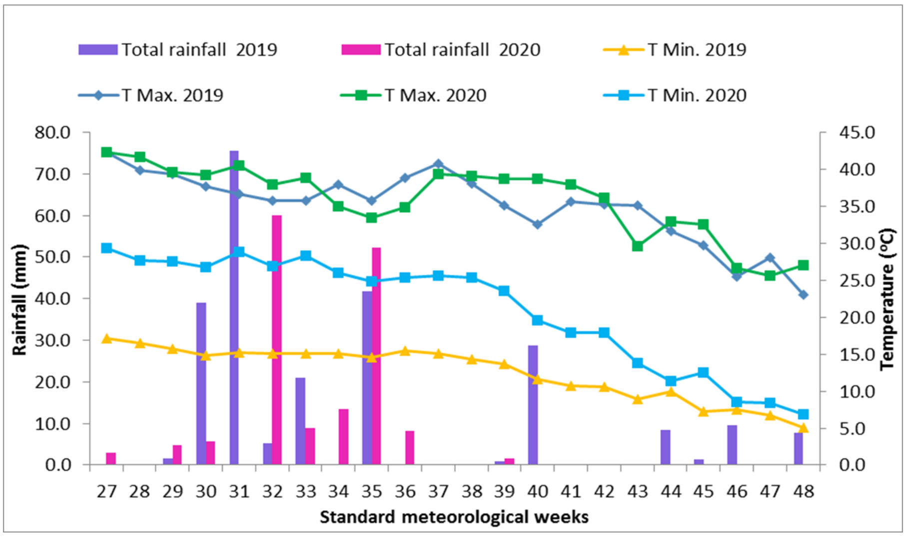

Figure 1: Mean Weekly Meteorological data recorded during *kharif* season of 2019 and 2020

The soil was loamy sand in texture (sand 82.68-83.05%, silt 10.45-10.60% and clay 6.49-6.71%) low in organic carbon (0.11%) with slightly alkaline pH (8.5). Details of basic soil characteristics of the experimental field are included in table 1.

Table 1: Initial soil properties of surface layer (0-15 cm)

Properties	Value (mean ± S.D.)	Method Used
Sand (%)	83.05±0.77	Hydrometer method[20]
Silt (%)	10.45±0.76	
Clay (%)	6.49±0.50	
Textural class	Loamy Sand	USDA triangular method[21]
Bulk density (Mg m^{-3})	1.54±0.1	Undisturbed core sampler method[22]
Infiltration rate (cm hr^{-1})	0.40±0.08	Double ring infiltrometer method[23]
pH (1:2 soil: water)	8.5±0.16	Method No. 21 (b), USDA Hand Book No. 60[23]
Electrical conductivity (EC) (dSm^{-1})	0.22±0.06	Conductivity bridge method[24]
Organic carbon (OC) (%)	0.11±0.02	Walkley and Black's rapid titration method[25]
Available P (kg ha^{-1})	18.68±5	0.5 *M* $NaHCO_3$-extractable[26]
Available N (kg ha^{-1})	120.4±9.5	Alkaline permanganate method[27]
Available K (kg ha^{-1})	254.6±13	Flame photometric method[26]

Table 2: Detail of tillage, crop and nutrient management under different treatments of peanut cultivation

