**Cotton growth indices, productivity and profitability response to *in-situ* moisture conservation measures with soil conditioner (Pusa hydrogel) under rainfed condition**

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**Abstract:** The present study was undertaken to evaluate the impact of *in-situ* moisture conservation and stress management practices on soil moisture retention, and productivity of cotton under rainfed vertisol. to study the The experiments were laid out at Regional Research Station, Aruppukottai, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu during *rabi* season of 2016, and 2017 in split-plot design replicated thrice using cotton variety SVPR. The main plot treatments consisted of different *in-situ* moisture conservation measures *viz.,* Broad Bed and Furrows (I1), Ridges and Furrows (I2) and Compartmental Bunding (I3). The subplot comprises with stress management practices *viz.,* Soil application of pusa hydrogel @ 5 kg ha-1 (S­1), Soil application of pusa hydrogel @ 5 kg ha-1 + foliar spray of 1% KCl (S­2) , Soil application of pusa hydrogel @ 5 kg ha-1 + foliar spray of 5% Kaolin (S­3), Soil application of pusa hydrogel @ 5 kg ha-1 + foliar spray of PPFM @ 500 ml ha-1 (S­4), Soil application of pusa hydrogel @ 5 kg ha-1 + foliar spray of Salicylic acid 100 ppm (S­5) and Control (S­6). The results revealed that treatment combination of broad bed and furrow and soil application of Pusa hydrogel @ 5 kg ha-1 + foliar spray of PPFM @ 500 mL ha-1 recorded significantly higher crop growth indices like CGR, RGR NAR and seed cotton yield (1,580 and 1,943 kg ha-1 during 2016 and 2017, respectively) and also which realized the highest net income of  44,708 ha-1 in 2016 and  66,488 ha-1 in 2017with benefit cost ratio of 1.89 in 2016 and 2.30 in 2017.

***Key words****:* Broad Bed and Furrows, Pusa hydrogel, Rainfed cotton

**Introduction**

 Cotton, as a crop as well as a commodity, plays an important role in the agrarian and industrial activities of the nation and has a unique place in the economy of the country. Cotton, popularly known as “White Gold” is cultivated mainly for fibre besides an important source of edible oil. Globally, India ranks first in area (11.88 M ha), accounting 30 % of world acreage and 22 % (351 lakh bales of lint) of the world cotton production with lint productivity of 568 kg ha-1 (DCD, 2017). Nearly 65 % of the cotton crop is cultivated under rainfed conditions in the country. In Tamil Nadu, 1.33 lakh ha is under cotton cultivation with the production of 6.5 lakh bales with and lint productivity is 620 kg ha-1. India has been the traditional home of cotton and their textiles. India has progressed substantially in improving both production and productivity of cotton, transforming from a net importer of cotton to become one among the largest exporters, shipping 6.9 million bales (2015-16) followed by USA (Kannan *et al.*, 2017).

 To combat such adverse soil moisture scarcity conditions, matching integrated drought management practices need to be evolved. Water stress is one of the most important factors limiting crop productivity and adversely affects square and boll formation, lint yield, and fibre quality of cotton. The loss of productivity due to the lack of rainfall and insufficient frequency in irrigation has threatened cotton farming. Rainfed areas can be made productive and profitable by adopting improved technologies for rainwater conservation and commensurate agricultural production technologies. Soil management practices are tailored to store and conserve as much rainfall as possible by reducing runoff and increasing the storage capacity of a soil profile. The most efficient and cheapest way of conserving rainfall is to hold it *in-situ.* The principle behind the different *in-situ* moisture conservation practices is to increase the infiltration by reducing runoff, temporarily impounding the water on the surface of the soil to increase the opportunity time for infiltration and modifying the land configuration for inter plot water harvesting (Muthamilselvan *et al.*, 2006).

 The moisture stress during the crop growth period is the primary cause of the yield reduction in cotton. To improve the soil moisture availability by reducing the evaporation losses and retaining the moisture in the effective rooting zone. The soil application of superabsorbent polymers (SAPs) is found to be a promising methodology in rainfed areas. However, very limited research work has experimented with this. One such developed product is ‘Pusa hydrogel,’ which is the first successful indigenous semi-synthetic superabsorbent technology for conserving water and enhancing crop productivity and thereby increasing water use efficiency (IARI, 2012). To reduce transpiration losses, foliar application of nutrient formulations, growth regulators, antitranspirants *etc*. in cotton are being tried by many researchers. Keeping this in view, an attempt was made to study the impact of *in-situ* moisture conservation, stress management practices on crop growth indices, and productivity of cotton under rainfed agroecosystem.

**Materials and Methods**

Field experiments were was conducted at the Regional research station, Aruppukottai, Tamil Nadu Agricultural University, Tamil Nadu during *rabi* season of 2016, and 2017 with the cotton crop using the test variety SVPR - 2. The experimental site comes under the Southern agro-climatic zone of Tamil Nadu and geographically situated at 9º 33’N latitude, 78º 05’ E longitude, and at an altitude of 50 m above mean sea level. North-East Monsoon season was found more favorable in the Aruppukottai region since 42 percent of annual rainfall is being received during this monsoon season. The soil of the experimental fields was medium-deep, well-drained vertisol (*Type Chromusterts*). The soil is low in available nitrogen, low in available phosphorus and high in available potassium status. All packages of practices were carried out as per the recommendation of (CPG, 2020).

The experiment was laid out in split-plot design, replicated thrice. The main plot treatments consisted of different *in-situ* moisture conservation measures *viz.,* Broad Bed and Furrows (I1), Ridges and Furrows (I2) and Compartmental Bunding (I3). The subplot comprises with stress management practices *viz.,* Soil application of Pusa hydrogel @ 5 kg ha-1 (S­1), Soil application of pusa hydrogel @ 5 kg ha-1 + foliar spray of 1% KCl (S­2), Soil application of Pusa hydrogel @ 5 kg ha-1 + foliar spray of 5% Kaolin (S­3), Soil application of Pusa hydrogel @ 5 kg ha-1 + foliar spray of PPFM @ 500 ml ha-1 (S­4), Soil application of Pusa hydrogel @ 5 kg ha-1 + foliar spray of Salicylic acid 100 ppm (S­5) and Control (S6).

