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Characterization of drain discharge from subsurface drainage system with 60 m lateral spacing in saline Vertisols of Tungabhadra command area

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Abstract
Characterization of drain water for irrigation over the cropping season was assessed during rabi/summer 2020-21 at Agricultural Research Station, Gangavati in the TBP command area. Drain water samples collected fifteen times over the cropping season from man holes revealed that the pH and EC values of drain water varied from 7.55 to 7.09 with a mean of 7.27 and 5.25 to 4.33 dS m^{-1} with a mean of 4.73 dS m^{-1} respectively. The SAR and RSC values in drain discharge varied from 25.20 to 18.10 $(mmol/L)^{1/2}$ with a mean value of 21.60 $(mmol/L)^{1/2}$ and from 11.50 to 9.50 me L^{-1} with a mean value of 9.00 me L^{-1}. The DCR and SSP in drain discharge varied from 0.19 to 0.12 with a mean value of 0.14 and from 88.40 to 80.90 with a mean value of 85.60 respectively. The Mg/Ca and Cl/SO_4 ratios in drain discharge varied from5.00 to 0.13 with a mean value of 0.98 and from 1.80 to 0.97 with a mean value of 0.63 respectively. The EC, SAR, RSC, and SSP values of drain water are the major constraints as far as their irrigation feasibility is concerned.

Keywords: Pigeonpea, planting geometry, paired row, growth, yield, pigeonpea equivalent yield

Introduction
Waterlogging and soil salinization are the twin problems of major irrigation command areas including Tungabhadra Command Area in Karnataka. Subsurface drainage system (SSD) is a proven and viable curative technology to combat these twin problems through maintenance of salt and water balance in the crop root zone (Tiwari and Goel, 2017) [19]. Subsurface drainage helps to lower water tables, prevent water-logging, control soil salinity, reduces surface runoff, sediment losses and the movement of contaminants attached to the sediment into surface waters. Based on the extent of soil salinity, irrigation management and crop to be grown, depth and spacing of laterals (between two laterals) in SSD system will vary. In the process of reclamation through subsurface drainage system, soluble salts in the soil profile are leached or flushed down through irrigation water and discharge into natural drain or streams which finally discharge into the river. The quality of drain discharge will be different than the irrigation water applied (Canal water) as it carries soluble salts from the soil profile. Drainage water that flows over or through the soil will pick up a variety of dissolved and suspended substances and soil particles. As subsurface drainage water itself is commonly higher in total salts agricultural water users would be affected by its discharge into usable water supplies *viz.*, natural streams or locally referred to as nala. As indicated by Norman *et al.* (1995) [12], agricultural subsurface drainage effects on drain discharge water quality are both positive and negative i.e., reduction in sediment and phosphorus, and increase in nitrate-nitrogen delivery to receiving waters. Efforts are being made elsewhere for reuse of such drainage water in crop production. Hence, quality assessment or feasibility studies of drain discharge/water both in short and long-term adoption of SSD with specific lateral spacing is prerequisite for its reuse in crop production. Such, feasibility studies on characterization of drain discharge from subsurface drainage systems are lacking in TBP command area. Hence, this study was under taken.

Materials and Methods

Experimental layout

A field experiment on subsurface drainage system with 60m lateral spacing was initiated during *Rabi/Summer* 2012-13 on a 2.62 ha area at Agricultural Research Station (ARS), Gangavathi (15° 27′ 14.1″ N, 76° 32′ 06.12″ E) in Karnataka, India (Figure 1a). The soils of the experimental site were predominantly of clay loam with weathered calcareous parent material locally known as *murrum* at a depth of about 1.0 m. Hydraulic conductivity measured using the augur-hole method varied from 0.0503 and 0.092 m day^{-1} at 1.0 m depth. During *Rabi/Summer* 2020-21, drain water samples were collected fifteen times over the season from man holes at three-day intervals (Figure 1b). Simultaneously, water samples were also collected from the canal for comparison. To assess the changes in soil salinity, soil samples up to a depth of 90 cm were collected randomly from the experimental plot before (May 2020) and after the harvest of crop during *Rabi/Summer* 2020-21.