Sl.No.	Abbreviation	Treatments	Tillage	Crop establishment	Water management	Sheep manure	Crop management
Main-plot treatments (Tillage)							
1.	DT	Deep Tillage	1passes of disc harrow,1passes of harrow,1passes of rotavator, 1 passes of tiller, 1 pass of planking	Multi crop planter	Based on critical growth stages	Broadcasted @10t ha^{-1} uniformly	Standard practices followed
2.	ST	Shallow tillage	1passes of harrow, 1passes of rotavator, 1 passes of tiller, 1 pass of planking	Multi crop planter	Based on critical growth stages	Broadcasted @10t ha^{-1} uniformly	Standard practices followed
3.	MT	Minimum tillage	1 passes of rotavator, 1 pass of planking	Multi crop planter	Based on critical growth stages	Broadcasted @10t ha^{-1} uniformly	Standard practices followed
Sub-plot treatments (Integrated Nutrient Management practices, NM)							
1.	F0	No fertilizer applied (control)					
2.	F1	Recommended dose of fertilizer NK (20 kg N +15 kg K ha^{-1})					
3.	F2	Recommended dose of fertilizer NPK @ 20:32:15 kg ha^{-1} (RDF)					
4.	F3	RDF + Phosphate solubilizing bacteria (PSB) @ 2.5 kg ha^{-1}					
5.	F4	RDF + PSB @ 2.5 kg ha^{-1} + Arbuscular mycorrhizal fungi (AMF) @ 2 kg ha^{-1}					
6.	F5	RDF + PSB @ 2.5 kg ha^{-1} + AMF @ 4 kg ha^{-1}					

Seeding and seed treatment

Peanut cultivar HNG-69 was seeded at the rate of 120 kg seed ha−1 in the mid of June month every year. The crop was sown using multi crop planter at plant geometry of 10 cm from plant to plant and 30 cm from row to row. Prior to sowing, peanut seeds were treated with insecticides and fungicide (imidachloropid and tabuconazole) @ 5 ml kg−1 and 1 g kg−1 seed to control any pest and disease infestation. Handling of plants was carried out in accordance with relevant guidelines and regulations of SKRAU, Bikaner, Rajasthan.

Observations and calculations

Crop yield and net returns

Peanut was harvested and threshed (crop was uprooted by tractor drawn peanut digger when leaf veins started yellowing and about 80 per cent pods became fully mature). At maturity, data of pod and halum yields of peanut were taken on an area of 16 m^2 by sub-sampling from four places of 4 m^2 area within each plot.

The input data on number of tillage operations, seed rate, fertilizer, number of irrigations, fuel consumption, herbicide, pesticide, and labour wages were taken for each treatment. All these costs were summed up for calculation of the total cost of production. The cost of inputs and outputs used for economic analysis during the two years are depicted in Table 3. Gross returns were obtained as per the prevailing market rates of the commodity (pod and haulm) over the two years of experimentation. Values of net returns were obtained by subtracting the cultivation cost from the gross returns.

Table 3: Monetary values of inputs and outputs in USD used for calculating economics in peanut during different years

Particulars	2019	2020
Price of peanut seeds (USD[a] kg^{-1})	0.73	0.75
Price of peanut haulm (USD kg^{-1})	0.04	0.04
Labour wage (USD day^{-1})	3.04	3.04
Urea (USD kg^{-1})	0.08	0.08
DAP (USD kg^{-1})	0.34	0.34
Muriate of potash (USD kg^{-1})	0.26	0.26
peanut seed (USD kg^{-1})	1.71	1.71
PSB @ 2.5 kg ha^{-1}	5.71	5.71
AMF @ 4.0 kg ha^{-1}	13.71	13.71
Rotavator	22.86	22.86
Disc plough	22.86	22.86
Harrow	17.14	17.14
INR/USD exchange rate	70	70

aUSD- United states dollar

Peanut kernel quality parameters

The N content of kernel was determined by the method of Jackson (1973). Oil content in the kernel was determined with the Soxtec-Avanti 2050 total fat system (Foss Co., Denmark) [28].The protein content in kernels was calculated by multiplying total N content with a standard factor (6.25) for peanuts [29].