**Broad bed furrow (BBF)**

Broad bed furrow was formed with a bed size of 120 cm and furrow size of 30 cm with a depth of 15 cm on either side with a gradient of 0.8 per cent using the tractor-drawn broad bed furrow former.

**Ridges and furrows (RF)**

Ridges and furrows were formed at 45 cm spacing by using the tractor-drawn ridge plough.

**Compartmental bunding (CB)**

Small bunds of 15 cm width and 15cm height were formed in both directions (across and along the slope) to divide the field into small compartments by using manual labor with a spade.

**Method of PUSA gel application**

The desired amount of hydrogel (5 kg ha-1) was mixed with dry and fine sand of less than 0.25 mm size in 1:10 ratio, in order to distribute uniformly along the row. The sand mixed hydrogel was applied in line where the seed was sown (Narjary *et al.*, 2013).

**Foliar application to alleviate stress**

Calculated quantity of foliar solution was sprayed to the respective treatment plots using hand-operated knapsack sprayer fitted with fan type WFN 40 nozzle by controlled droplet application method at moisture stress.

1. The potassium enhanced drought tolerance in plants by mitigating harmful effects by increasing translocation and by maintaining water balance. The required quantity of 10 g Kcl dissolved in one litre of water and spray solution was prepared at the time of spray.
2. Kaolin is an antitranspirant; it was applied as a suspension to plant canopies and forms a film on leaves that increases reflection and reduces the absorption of light. The required quantity of 50 g Kaolin dissolved in one litre of water and spray solution was prepared at the time of spray.
3. Pink pigmented facultative methylobacteria (PPFM) are widely explored for plant growth promotion and induction of defense mechanisms in plants.The required quantity of 500 ml of PPFM dissolved in 500 liters of water and spray solution was prepared at the time of spray.
4. Salicylic acid is an endogenous growth regulator of phenolic nature, which participates in the regulation of physiological processes in plants such as growth, photosynthesis, nitrate metabolism, ethylene production, heat production, and flowering. The required quantity of 100 mg of Salicylic acid dissolved in one litre of water and spray solution was prepared at the time of spray.

**Time and method of foliar application for stress management**

The data analysis for the probability occurrence of 30 years rainfall in a standard week showed that there is a possibility of consecutive dry spells during 45th and 50th standard meteorological weeks with more than 80 percent probability based on historical rainfall probability analysis by markov chain method. So, to avoid stress, foliar spray has given at 45th and 50th standard weeks for the years of study 2016 and 2017 based on historical rainfall probability analysis by Markov chain method to fix foliar spray application during the experimentation period

**Crop Growth Rate**

The mean crop growth rate was calculated as suggested by Watson (1958) and expressed in g m-2 day-1.

|  |  |  |
| --- | --- | --- |
| CGR | = | (W2 – W1) |
| P (t2 – t1) |

Where,

W2 and W1 are plant dry weight at times t2 and t1, respectively.

P = space occupied by the crop (m2)

t1 and t2 are the time interval in days.

**Relative growth rate (RGR)**

The mean relative growth rate was calculated as suggested by (Enyi, 1962) and expressed in g g-1 day-1.

|  |  |  |
| --- | --- | --- |
|  RGR | = | loge W2 – logeW1 |
| t2 – t1 |

Where,

W2 and W1 are shoot dry weight of the plant at time t2 and t1

# Net Assimilation Rate (NAR)

The mean NAR was estimated as suggested by Enyi, 1962 following the formula and expressed as mg cm-2 day-1.

|  |  |  |
| --- | --- | --- |
| NAR | = | (W2 – W1) (Loge A2 – Loge A1) |
| (t2 – t1) (A2 – A1) |

Where,

 W1 and W2 are the plant dry weight at time t1 and t2 respectively

 A1 and A2 are the leaf area at time t1 and t2 respectively

**Seed cotton yield**

The seed cotton yield was obtained from the net plot area was shade dried, weighed at each picking, and yields of all picking were added and then expressed in kilogram per hectare.

**Statistical analysis**

The data pertaining to the experiment were subjected to statistical analysis by Analysis of Variance (ANOVA) using AGRES (Data Entry Module for Agrees Statistical software version 3.01, 1994 Pascal Intl. Software Solutions). Differences between mean values were evaluated for significance using Least Significant Difference (LSD) at 5% probability level as suggested by (Gomez *et al.*, 1984).

**Results and Discussion**

***Growth indices of cotton***

Crop growth rate, Relative growth rate, and net assimilation rate were recorded at 30-60, 60-90 and 90-120 DAS. The *in-situ* moisture conservation practices and stress management measures exerted significant influence on the CGR, RGR and NAR of cotton at all stages of observation.

***Crop Growth Rate (CGR) (Table 1 and 2)***

The crop growth rate was recorded between 30-60, 60-90, and 90-120 DAS. *In-situ* moisture conservation practices and stress management measures exerted a significant influence on the CGR of cotton at all stages of observation.

Among the *in-situ* moisture conservation measures, Broad bed and furrows (BBF) (I1) recorded significantly higher CGR (4.30, 4.94, 4.51 and 5.01, 5.37, 5.15 g m-2 day-1) at 30-60, 60-90 and 90-120 DAS during 2016 and 2017 respectively followed by ridges and furrows (I2). The lower CGR (3.89, 4.51, 4.07 and 4.45, 4.77, 4.27 g m-2 day-1) was recorded under compartmental bunding (I3) at all stages of observation in both the years of experimentation.

Regarding stress management practices, the values were significantly superior to the control plot (S6). Pusa hydrogel applied plots registered higher CGR between 30-60 DAS. Between 60-90 and 90-120 DAS observation, it showed that the soil application of Pusa hydrogel @ 5 kg ha-1 + foliar spray of PPFM @ 500 ml ha-1 (S­4) performed better in achieving (5.45, 4.71 and 5.86, 5.57 g m-2 day-1) maximum CGR at during both the years. It was followed by soil application of Pusa hydrogel @ 5 kg ha-1 + foliar spray of 1% KCl (S2). The minimum CGR was recorded (3.60, 4.13, 3.94 and 4.18, 4.51, 4.02 g m-2 day-1) under control (S6) between 30-60, 60-90 and 90-120 DAS respectively during 2016 and 2017.