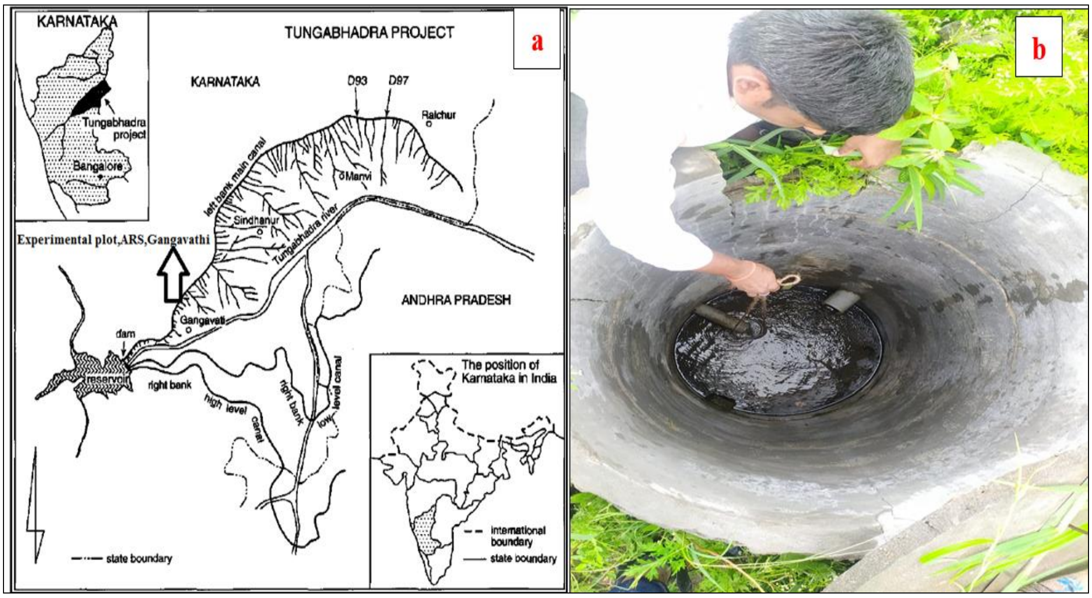

Fig 1: a: Location of experimental site in the TBP command area (Source: Manjunatha *et al*., 2004) and b: A view of collection of drain discharge from man hole in the conventional SSD system imposed at 40 m lateral spacing at Agricultural Research Station, Gangavathi.

Soil samples were analyzed for pH and salinity (EC, dS m^{-1}) in a 1:2.5 soil water suspension and the EC values thus obtained were converted to ECe (dS m^{-1}), *i.e*., EC of saturation paste extract by multiplying with a conversion factor of 2.66 which was worked out for these soils at ARS, Gangavathi (personal communication).

Immediately after the collection of drain discharge and canal water samples, pH and EC was determined and these samples were stored for further analysis after adding 1ml toluene to avoid the microbial growth. The pH and EC of water samples was determined by using glass electrode and conductivity meter (Jackson, 1973) [5]. The cationic concentrations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and anionic concentrations (Cl^{-}, SO_4^{2-}, CO_3^{2-}, HCO_3^{-}) were measured following standard procedures outlined by Richards (1968) [15]. The values obtained were used to compute for sodium adsorption ratio (SAR), residual sodium carbonate (RSC), magnesium to calcium ratio (Mg/Ca), divalent cation ratio (DCR), Cl/SO_4, soluble sodium percentage (SSP). Irrigation water quality of these samples was classified into 16 categories of salinity and/or sodicity hazard based on electrical conductivity and SAR as suggested by Richards (1968) [15].

Results and Discussion

Soil pH and salinity (ECe) at different depths as influenced by subsurface drainage system was presented in Table 1. Before the *kharif* crop, soil pH varied from 8.14 to 7.73 (0-15 cm), 8.43 to 7.86 (15-30 cm), 8.41 to 7.86 (30-60 cm) and 8.46 to 7.98 (60-90 cm) with a mean value of 7.94, 8.19, 8.09 and 8.19. After the harvest of *R/S* paddy crop (May 2021), soil pH varied from 8.29 to 7.82 (0-15 cm), 8.46 to 7.87 (15-30 cm), 8.59 to 8.09 (30-60 cm) and 8.64 to 8.06 (60-90 cm) with a mean value of 8.05, 8.15, 8.30 and 8.27. Compared to before and after the crop harvest, irrespective of soil depth, soil pH did not vary and soils were alkaline in soil reaction. It could be due to the reason that the systems were established seven seasons prior to the present investigation by then the systems must have stabilized particularly with respect to soil pH.