Water productivity

Water productivity (WP) was computed by dividing the economic yield and amount of irrigation water applied (mm) to respective plots and expressed in kg ha^{-1} mm^{-1} [30].

$$WP\,(kgha^{-1}mm) = \frac{\ker nel\ \ yield\,(kgha^{-1})}{Irrigation\ \ water\ \ applied\,(mm)}$$

Energy analysis

For the estimation of the total energy input, energy equivalent (MJ unit^{-1}) values of all the inputs (seed, fertilizer, irrigation, labour, machinery, diesel, pesticides etc.) were used (Table 4). The energy equivalent (MJ unit^{-1}) values of outputs (grain and straw) from different treatments were used to estimate the total energy output. The energy use efficiency (EUE) and energy productivity (EP) was calculated on the basis of energy equivalents of the inputs and outputs by using the equation 1 and 2.

Energy use efficiency (MJ ha^{-1}) = Total energy Output (MJ ha^{-1})/Total energy Input (MJ ha^{-1}) (1)

Energy productivity (kg MJ^{-1}) = Grain output (kg ha^{-1})/ Total energy input (MJ ha^{-1})(2)

Table 4: Energy equivalents (MJ unit−1) used for calculating energy inputs and outputs

Particulars	Units	Energy equivalents (MJ $Unit^{-1}$)	References
Input			
Human labour	Man-hour	1.96	Gathala *et al.* (2016)[32]
Diesel	Liter	56.31	Gathala *et al.*(2016)[32]
Nitrogen (N)	kg^{-1}	66.14	Gathala *et al.*(2016)[32]
Phosphorus (P_2O_5)	kg^{-1}	12.44	Gathala *et al.*(2016)[32]
Potassium (K_2O)	Kg	11.15	Gathala *et al.*(2016)[32]
Herbicides, insecticides and pesticides	Kg	120.00	Gathala *et al.*(2016)[32]
Manures	Kg	0.3	Mittal *et al.*(1985)[33]
Irrigation water	ha-cm	143.56	Gathala *et al.*(2016)[32]
Groundnut seed	Kg	25.00	Panesar *et al.*(1994)[34]
Output			
Peanut pod yield	Kg	25.00	Panesar *et al.*(1994)[34]
Peanut haulm yield	Kg	18.00	Panesar *et al.*(1994)[34]

Statistical analysis

The data recorded for different parameters of peanut were analysed using analysis of variance (ANOVA) technique [35] for randomized split plot design using SAS 9.1 software (SAS Institute, 2001). Tukey's honestly significant difference (HSD at 5% level of significance) was used for comparing treatment means.

Results

Pod and kernel yield

Interaction effects of tillage × fertilizer nutrient management were found significant in kernel yield but non-significant in pod yield (Table 5). Pod and kernel yield of peanut were significantly ($p < 0.001$) affected by tillage and nutrient management practices during both the study years (Table 6). Pod yield was 11.4% and 4.3% lower in the MT and ST compared to DT treatment, respectively. Similar trend was also observed for kernel yield of peanut. Irrespective of tillage management, similar results were observed for pod yield in F4 and F5 which was significantly higher by 41-44% compared to F0 (Table 6). Fertilizer treatments F3 and F2 increased pod yield by 28.6% and 22.9% compared to F0, respectively (Table 6).

Table 5: Analysis of variance (ANOVA) showing significance of the effects of main sub treatments and their interaction on pod and kernel yield (Mg ha-1), water use efficiency (kg ha-1 mm) and net returns (US$ ha-1), oil and protein yield of peanut, as resulted from analysis of variance (ANOVA)

Treatments	Tillage	Nutrients	Tillage x Nutrients
Pod yield	0.0028**	<.0001**	0.9148
Kernel yield	0.0001**	<.0001**	<.0001**
Oil yield	0.0001**	<.0001**	0.0113*
Protein yield	0.0002**	<.0001**	<.0001**
Water use efficiency	0.0089**	<.0001**	0.9326
Net returns	0.0033**	<.0001**	0.9064
Energy input	<.0001**	<.0001**	0.7955
Energy output	0.0078**	<.0001**	0.9045
Energy use efficiency	0.0015**	<.0001**	0.8017
Energy productivity	0.0026**	<.0001**	0.8251