***Relative Growth Rate (RGR) (Table 3 and 4)***

The relative growth rate was recorded between 30-60, 60-90 and 90-120 DAS. *In-situ* moisture conservation measures and stress management practices exerted a significant influence on the RGR of cotton at all stages of observation.

Among the *in-situ* moisture conservation measures, BBF (I1) recorded (0.0418, 0.0309, 0.0118 and 0.0429, 0.0204, 0.0121 mg g-1 day-1) higher RGR at 30-60, 60-90 and 90-120 DAS respectively during 2016 and 2017and comparable with RF (I2). Significantly lower RGR (0.0386, 0.0291, 0.0105 and 0.0383, 0.0168, 0.0100 mg g-1 day-1) was recorded under compartmental bunding (I3) at 30-60, 60-90 and 90-120 DAS respectively in 2016 and 2017.

Data revealed that soil application of Pusa hydrogel @ 5 kg ha-1 + foliar spray of PPFM @ 500 ml ha-1 (S­4) recorded (0.0347, 0.0122, and 0.0214, 0.0129 g m-2 day-1) recorded significantly higher RGR at 60-90 and 90-120 DAS during both the years. Though, it was comparable at the early stages of observation with other stress management practices. Further, it was followed by soil application of Pusa hydrogel @ 5 kg ha-1 + foliar spray of 1% KCl (S2). The minimum RGR was recorded (0.0377, 0.0258, 0.0100 and 0.0368, 0.0148, 0.0089 g m-2 day-1) under control (S6) at all the stages of observation respectively at all stages of observation in both years of experimentation.

***Net Assimilation Rate (NAR) (Table 5 and 6)***

Net assimilation raterecorded between 30-60, 60-90, and 90-120 DAS, showed that the *in-situ* moisture conservation measures and stress management practices had a significant influence on the NAR of cotton at all stages of observation.

Among the *in-situ* moisture conservation measures, BBF (I1) recorded (0.03763, 0.1954, 0.1121 and 0.03787, 0.1732, 0.1142 mg cm-2 day-1) higher NAR at all the stages of observation in both years and on par with RF (I2). The lowest RGR (0.3263, 0.1638, 0.1006 and 0.3210, 0.1514, 0.0998 mg cm-2 day-1) was noticed under CB (I3) at 30-60, 60-90 and 90-120 DAS in both the years of experimentation.

Regarding stress management practices, soil application of pusa hydrogel @ 5 kg ha-1 + foliar spray of PPFM @ 500 ml ha-1 (S­4) recorded (0.2292, 0.1213 and 0.1950, 0.226 mg cm-2 day-1) maximum NAR at 60-90 and 90-120 DAS during both the years, though it was on par with other stress management practices at 30-60 DAS. Further,S­4 followed by soil application of pusa hydrogel @ 5 kg ha-1 + foliar spray of 1% KCl (S2). The minimum NAR was recorded (0.3191, 0.1328, 0.0968 and 0.3182, 0.221, 0.0991 mg cm-2 day-1) under control (S6) at 30-60, 60-90 and 90-120 DAS respectively in 2016 and 2017.

Physiological parameters like CGR, RGR and NAR were found to increase up to 90 DAS, and decrease thereafter. The increasing trend between 60-90 DAS may be due to the canopy achieves full interception of light, the variation in leaf area is a powerful determinant for differences in crop growth (Gifford Roger and Jenkins Colln, 1982)**.** However, after canopy closure, photosynthetic CO2 exchange per unit leaf area may become an important determinant of CGR, RGR and NAR. Therefore, it is assumed that a decline in growth parameters after flowering might be due to a reduction in CO2 exchange per unit leaf area as a result of mutual shading. An increase in the net assimilation rate may be attributed to increased photosynthetic capacity.

As an *in-situ* moisture conservation measure, BBF recorded higher values of CGR, RGR and NAR at different stages of the crop in both the years, compared to other land configurations for *in-situ* moisture conservation. This might be due to higher soil moisture, which favors the nutrient uptake, which in turn reflected in higher LAI, specific leaf weight and dry matter production. A sufficient amount of soil moisture to meet the plant requirement under this treatment produced taller plants and higher LAI and consequently higher DMP, which led to higher physiological parameters. This result corroborates the findings of Nasrullah *et al.* (2011). Further, during the period of heavy rainfall BBF allow water to drain safely from the plots and thus avoid water congestion to the crop.

Regarding stress management practices, soil application of Pusa hydrogel @ 5 kg ha-1 + foliar spray of PPFM @ 500 ml ha-1 registered highest values of CGR, RGR, and NAR at different stages of crop in both the years of experimentation. CGR is influenced by LAI, photosynthetic rate, and leaf angle. A similar increase in CGR was observed in the soil treated with the superabsorbent polymer. Similar results also recorded by Yazdani *et al.* (2007) in soybean. SAPs can be efficiently used to reduce erosion, runoff, and soil losses, increasing the infiltration rates and the hydrophilic nature of the soil surface, which aids seed germination, emergence, and growth rate (Roqieh Barihi *et al.*, 2013).

Further, PPFM favored the production of plant growth regulators, IAA, cytokinin, and GA, which resulted in diverse physiological effects in plants. It stimulates the division, extension and differentiation of plant cells, enhances plant growth parameters like CGR, RGR and NAR. Similar results were also reported by Sivakumar *et al.* (2017).

***Seed cotton yield***

Yield is contributed by different yield parameters and any change in one parameter as influenced by an extraneous factor will alter the yield significantly. In the present study, the increase in seed cotton yield could be attributed to greater and consistent available soil moisture due to combined influence of BBF, soil conditioner and foliar nutrition of PPFM increased that resulted in better crop growth rate and seed cotton yield***(Table 7)***.

Among the *in-situ* moisture conservation measure, BBF recorded a significantly higher seed cotton yield of 1,246 in 2016 and 1,590 kg ha-1 during 2017. The yield increases under BBF were 23 % (2016) and 19 % (2017) as compared to compartmental bunding (Fig.1). The broad bed furrow system significantly influenced the seed cotton yield as compared to other land configuration. Increment in seed cotton yield is due to more soil moisture availability at the root zone which favored better crop growth rate and higher translocation leading to the production of larger leaf area which was responsible for harvesting more solar energy. This, coupled with higher stomatal conductance and transpiration rate resulted in the accumulation of more photosynthates and, ultimately, the seed cotton yield. This is in similarity to the findings of Muralidaran and Solaimalai (2005).