In May 2020 (before the *kharif* crop), soil ECe varied from 19.95 to 2.66 (0-15 cm), 16.23 to 3.19 (15-30 cm), 17.85 to 3.78 (30-60 cm) and 19.05 to 5.37 (60-90 cm) with a mean value of 5.57, 7.75, 10.83 and 11.54 dS m^{-1} respectively. After the harvest of *R/S* paddy crop (May 2021), soil ECe varied from 4.36 to 0.74 (0-15 cm), 9.28 to 1.81 (15-30 cm), 16.41 to 3.72 (30-60 cm) and 16.60 to 5.19 (60-90 cm) with a mean value of 2.96, 4.14, 10.13 and 10.73 dS m^{-1} respectively. The decrease in soil salinity was to the greater extent and was within the permissible limit (< 4 dS/m) in the effective root zone i.e., 0-30 cm whereas at lower depths decrease in soil salinity was minimal and still more than the permissible limit.

Table 1: Soil pH and salinity as influenced by SSD at 60 m lateral spacing.

Statistic	Soil pH								Soil ECe (dS m^{-1})							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm		0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	Conv.	Cont.	Conv.	Cont.	Conv.	Cont.	Conv.	Cont.	Conv.	Cont.	Conv.	Cont.	Conv.	Cont.	Conv.	Cont.
	Before transplanting (Summer 2020)															
Maximum	8.14	8.09	8.43	8.60	8.41	8.53	8.46	8.71	19.95	7.13	16.23	11.36	17.85	16.07	19.05	16.12
Minimum	7.73	7.71	7.86	7.75	7.86	7.96	7.98	8.03	2.66	1.01	3.19	0.85	3.78	1.17	5.37	0.56
Average	7.94	7.86	8.19	8.11	8.09	8.24	8.19	8.31	5.75	3.06	7.75	4.32	10.83	6.61	11.54	6.24
	After harvest (*R/S*2020-21)															
Maximum	8.29	8.51	8.46	8.55	8.59	8.79	8.64	8.52	4.36	4.42	9.28	8.70	16.41	12.95	16.60	15.99
Minimum	7.82	7.79	7.87	7.87	8.09	8.10	8.06	8.01	0.74	1.22	1.81	1.44	3.72	2.77	5.19	3.27
Average	8.05	8.08	8.15	8.11	8.30	8.33	8.27	8.28	2.96	2.72	4.14	3.82	10.13	7.94	10.73	8.81

The water quality parameters *viz.*, pH, EC, RSC, SAR, DCR, Mg/Ca, SSP, Cl/SO_4 ratios in water samples collected from manholes is presented in Table 2.

pH

Temporally, the pH of drain water collected from manhole varied from 7.09 to 7.55 with a mean value of 7.27. Manjunath *et al*. (2019) [10]reported that the pH of water samples collected from natural streams in Gangavathi taluk of TBP command area during Kharif 2019 ranged from 7.50 to 8.00 and 8.0 to 8.50.

Similar results were reported by Mallika (2017) at 40, 50 and 60 m subsurface drain spacing experiment in Mallapur village (middle region of TLBC) wherein the mean pH values were 7.43, 7.56 and 7.56 at 90 days after transplanting respectively. Similarly, in Gundur village blocks the drain leachate pH ranged from 7.12-8.03, 7.37-8.03 and 7.21-8.02 respectively. Rahul (2016) [14] also reported that the drain discharge pH ranging from 7.10 to 9.10 in the outlets.

Ayers and Westcott (1976) [2] in their guideline for the interpretation of water quality of irrigation water regarded 6.5 to 8.4 as a normal range of pH for safe irrigation. Accordingly, the mean water pH recorded was within this range. An abnormal value is a warning that the water needs further evaluation. Irrigation water with a pH outside the normal range may cause a nutritional imbalance or may contain a toxic ion.