** - Significant at 1%, * - Significant at 5%

Table 6: Effect of tillage and fertilizer nutrient management practices on pod and kernel yield (Mg ha-1) of peanut (2- year mean)

Treatments	F0	F1	F2	F3	F4	F5	Mean
Pod yield (Mg ha^{-1})							
DT	2.49	2.62	2.86	3.01	3.42	3.50	2.98^{A}
ST	2.33	2.54	2.86	2.98	3.18	3.23	2.85^{A}
MT	1.99	2.29	2.67	2.78	3.02	3.08	2.64^{B}
Mean	2.27^{D}	2.48^{C}	2.79^{B}	2.92^{B}	3.2^{A}	3.27^{A}	
Kernel yield (Mg ha^{-1})							
DT	1.72	1.80	2.12	2.25	2.48	2.59	2.16^{A}
ST	1.44	1.67	1.99	2.15	2.36	2.44	2.01^{B}
MT	1.31	1.48	1.70	1.80	1.98	2.01	1.71^{C}
Mean	1.49^{F}	1.65^{E}	1.94^{D}	2.07^{C}	2.27^{B}	2.35^{A}	

Oil and protein yield

In present study, different tillage and nutrient management practices significantly ($p \leq 0.05$) influenced the protein and oil yields (Table 7). DT and ST improved the protein and oil yields by 26.3%, 15.8% and 28.2%, 18.3% (mean for 2 years), respectively compared to MT (0.19 and 0.71 Mg ha^{-1}). Irrespective of nutrient management, F5 and F4 significantly increased protein yield by 68.8% and 62.5% over F0, respectively. The corresponding increase in pod yield in F3 and F2 was 43.8% and 31.3%, irrespective of tillage practices (Table 7). Similar trend also was observed to oil yield of peanut. The tillage and nutrient management interactions significantly ($p < 0.05$) influenced protein and oil yields (Table 7).

Table 7: Effect of tillage and fertilizer management practices on oil and protein yield (Mg ha-1) of peanut (2- year mean)

Treatments	F0	F1	F2	F3	F4	F5	Mean
Oil yield (Mg ha^{-1})							
DT	0.69	0.74	0.89	0.95	1.06	1.11	0.91^{A}
ST	0.58	0.69	0.83	0.90	1.00	1.04	0.84^{B}
MT	0.51	0.60	0.70	0.75	0.83	0.86	0.71^{C}
Mean	0.59^{F}	0.68^{E}	0.8^{D}	0.87^{C}	0.96^{B}	1^{A}	
Protein yield (Mg ha^{-1})							
DT	0.18	0.20	0.24	0.25	0.28	0.29	0.24^{A}
ST	0.15	0.18	0.22	0.24	0.27	0.28	0.22^{B}
MT	0.14	0.16	0.19	0.20	0.22	0.23	0.19^{C}
Mean	0.16^{F}	0.18^{E}	0.21^{D}	0.23^{C}	0.26^{B}	0.27^{A}	

Water productivity (WP)

Tillage and fertilizer nutrient management practices significantly ($p \leq 0.05$) influenced the WP (Table 8). The WP varied from 6.33 to 7.1 kg ha^{-1} mm^{-1} and 5.4 to 7.81 kg ha^{-1} mm^{-1} in different tillage and management practices, respectively. The DT had significantly higher (12.2%) WP over MT. Irrespective of tillage practices, F5 (+44.6%) and F4 (+42.6%) produced significantly higher WP followed by F3 (+29.6%), F2 (+23.9%) and F1 (+10.2%) compared to F0 in various tillage practices (Table 8). The tillage and nutrient management interactions were non-significant ($p < 0.05$) in WP (Table 8).