Higher seed cotton yield was realized with a complementary alliance of *in-situ* moisture conservation measures with stress management practices in the present study. Significant influence by stress management practices also recorded with soil application of Pusa hydrogel @ 5 kg ha-1 + foliar spray of PPFM @ 500 ml ha-1 which registered higher seed cotton yield of 1,394 and 1,786 kg ha-1 during 2016 and 2017, respectively. This was followed by soil application of Pusa hydrogel @ 5 kg ha-1 + foliar spray of 1% KCl (S2) with 1,238 and 1,580 kg ha‑1 seed cotton during 2016 and 2017, respectively. The lower seed cotton yield was recorded under control (S6) with 869 and 1,109 kg ha-1 during 2016 and 2017, respectively. The increased seed cotton yield under soil application of Pusa hydrogel @ 5 kg ha-1 + foliar spray of PPFM @ 500 ml ha-1 were 60 per cent during 2016 and 61 % during 2017 over the control. This may be due to the increased growth indices, could be because of sufficient availability of soil moisture and better nutrients availability due to superabsorbent polymer application under water stress condition, which in turn leads to better translocation of water, nutrients and photoassimilates and finally better plant development. Similar findings were also reported by El-Hady *et al.* (1981) under water stress conditions. The increase in the seed cotton yield because of the several factors such as the release of growth-promoting substances like auxins, particularly indole-3-acetic acid (IAA) and indole-3-pyruvic acid, zeatin, zeatinriboside, proliferation of beneficial organisms in the phyllosphere and reacted cytokinins by methylotrophs has been reported as the factors that enhance plant growth of crops, the increase in the vegetative growth of the plant attributed to the increase in the yield of a crop. From the above discussion, it could be concluded that foliar application of PPFM favorably influenced the seed cotton yield.

The interaction effect was also found significant. The combination of BBF with soil application of Pusa hydrogel @ 5 kg ha-1 + foliar spray of PPFM @ 500 ml ha-1recorded higher yield with increased yield percentage of 133 and 150 % during 2016 and 2017, respectively over compartmental bunding with control. This may be due to the favorable environment provided by the *in-situ* moisture conservation and stress management practices, which enhanced the growth and yield attributing characters of cotton during both the years of study.

***Effect of in-situ moisture conservation and stress management practices on economics (Table 8 and 9)***

The cost invested in cultivation, gross return, and net return earned under *in-situ* moisture conservation measures and stress management practices were worked out, and B: C ratio was calculated are presented in Tables 5 and 6.

***Cost of cultivation***

The investment ( 48,801 ha-1) was found to be highest under *in-situ* moisture conservation measure either BBF (I1) or RF (I2) or CB (I3) where combined with soil application of pusa hydrogel @ 5 kg ha-1 + foliar spray of 5% Kaolin followed by *in-situ* moisture conservation measures with soil application of Pusa hydrogel @ 5 kg ha-1 + foliar spray of Salicylic acid 100ppm(I1S5) during both the years 2016 and 2017. The cost of cultivation ( 40,707 ha-1) was lesser in *in-situ* moisture conservation measures alone, followed with not any hydrogel and foliar application as a control plot.

***Gross return***

The economic analysis of *in-situ* moisture conservation measures and stress management practices revealed that BBF (I1) with soil application of Pusa hydrogel @ 5 kg ha-1 + foliar spray of PPFM @ 500 ml ha-1 (I1S4) fetched higher gross income during 2016( 79,000 ha-1) and 2017( 97,150 ha-1) than the rest of other treatment combinations. It was closely followed by ( 68,450 ha-1 in 2016and  84,300 ha-1 in 2017) BBF combined with soil application of Pusa hydrogel @ 5 kg ha-1 + foliar spray of 1% KCl (I1S2). The lowest gross return was recorded in compartmental bunding with control (I1S6).

***Net return and benefit cost ratio***

The treatment combination of BBF with soil application of Pusa hydrogel @ 5 kg ha-1 + foliar spray of PPFM @ 500 ml ha-1 (I1S4) recorded the highest net income during 2016( 31,250 ha-1) and 2017( 49,400 ha-1). The lowest net return of  581 and  3,943 ha-1 was obtained CB with control (I1S6).

The benefit cost ratio was also found to be highest in the treatment (I1S4) combination of soil application of Pusa hydrogel @ 5 kg ha-1 + foliar spray of PPFM @ 500 ml ha-1 recorded 1.65 in 2016and 2.03 in 2017. Following this, broad bed and furrows combined with soil application of Pusa hydrogel @ 5 kg ha-1 + foliar spray of 1% KCl (I1S2) registered B: C ratio of 1.44 in 2016and 1.77 in 2017. The lowest B: C ratio of 1.01 and 1.25 was obtained under CB with control (I1S6) during 2016 and 2017, respectively.

Higher net income of  31,250 ha-1 in 2016and  49,400 ha-1 in 2017 was realized under treatment combination of BBF with soil application of Pusa hydrogel @ 5 kg ha-1 + foliar spray of PPFM @ 500 ml ha-1 with higher B: C ratio of 1.65 (2016) and 2.03 (2017)(Fig.3). The lowest net return of  581 in 2016 and  3,943 ha-1 in 2017and B: C ratio of 1.01 in 2016 and 1.25 in 2017 was obtained in treatment combination of compartmental bunding with control.