Electrical conductivity (EC)

The drainage water salinity is a function of amount and quality of irrigation water, drainage water volume, soil salinity etc. Temporally, the EC of drain water samples collected at manhole varied from 4.33 to 5.25 with a mean value of 4.73 dS m^{-1}. Overall, the average drain water salinity was much higher than the average canal water salinity (0.36 dS m^{-1}) to the extent of 13.1 times.

As per classification of irrigation water by Richards (1968) [15], majority of drain water samples collected over the season water fall under category C4 (EC > 2.25 dS m^{-1}) which indicate high salinity hazard and hence not feasible for irrigation.

Man Singh *et al.* (2002) [9] reported the highest (44.7 dS m^{-1}) and lowest (3.86 dS m^{-1}) mean salinity of drainage effluent at 35 and 15 m drain spacing areas which were in initial stage of reclamation. Whereas, Karegoudar *et al*. (2019) [6] reported that the drain water salinity at 50 m drain spacing varied from 3.61 (*kharif* 2013) to 2.50 dS m^{-1} (*kharif* 2014) and 2.03 dS m^{-1} (*kharif* 2012) to 3.50 (*R/S* 2013–14) with a mean value of 3.03 and 2.98 dS m^{-1} under SSD respectively in the initial years of reclamation.

Similar findings were reported by Manjunath *et al*. (2019) [10] wherein the mean EC of majority of water samples of natural streams of LBMC in TBP command area were under category of C3 (EC 0.75 to 2.25 dS m^{-1}) which indicate high salinity hazard and hence not feasible for irrigation. The canal water which passes through waterlogged saline soil and discharged into the natural stream (nala) would be of poor quality as it carries salts present in the soil profile. Hence, depending on the soil properties through which canal water passes through the quality of natural stream water is expected to be different than the canal water with respect to salinity so also the ionic composition (Prasanna *et al.*, 2011) [13].

Residual sodium carbonate (RSC)

Temporally, the RSC values of drain water samples varied from 9.50 to 11.5 me L^{-1} with a mean value of 9.00 me L^{-1}. The mean RSC of drain water was 100 to 16.9 times higher compared to canal water. Overall, compared to canal water (0.09 me L^{-1}) the mean RSC values were 29.9 times higher in case of drain discharge samples.

Richards (1968) [15] based on the values of RSC classified water into safe (<1.25 me L^{-1}), moderately safe (1.25 to 2.5 me L^{-1}) and unsafe (>2.5 me L^{-1}) for irrigation. Larger RSC values indicate higher amounts of CO_3^{2-} and HCO_3^- in drain water which could induce soil sodicity upon its applications to soil particularly poorly drained black soils. Among collected water samples analyzed from manhole, about 50 percent samples are safe and remaining 50% are of unsafe for irrigation respectively.

Mallika (2017) [8] however reported generally zero RSC of drain discharge waters at different villages *viz.*, Chagabhavi (tail region of TLBC), Gundur (head region of TLBC) and Mallapur village (Middle region of TLBC) during *kharif* 2015 and 2016. With one-time sampling, Prasanna *et al*. (2011) [13] and Kumar (2014) [7] reported that the RSC values of the majority surface/stream/bore well water samples were under good category (<1.25 me L^{-1}) indicating feasibility for irrigation purpose.

Table 2: Quality parameters of drain discharge samples collected from 60 m lateral spacing SSD in ARS Gangavati of TBP command area, Karnataka

Date of sampling	Water quality parameters							
	pH	EC (dSm^{-1})	RSC (me L^{-1})	SAR (mmol/L)$^{1/2}$	Cl/SO_4	Mg/Ca	SSP	DCR
04/2/2021	7.11	5.25	6.0	19.65	0.80	0.44	82.7	0.17
08/2/2021	7.17	4.33	9.6	18.79	0.93	0.39	83.7	0.16
11/2/2021	7.20	4.48	7.7	21.52	0.94	0.70	86.3	0.14
15/2/2021	7.17	4.85	6.7	22.20	0.68	0.56	86.4	0.14
18/2/2021	7.09	4.49	10.0	20.28	0.85	1.95	84.9	0.15