Table 8: Effect of tillage and fertilizer management practices on water productivity (kg ha-1 mm) and net returns (USD ha-1) of peanut (2-year mean)

Treatments	F0	F1	F2	F3	F4	F5	Mean
water productivity (kg ha^{-1} mm)							
DT	5.88	6.25	6.81	7.18	8.21	8.27	7.1^{A}
ST	5.55	6.17	6.88	7.15	7.60	7.68	6.84^{A}
MT	4.76	5.44	6.39	6.67	7.28	7.47	6.33^{B}
Mean	5.4^{D}	5.95^{C}	6.69^{B}	7^{B}	7.7^{A}	7.81^{A}	General Mean=6.76

Net returns (USD ha^{-1})							
DT	1901.09	2005.55	2201.55	2328.70	2647.43	2708.32	2298.77^{A}
ST	1781.98	1947.50	2198.31	2294.51	2454.62	2493.15	2195.01^{A}
MT	1514.03	1748.31	2051.49	2141.72	2337.57	2384.92	2029.67^{B}
Mean	1732.36^{D}	1900.45^{C}	2150.45^{B}	2254.98^{B}	2479.87^{A}	2528.8^{A}	

Economic profitability

The tillage and nutrient management interactions were non-significantly differ ($p < 0.05$) in net returns (Table 8). The cultivation cost largely attributed to field operations, crop establishment, fertilizer, irrigation, pest and weed management, harvesting and post harvesting operations, and man-days involved in crop production. The net return from peanut varied from 1732 to 2529 USD ha^{-1} in nutrient management practices and 2030 to 2299 USD ha^{-1} in tillage during 2 year (Table 8). Among the different tillage and nutrient management practices, highest net return of 2299 and 2529 USD ha^{-1} was recorded with DT and F5, respectively. Deep tillage increased the net returns by 13.3% compared to minimum tillage (2030 USD ha^{-1}). The economic return was significantly higher in F4 and F5 compared to all other fertilizer treatments.

Energy efficiency and productivity

Higher energy consumption (17.38 $\times 10^3$ MJ ha^{-1}) was recorded in DT compared with all the other tillage operations, and lowest (14.9 $\times 10^3$ MJ ha^{-1}) input energy was observed in MT (Table 9). Minimum tillage practices saved 14.3 and 7.5% of input energy as compared to DT and ST, respectively. Among nutrient management practices, significantly lower input energy was noted with the F0 (14.52 $\times 10^3$ MJ ha^{-1}) compared with all other nutrient levels. The mean input energy was recorded 16.94% higher in F5 followed by F4 (15.29%), F3 (13.64%), F2 (11.57%) and F1 (9.1%).

Table 9: Effect of tillage and fertilizer management practices on energy input (×103 MJ ha-1), output (×103 MJ ha-1), energy efficiency (MJ ha-1) and energy productivity (kg MJ-1) of peanut (2-year mean)

Treatments	F0	F1	F2	F3	F4	F5	Mean
Energy input							
DT	15.78	17.09	17.45	17.75	17.99	18.23	17.38^{A}
ST	14.51	15.82	16.18	16.48	16.72	16.96	16.11^{B}
MT	13.29	14.60	14.97	15.27	15.51	15.75	14.9^{C}
Mean	14.52^{F}	15.84^{E}	16.2^{D}	16.5^{C}	16.74^{B}	16.98^{A}	
Energy output							
DT	138.22	143.97	157.91	166.84	182.30	184.73	162.33^{A}
ST	134.03	143.69	156.32	161.61	171.51	173.75	156.82^{A}
MT	119.86	130.65	148.47	152.76	167.47	170.05	148.21^{B}
Mean	130.7^{D}	139.43^{C}	154.23^{B}	160.4^{B}	173.76^{A}	176.18^{A}	
Energy use efficiency							