The profound influence of *in-situ* moisture conservation and stress management practices resulted in better crop growth development. Higher seed cotton yield realized might be the reason for improving higher net income and B: C ratio under BBF with soil application of Pusa hydrogel @ 5 kg ha-1 + foliar spray of PPFM @ 500 ml ha-1. Further, the higher cost of production owing to the application of super absorbent polymer can be compensated in spite of attaining the highest yield. The present study exhibited the advantage of using treatment combination of BBF with soil application of Pusa hydrogel + foliar spray of PPFM towards successful maintenance of crop under moisture stress condition and fetched higher benefit cost ratio showed it economic feasibility in adopting technology (Fig.2)

**Conclusion**

The crop grown under broad bed and furrows combined with foliar application of PPFM spray at 500 mL ha-1 was found superior for higher seed cotton yield and crop growth indices in both the years of investigation under rainfed areas. The higher values indicate that the moisture conservation and stress management practices improve growth rate performance; it leads to more yield potential of rainfed cotton. The economic analysis showed that the highest net income of  44,708 ha-1 in 2016 and  66,488 ha-1 in 2017 and benefit-cost ratio of 1.89 in 2016and 2.33 in 2017was obtained with the treatment combination of BBF with soil application of Pusa hydrogel @ 5 kg ha-1 + foliar spray of PPFM @ 500 ml ha-1. Broad bed and furrows combined with soil application of Pusa hydrogel @ 5 kg ha-1 + foliar spray of PPFM @ 500 mL ha-1 during the stress period was found to be the best agronomic management practice in order to conserve soil moisture, favourable yield attributing characters enhance yield and the highest net return and B: C ratio economic returns in cotton under rainfed vertisols.

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**Table 1. Effect of *in-situ* moisture conservation and stress management practices on crop growth rate (g m‑2 day‑1) of rainfed cotton during *rabi* 2016**

|  |  |  |  |
| --- | --- | --- | --- |
| **Treatments** | **30-60 DAS** | **60- 90 DAS** | **90-120 DAS** |
| **I1** | **I2** | **I3** | **Mean** | **I1** | **I2** | **I3** | **Mean** | **I1** | **I2** | **I3** | **Mean** |
| **S1** | 4.12 | 4.09 | 3.92 | 4.04 | 4.51 | 4.42 | 4.29 | 4.41 | 4.29 | 4.15 | 4.03 | 4.16 |
| **S2** | 4.45 | 4.25 | 4.02 | 4.24 | 5.11 | 4.96 | 4.78 | 4.95 | 4.75 | 4.49 | 4.18 | 4.47 |
| **S3** | 4.48 | 4.24 | 4.05 | 4.26 | 5.13 | 4.67 | 4.25 | 4.68 | 4.46 | 4.27 | 4.06 | 4.26 |
| **S4** | 4.56 | 4.21 | 4.09 | 4.29 | 5.87 | 5.34 | 5.14 | 5.45 | 5.21 | 4.72 | 4.19 | 4.71 |
| **S5** | 4.28 | 4.16 | 3.99 | 4.14 | 4.78 | 4.65 | 4.54 | 4.66 | 4.27 | 4.19 | 4.09 | 4.18 |
| **S6** | 3.91 | 3.62 | 3.28 | 3.60 | 4.22 | 4.12 | 4.05 | 4.13 | 4.05 | 3.92 | 3.86 | 3.94 |
| **Mean** | 4.30 | 4.10 | 3.89 |  | 4.94 | 4.69 | 4.51 |  | 4.51 | 4.29 | 4.07 |  |
|  | **I** | **S** | **I at S** | **S at I** | **I** | **S** | **I at S** | **S at I** | **I** | **S** | **I at S** | **S at I** |
| **S.Ed.** | 0.09 | 0.11 | 0.20 | 0.19 | 0.10 | 0.12 | 0.21 | 0.21 | 0.11 | 0.11 | 0.20 | 0.18 |
| **CD(P=0.05)** | 0.24 | 0.22 | NS | NS | 0.27 | 0.25 | NS | NS | 0.30 | 0.22 | NS | NS |

**Table 2.Effect of *in-situ* moisture conservation and stress management practices on crop growth rate (g m‑2 day‑1) of rainfed cotton during *rabi* 2017**

|  |  |  |  |
| --- | --- | --- | --- |
| **Treatments** | **30-60 DAS** | **60- 90 DAS** | **90-120 DAS** |
| **I1** | **I2** | **I3** | **Mean** | **I1** | **I2** | **I3** | **Mean** | **I1** | **I2** | **I3** | **Mean** |
| **S1** | 5.17 | 4.65 | 4.40 | 4.74 | 5.07 | 4.65 | 4.32 | 4.68 | 4.94 | 4.58 | 4.15 | 4.56 |
| **S2** | 5.22 | 4.79 | 4.51 | 4.84 | 5.52 | 5.43 | 5.38 | 5.44 | 5.41 | 5.12 | 4.46 | 5.00 |
| **S3** | 5.08 | 4.74 | 4.50 | 4.77 | 5.48 | 5.01 | 4.91 | 5.13 | 5.07 | 4.69 | 4.26 | 4.67 |
| **S4** | 5.24 | 4.79 | 4.57 | 4.87 | 6.02 | 5.85 | 5.72 | 5.86 | 6.41 | 5.55 | 4.75 | 5.57 |
| **S5** | 5.12 | 4.69 | 4.54 | 4.78 | 5.12 | 4.94 | 4.30 | 4.79 | 4.98 | 4.64 | 4.14 | 4.59 |
| **S6** | 4.22 | 4.17 | 4.15 | 4.18 | 5.02 | 4.50 | 4.01 | 4.51 | 4.11 | 4.07 | 3.87 | 4.02 |
| **Mean** | 5.01 | 4.64 | 4.45 |  | 5.37 | 5.06 | 4.77 |  | 5.15 | 4.78 | 4.27 |  |
|  | **I** | **S** | **I at S** | **S at I** | **I** | **S** | **I at S** | **S at I** | **I** | **S** | **I at S** | **S at I** |
| **SEd** | 0.10 | 0.12 | 0.21 | 0.20 | 0.09 | 0.17 | 0.22 | 0.24 | 0.15 | 0.12 | 0.24 | 0.20 |
| **CD(P=0.05)** | 0.28 | 0.24 | NS | NS | 0.25 | 0.35 | NS | NS | 0.41 | 0.24 | NS | NS |

**Table 3.Effect of *in-situ* moisture conservation and stress management practices on relative growth rate (g g‑1 day‑1) of rainfed cotton during *rabi* 2016**

|  |  |  |  |
| --- | --- | --- | --- |
| **Treatments** | **30-60 DAS** | **60- 90 DAS** | **90-120 DAS** |
| **I1** | **I2** | **I3** | **Mean** | **I1** | **I2** | **I3** | **Mean** | **I1** | **I2** | **I3** | **Mean** |
| **S1** | 0.0421 | 0.0407 | 0.0395 | 0.0408 | 0.0295 | 0.0288 | 0.0275 | 0.0286 | 0.0112 | 0.0102 | 0.0104 | 0.0106 |
| **S2** | 0.0421 | 0.0413 | 0.0393 | 0.0409 | 0.0327 | 0.0319 | 0.0310 | 0.0319 | 0.0125 | 0.0110 | 0.0107 | 0.0114 |
| **S3** | 0.0419 | 0.0402 | 0.0390 | 0.0404 | 0.0305 | 0.0289 | 0.0293 | 0.0296 | 0.0113 | 0.0109 | 0.0106 | 0.0109 |
| **S4** | 0.0425 | 0.0412 | 0.0392 | 0.0410 | 0.0373 | 0.0344 | 0.0325 | 0.0347 | 0.0138 | 0.0120 | 0.0109 | 0.0122 |
| **S5** | 0.0425 | 0.0405 | 0.0385 | 0.0405 | 0.0293 | 0.0290 | 0.0287 | 0.0290 | 0.0115 | 0.0106 | 0.0104 | 0.0108 |
| **S6** | 0.0394 | 0.0378 | 0.0360 | 0.0377 | 0.0260 | 0.0259 | 0.0256 | 0.0258 | 0.0103 | 0.0097 | 0.0100 | 0.0100 |
| **Mean** | 0.0418 | 0.0403 | 0.0386 |  | 0.0309 | 0.0298 | 0.0291 |  | 0.0118 | 0.0107 | 0.0105 |  |
|  | **I** | **S** | **I at S** | **S at I** | **I** | **S** | **I at S** | **S at I** | **I** | **S** | **I at S** | **S at I** |
| **SEd** | 0.0008 | 0.0011 | 0.0019 | 0.0019 | 0.0004 | 0.0008 | 0.0011 | 0.0011 | 0.0004 | 0.0003 | 0.0006 | 0.0006 |
| **CD(P=0.05)** | 0.0023 | 0.0022 | NS | NS | 0.0015 | 0.0017 | NS | NS | 0.0010 | 0.0007 | NS | NS |

**Table 4.Effect of *in-situ* moisture conservation and stress management practices on relative growth rate (g g‑1 day‑1) of rainfed cotton during *rabi* 2017**

|  |  |  |  |
| --- | --- | --- | --- |
| **Treatments** | **30-60 DAS** | **60- 90 DAS** | **90-120 DAS** |
| **I1** | **I2** | **I3** | **Mean** | **I1** | **I2** | **I3** | **Mean** | **I1** | **I2** | **I3** | **Mean** |
| **S1** | 0.0431 | 0.0415 | 0.0389 | 0.0412 | 0.0196 | 0.0170 | 0.0146 | 0.0171 | 0.0111 | 0.0104 | 0.0099 | 0.0105 |
| **S2** | 0.0438 | 0.0412 | 0.0398 | 0.0416 | 0.0210 | 0.0196 | 0.0188 | 0.0198 | 0.0129 | 0.0117 | 0.0106 | 0.0117 |
| **S3** | 0.0441 | 0.0418 | 0.0384 | 0.0414 | 0.0207 | 0.0193 | 0.0181 | 0.0194 | 0.0126 | 0.0109 | 0.0104 | 0.0113 |
| **S4** | 0.0444 | 0.0415 | 0.0392 | 0.0417 | 0.0232 | 0.0211 | 0.0200 | 0.0214 | 0.0149 | 0.0131 | 0.0108 | 0.0129 |
| **S5** | 0.0432 | 0.0409 | 0.0394 | 0.0412 | 0.0195 | 0.0185 | 0.0176 | 0.0185 | 0.0116 | 0.0106 | 0.0099 | 0.0107 |
| **S6** | 0.0385 | 0.0376 | 0.0342 | 0.0368 | 0.0183 | 0.0147 | 0.0114 | 0.0148 | 0.0093 | 0.0088 | 0.0086 | 0.0089 |
| **Mean** | 0.0429 | 0.0408 | 0.0383 |  | 0.0204 | 0.0184 | 0.0168 |  | 0.0121 | 0.0109 | 0.0100 |  |
|  | **I** | **S** | **I at S** | **S at I** | **I** | **S** | **I at S** | **S at I** | **I** | **S** | **I at S** | **S at I** |
| **SEd** | 0.0009 | 0.0011 | 0.0020 | 0.0019 | 0.0005 | 0.0004 | 0.0009 | 0.0007 | 0.0003 | 0.0003 | 0.0008 | 0.0005 |
| **CD(P=0.05)** | 0.0025 | 0.0023 | NS | NS | 0.0015 | 0.0009 | NS | NS | 0.0005 | 0.0004 | NS | NS |

**Table 5.Effect of *in-situ* moisture conservation and stress management practices on net assimilation rate (mg cm-2 day-1) of rainfed cotton during *rabi* 2016**