DT	8.50	8.41	8.96	9.10	9.53	9.53	9[B]
ST	9.53	9.10	9.76	10.12	10.90	10.89	10.05[A]
MT	9.02	8.95	9.92	10.01	10.80	10.80	9.92[A]
Mean	9.01[C]	8.82[C]	9.55[B]	9.74[B]	10.41[A]	10.41[A]	
Energy productivity							
DT	0.15	0.15	0.16	0.17	0.18	0.18	0.16[C]
ST	0.17	0.17	0.18	0.18	0.20	0.21	0.18[A]
MT	0.15	0.16	0.18	0.18	0.20	0.20	0.18[B]
Mean	0.16[C]	0.16[C]	0.17[B]	0.18[B]	0.19[A]	0.19[A]	

Higher output energy was recorded under the DT and ST (162.3×10^3 and 156.8×10^3 MJ ha^{-1}), respectively compared to MT during 2 years of the study (Table 9). The lowest energy output was recorded in MT (148.2×10^3 MJ ha^{-1}). Among nutrient management practices, F5 and F4 respectively recorded 34.8 and 32.9% higher energy (mean) output compared to F0. The tillage and nutrient management showed non-significant interactions ($p < 0.05$) in energy input, output, EUE and EP (Table 9).

Both the energy efficiencies (EUE and EP) were significantly higher in ST and DT compared to DT, irrespective of nutrient management practices during 2 years of study (Table 9). The EUE and EP were 11.7 and 12.5% higher in ST and 10.2 and 12.5% higher in MT, respectively compared to DT (9 MJ ha^{-1} and 0.16 kg MJ^{-1}). The nutrient management practices (mean of F1 to F5) increased EUE and EP by about 8.6 and 11.3%, respectively compared to F0 (9.01 MJ ha^{-1} and 0.16 kg MJ^{-1}). In the study period, higher EUE and EP were associated with F5 (Table 9).

Discussion

Crop productivity

The peanut pod and kernel yields were significantly affected with different tillage and nutrient management practices. Reported higher number of filled grains in maize with tillage and integrated nutrient management (RDF + 10 Mg FYM ha^{-1}) [36]. Both deep tillage and shallow tillage were recorded 13.1 and 8.2 % higher pod yield compared to MT. DT also recorded 26.1% higher kernel yield over MT might be due to better crop growth and development. Similar results were also obtained in peanut [37,38]. Advantageous effects of mechanical tillage practices on crop yield and yield attributes of sorghum and pearl millet have also been documented by other researchers [39,40].

Use of bio-inoculant (PSB+AMF) with RDF increased yields of pod and kernel might be due to the balanced nutrition along with the beneficial effects of bio-inoculants (PSB+AMF) on growth and development, and impact on morphological and photosynthetic components, which ultimately led to profuse root growth and nutrient uptake of the crop. Similar results were also reported in summer groundnut [41,34]. The use of microbial inoculants increased the kernel yield of summer groundnut [42] and grain yield of sorghum [40] as it improved the N assimilation and distribution which considered as the basis of yield improvement [43,44].

Protein and oil yield

The peanut protein and oil yield were affected with different tillage and nutrient management practices in the present study period. Higher protein and oil yields under DT and ST were due to the higher grain yield of crops. Achieved higher protein content in maize grain with more intensive tillage compared to minimum tillage due to better soil physic-chemical properties [45]. Similarly, reported higher protein content in wheat grain (*Triticum durum* L.) grown under conventional tillage compared to minimum tillage [46]. There is however, limited information on the effect of soil fertility on grain protein contents of ground. Different nutrient management practices improved the protein and oil yield and quality mainly by increasing kernel yield. The protein and oil yields were significantly higher in treatments using RDF along with biofertilizers. Integrated nutrient management directly influence the photosynthesis which improved the N distribution and assimilation in plants resulted in improved kernel quality of peanut [42,41,47]. Nitrogenous fertilizer improved the protein content in peanut, and its association with phosphate and potassium fertilizer in reasonable ratio could increase the crude fat and acids (oleic and linoleic) content [48].