|  |  |  |  |
| --- | --- | --- | --- |
| **Treatments** | **30-60 DAS** | **60- 90 DAS** | **90-120 DAS** |
| **I1** | **I2** | **I3** | **Mean** | **I1** | **I2** | **I3** | **Mean** | **I1** | **I2** | **I3** | **Mean** |
| **S1** | 0.3762 | 0.3503 | 0.3338 | 0.3534 | 0.1550 | 0.1524 | 0.1491 | 0.1522 | 0.1041 | 0.1002 | 0.0974 | 0.1006 |
| **S2** | 0.3880 | 0.3542 | 0.3319 | 0.3580 | 0.2329 | 0.2059 | 0.1741 | 0.2043 | 0.1155 | 0.1075 | 0.1032 | 0.1087 |
| **S3** | 0.3861 | 0.3522 | 0.3284 | 0.3556 | 0.1996 | 0.1845 | 0.1700 | 0.1847 | 0.1089 | 0.1023 | 0.1011 | 0.1041 |
| **S4** | 0.3990 | 0.3519 | 0.3222 | 0.3577 | 0.2623 | 0.2301 | 0.1953 | 0.2292 | 0.1378 | 0.1209 | 0.1052 | 0.1213 |
| **S5** | 0.3790 | 0.3559 | 0.3325 | 0.3558 | 0.1842 | 0.1751 | 0.1671 | 0.1755 | 0.1063 | 0.1025 | 0.1021 | 0.1036 |
| **S6** | 0.3295 | 0.3188 | 0.3090 | 0.3191 | 0.1385 | 0.1325 | 0.1273 | 0.1328 | 0.0997 | 0.0963 | 0.0945 | 0.0968 |
| **Mean** | 0.3763 | 0.3472 | 0.3263 |  | 0.1954 | 0.1801 | 0.1638 |  | 0.1121 | 0.1050 | 0.1006 |  |
|  | **I** | **S** | **I at S** | **S at I** | **I** | **S** | **I at S** | **S at I** | **I** | **S** | **I at S** | **S at I** |
| **SEd** | 0.0095 | 0.0113 | 0.0201 | 0.0195 | 0.0067 | 0.0084 | 0.0149 | 0.0145 | 0.0032 | 0.0036 | 0.0065 | 0.0062 |
| **CD(P=0.05)** | 0.0264 | 0.0230 | NS | NS | 0.0187 | 0.0171 | NS | NS | 0.0089 | 0.0074 | NS | NS |

**Table 6.Effect of *in-situ* moisture conservation and stress management practices on net assimilation rate (mg cm-2 day-1) of rainfed cotton during *rabi* 2017**

|  |  |  |  |
| --- | --- | --- | --- |
| **Treatments** | **30-60 DAS** | **60- 90 DAS** | **90-120 DAS** |
| **I1** | **I2** | **I3** | **Mean** | **I1** | **I2** | **I3** | **Mean** | **I1** | **I2** | **I3** | **Mean** |
| **S1** | 0.3818 | 0.3554 | 0.3290 | 0.3554 | 0.1463 | 0.1391 | 0.1373 | 0.1409 | 0.1080 | 0.0964 | 0.0847 | 0.0964 |
| **S2** | 0.3857 | 0.3567 | 0.3240 | 0.3555 | 0.1972 | 0.1794 | 0.1635 | 0.1800 | 0.1184 | 0.1109 | 0.1033 | 0.1109 |
| **S3** | 0.3834 | 0.3562 | 0.3278 | 0.3558 | 0.1870 | 0.1692 | 0.1559 | 0.1707 | 0.1106 | 0.1074 | 0.1043 | 0.1074 |
| **S4** | 0.3894 | 0.3584 | 0.3243 | 0.3574 | 0.2101 | 0.1963 | 0.1785 | 0.1950 | 0.1392 | 0.1203 | 0.1082 | 0.1226 |
| **S5** | 0.3871 | 0.3483 | 0.3296 | 0.3550 | 0.1686 | 0.1591 | 0.1579 | 0.1619 | 0.1062 | 0.1044 | 0.1026 | 0.1044 |
| **S6** | 0.3450 | 0.3182 | 0.2914 | 0.3182 | 0.1298 | 0.1212 | 0.1152 | 0.1221 | 0.1028 | 0.0991 | 0.0954 | 0.0991 |
| **Mean** | 0.3787 | 0.3489 | 0.3210 |  | 0.1732 | 0.1607 | 0.1514 |  | 0.1142 | 0.1064 | 0.0998 |  |
|  | **I** | **S** | **I at S** | **S at I** | **I** | **S** | **I at S** | **S at I** | **I** | **S** | **I at S** | **S at I** |
| **SEd** | 0.0101 | 0.0110 | 0.0202 | 0.0191 | 0.0054 | 0.0066 | 0.0118 | 0.0114 | 0.0036 | 0.0036 | 0.0068 | 0.0063 |
| **CD(P=0.05)** | 0.0281 | 0.0225 | NS | NS | 0.0150 | 0.0135 | NS | NS | 0.0099 | 0.0074 | NS | NS |

**Table.7.Effect of *in-situ* moisture conservation and stress management practices on seed cotton yield (kg ha-1) under rainfed condition during *rabi* 2016 and 2017**

|  |  |  |
| --- | --- | --- |
| **Treatments** | ***Rabi* 2016** | ***Rabi* 2017** |
| **I1** | **I2** | **I3** | **Mean** | **I1** | **I2** | **I3** | **Mean** |
| **S1** | 1,112 | 1,039 | 979 | 1,043 | 1,457 | 1,373 | 1,299 | 1,376 |
| **S2** | 1,369 | 1,260 | 1,084 | 1,238 | 1,686 | 1,579 | 1,475 | 1,580 |
| **S3** | 1,229 | 1,160 | 1,065 | 1,151 | 1,582 | 1,484 | 1,389 | 1,485 |
| **S4** | 1,580 | 1,350 | 1,253 | 1,394 | 1,943 | 1,785 | 1,631 | 1,786 |
| **S5** | 1,189 | 1,094 | 992 | 1,092 | 1,544 | 1,472 | 1,411 | 1,476 |
| **S6** | 998 | 884 | 724 | 869 | 1,328 | 1,107 | 893 | 1,109 |
| **Mean** | 1,246 | 1,131 | 1,016 |  | 1,590 | 1,467 | 1,350 |  |
|  | **I** | **S** | **I at S** | **S at I** | **I** | **S** | **I at S** | **S at I** |
| **S.Ed** | 33 | 33 | 61 | 57 | 32 | 48 | 71 | 68 |
| **CD (P=0.05)** | 90 | 67 | 138 | 116 | 117 | 100 | 178 | 141 |