Water productivity (WP)

The water productivity and water use efficiency (WUE) is directly related to crop yield and irrigation water used in peanut. In any crop production system, soil texture and structure, porosity, aggregation and pore size distribution affects the hydrological properties of soil. Different tillage practice affects the WP by altering the hydrological properties like water absorption and adsorption, wettability, transport of solutes etc. of the soil which directly influences on crop root development [6]. The higher use efficiency of irrigation water was perceived with deep and shallow tillage compared to minimum tillage in peanut (Table 7). Similar observations on water-use efficiency were recorded with deep tillage + two inter-culture over minimum tillage (without disc ploughing) due to improved soil physical conditions [57]. Found significantly higher values of WUE with integrated nutrient management (INM) practices (7.47 kg ha^{-1} mm^{-1}) and it was followed by organic manures (6.99 kg ha^{-1} mm^{-1}) due to higher pod yield of groundnut and less irrigation water use [13]. In leguminous crop (mungbean), supplementation of chemical fertilizers with biofertilizer helped in increasing the water use efficiency through enhanced efficiency of plants in absorbing water and nutrients from the soil solution [49].

Profitability

Lower production cost in MT-based treatments compared with DT-based systems contributed towards the higher net returns, irrespective of nutrient management practices throughout the experimental years. Higher net income under DT and ST was due to higher kernel yield of peanut. In earlier studies, higher net profits were however, reported in conventional tillage in soybean-based cropping systems and peanut [10,48]. Observed significantly higher net return with mouldboard plough over cultivator in peanut [50]. Highest net return (2529 USD ha^{-1}) was obtained in the plots where recommended dose of fertilizer was integrated with AMF and PSB. The additional cost of bio-fertilizer was compensated by the increases in yield of peanut. Also reported highest economic return and benefit: cost ratio in 75% RDF+ vermicompost (1 Mg ha^{-1}) + PSB treatment than RDF alone [51].

Energy use efficiency and productivity

Higher energy was consumed in deep tillage compared with all other tillage and the lowest input energy was recorded in minimum tillage. Consistent with our earlier studies, found maximum energy use under conventional tillage followed by minimum tillage in soybean–wheat cropping system [10,52]. Significantly lower input energy was recorded with the control compared with all other treatment. A major part (40.8%) of total input energy represented the energy used by fertilizers which was only 5% more than that of total energy used in fertilizer under various cropping systems [9]. Higher energy output was recorded under deep and shallow tillage compared to shallow tillage. Recorded maximum output energy with conventional tillage practices in soybean–lentil rotation [10]. The EUE and EP are directly related to the energy adhere with all the inputs used under the particular treatments. Both EUE and EP were markedly improved in F4 and F5 compared to other nutrient management treatments due to higher pod yield. Biofertilizers or microbial inoculants in leguminous crop increased the mobilization and availability of plant nutrients to crop that resulted in to higher pod/grain yield [15]. There was no much difference was recorded with energy input in the bio fertilizer layered treatments compared to RDF. The higher EUE and EP were also recorded under peanut crop by the other workers [54,55]. Maize-wheat-mungbean system recorded the maximum EUE and EP with nutrient expert decision software [56].

Conclusion

Results of the present study revealed the positive effects of deep tillage on pod and kernel yield, protein yield and oil content in peanut compared to minimum tillage. Application of RDF @ 20:32:15 kg ha^{-1} along with phosphate solubilizing bacteria (PSB) @ 2.5 kg ha^{-1} and arbuscular mycorrhizal fungi (AMF) @ 4 kg ha^{-1} as soil application provided optimum nutrition for peanut to achieve maximum economic yield. Seed inoculation with PSB and AMF in combination with RDF recorded the maximum irrigation water productivity, net return and energy productivity over rest of the nutrient management practices. Thus, to maximize the peanut yield, water productivity, energy efficiency and net economic returns, deep tillage along with RDF and bio fertilizers can recommended to the growers in the arid climate of Thar desert.

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