**Table 8. Effect of *in-situ* moisture conservation and stress management practices on gross income and B: C ratio during *rabi* 2016-17**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Treatments** | **Total cost of cultivation(**Description: Description: INR  **ha-1)** | **Gross income****(**Description: Description: INR **ha-1)** | **Net income****(**Description: Description: INR **ha-1)** | **B:C ratio** |
| I1S1 | BBF + PH @ 5 kg ha-1 | 46,952 | 55,600 | 8,648 | 1.18 |
| I1S2 | BBF + PH @ 5 kg ha-1 + foliar spray of 1% KCl | 47,559 | 68,450 | 20,891 | 1.44 |
| I1S3 | BBF + PH @ 5 kg ha-1 + foliar spray of 5% Kaolin | 48,801 | 61,450 | 12,649 | 1.26 |
| I1S4 | BBF + PH @ 5 kg ha-1 + foliar spray of PPFM @ 500 ml ha-1 | 47,750 | 79,000 | 31,250 | 1.65 |
| I1S5 | BBF + PH @ 5 kg ha-1 + foliar spray of foliar spray of Salicylic acid 100 ppm | 47,849 | 59,450 | 11,601 | 1.24 |
| I1S6 | BBF + control | 40,707 | 49,900 | 9,193 | 1.23 |
| I2S1 | RF+ PH @ 5 kg ha-1 | 46,952 | 51,950 | 4,998 | 1.11 |
| I2S2 | RF + PH @ 5 kg ha-1 + foliar spray of 1% KCl | 47,559 | 63,000 | 15,441 | 1.32 |
| I2S3 | RF + PH @ 5 kg ha-1 + foliar spray of 5% Kaolin | 48,801 | 58,000 | 9,199 | 1.19 |
| I2S4 | RF + PH @ 5 kg ha-1 + foliar spray of PPFM @ 500 ml ha-1 | 47,750 | 67,500 | 19,750 | 1.41 |
| I2S5 | RF + PH @ 5 kg ha-1 + foliar spray of foliar spray of Salicylic acid 100 ppm | 47,849 | 54,700 | 6,851 | 1.14 |
| I2S6 | RF + control | 40,707 | 44,200 | 3,493 | 1.09 |
| I3S1 | CB + PH @ 5 kg ha-1 | 46,952 | 48,950 | 1,998 | 1.04 |
| I3S2 | CB + PH @ 5 kg ha-1 + foliar spray of 1% KCl | 47,559 | 54,200 | 6,641 | 1.14 |
| I3S3 | CB + PH @ 5 kg ha-1 + foliar spray of 5% Kaolin | 48,801 | 53,250 | 4,449 | 1.09 |
| I3S4 | CB + PH @ 5 kg ha-1 + foliar spray of PPFM @ 500 ml ha-1 | 47,750 | 62,650 | 14,900 | 1.31 |
| I3S5 | CB + PH @ 5 kg ha-1 + foliar spray of foliar spray of Salicylic acid 100 ppm | 47,849 | 49,600 | 1,751 | 1.04 |
| I3S6 | CB+ control | 40,707 | 41,288 | 581 | 1.01 |

**BBF -** Broad bed and furrows, **RF -** Ridges and furrows, **CB -** Compartmental bunding, **PH** - Pusa hydrogel

**Table 9. Effect of *in-situ* moisture conservation and stress management practices on gross income and B: C ratio during *rabi* 2017-18**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Treatments** | **Total cost of cultivation(**Description: Description: INR  **ha-1)** | **Gross income****(**Description: Description: INR **ha-1)** | **Net income****(**Description: Description: INR **ha-1)** | **B:C ratio** |
| I1S1 | BBF + PH @ 5 kg ha-1 | 46,952 | 72,850 | 25,898 | 1.55 |
| I1S2 | BBF + PH @ 5 kg ha-1 + foliar spray of 1% KCl | 47,559 | 84,300 | 36,741 | 1.77 |
| I1S3 | BBF + PH @ 5 kg ha-1 + foliar spray of 5% Kaolin | 48,801 | 79,100 | 30,299 | 1.62 |
| I1S4 | BBF + PH @ 5 kg ha-1 + foliar spray of PPFM @ 500 ml ha-1 | 47,750 | 97,150 | 49,400 | 2.03 |
| I1S5 | BBF + PH @ 5 kg ha-1 + foliar spray of foliar spray of Salicylic acid 100 ppm | 47,849 | 77,200 | 29,351 | 1.61 |
| I1S6 | BBF + control | 40,707 | 61,400 | 20,693 | 1.51 |
| I2S1 | RF+ PH @ 5 kg ha-1 | 46,952 | 68,650 | 21,698 | 1.46 |
| I2S2 | RF + PH @ 5 kg ha-1 + foliar spray of 1% KCl | 47,559 | 78,950 | 31,391 | 1.66 |
| I2S3 | RF + PH @ 5 kg ha-1 + foliar spray of 5% Kaolin | 48,801 | 74,200 | 25,399 | 1.52 |
| I2S4 | RF + PH @ 5 kg ha-1 + foliar spray of PPFM @ 500 ml ha-1 | 47,750 | 89,250 | 41,500 | 1.87 |
| I2S5 | RF + PH @ 5 kg ha-1 + foliar spray of foliar spray of Salicylic acid 100 ppm | 47,849 | 73,600 | 25,751 | 1.54 |
| I2S6 | RF + control | 40,707 | 55,350 | 14,643 | 1.36 |
| I3S1 | CB + PH @ 5 kg ha-1 | 46,952 | 64,950 | 17,998 | 1.38 |
| I3S2 | CB + PH @ 5 kg ha-1 + foliar spray of 1% KCl | 47,559 | 73,750 | 26,191 | 1.55 |
| I3S3 | CB + PH @ 5 kg ha-1 + foliar spray of 5% Kaolin | 48,801 | 69,450 | 20,649 | 1.42 |
| I3S4 | CB + PH @ 5 kg ha-1 + foliar spray of PPFM @ 500 ml ha-1 | 47,750 | 81,550 | 33,800 | 1.71 |
| I3S5 | CB + PH @ 5 kg ha-1 + foliar spray of foliar spray of Salicylic acid 100 ppm | 47,849 | 70,550 | 22,701 | 1.47 |
| I3S6 | CB+ control | 40,707 | 44,650 | 3,943 | 1.10 |

**BBF -** Broad bed and furrows, **RF -** Ridges and furrows, **CB -** Compartmental bunding, **PH** - Pusa hydrogel

**Fig.1. Effect of *in-situ* moisture conservation and stress management practices on crop growth rate (g m‑2 day‑1) of rainfed cotton during *rabi* 2016 and 2017**

**Fig.2. Effect of *in-situ* moisture conservation and stress management practices on net income and benefit cost ratio during *rabi* 2016 and 2017**