22/2/2021	7.16	4.69	8.2	21.66	0.56	0.13	85.9	0.14
25/2/2021	7.25	4.54	6.5	22.82	1.02	0.20	86.8	0.13
01/3/2021	7.36	4.72	6.5	22.02	0.85	0.50	86.4	0.14
04/3/2021	7.34	4.72	8.7	21.23	1.15	0.80	85.7	0.14
08/3/2021	7.55	4.85	9.5	22.69	0.90	0.63	85.8	0.14
12/3/2021	7.31	4.83	10.8	18.14	1.17	0.46	80.9	0.19
15/3/2021	7.42	4.75	10.3	23.30	1.13	0.90	87.3	0.13
18/3/2021	7.29	4.76	11.5	20.23	1.80	0.71	84.4	0.16
23/3/2021	7.32	4.76	9.5	25.15	0.97	1.29	88.3	0.12
25/3/2021	7.38	4.87	9.0	24.72	0.63	5.00	87.7	0.12
Maximum	7.55	5.25	11.5	25.2	1.80	5.00	88.4	0.19
Minimum	7.09	4.33	9.50	18.1	0.97	0.13	80.9	0.12
Average	7.27	4.73	9.00	21.6	0.63	0.98	85.6	0.14

Sodium adsorption ratio (SAR)

Temporally, the SAR values of drain water samples varied from 18.1 to 25.2 $(mmol/L)^{1/2}$ with a mean value of 21.6 $(mmol/L)^{1/2}$. The mean SAR values of drain water were 21.6 times higher compared to mean canal water 1.00 $(mmol/L)^{1/2.}$ However, the mean SAR values at all sampling stations (SAR>10) indicate water is unsafe for irrigation. Anand (2003) [1] reported that the SAR in the drainage water ranged from 9.90 (January 2002 in Kapli site) to 14.66 (October 2001 in Shirol site) respectively.

Based on classification of irrigation waters by Richards (1968) [15], most of the drain water samples fall under category C4S2 (C4- > 2.25 dS m^{-1}, S2- 10-18 SAR) which are moderately safe for irrigation.

Chloride to sulphate ratio (Cl/SO_4)

Temporally, the Cl/SO_4 ratio of drain water samples varied from 0.97 to 1.80 with a mean value of 0.63. The mean Cl/SO_4 of drain water was 4.9 times lower compared to canal water (3.08 me L^{-1}).

Magnesium to calcium ratio (Mg/Ca)

Temporally, the Mg/Ca ratio of drain discharge water samples collected from manhole varied from 0.13 to 5.00 with a mean value of 0.98. The mean Mg/Ca of drain water was 5.3 times higher compared to canal water (0.36). Based on ratio of Mg to Ca, waters are categorized as safe (<1.5), moderately safe (1.5 to 3.0) and unsafe (>3.0) for irrigation (Tandon, 2017) [18]. Hence, drain water samples analyzed fall under category moderately safe. However, Das (2004) [4] mentioned that the magnesium hazard in irrigation water is expected having Mg/Ca ratio more than 1.

Soluble sodium percentage (SSP)

Temporally, the soluble sodium percentage of drain water varied from 80.9 to 88.4 with a mean value of 85.6.

The mean SSP of drain discharge was 2.91 times higher compared to canal water (29.4). As per the guidelines, irrigation water having SSP value of 60 and above are considered as harmful (Sathyanarayana *et al.*, 2020) [17]. All the drain water samples analyzed from manhole had soluble sodium percentage values above 60 and are considered as harmful for soils and crops.

Divalent Cation ratio (DCR)

Temporally, the divalent cation ratio of drain water samples varied from 0.12 to 0.19 with a mean value of 0.14. The mean DCR of drain water was 15.3 times higher compared to canal water (2.14). Generally the mean DCR of drain discharge water appears to be either low or at the boundary of permissible limit *i.e.*, 0.25. Generally, it is suggested that low RSC and SAR waters are of good quality and have the divalent to total cationic concentration ($M^{2+} / \Sigma M^{n+}$) ratio of >0.25

The drain discharge, salt output, NO_3-N concentration in the drain discharge and loss of nitrogen through drain discharge under subsurface drainage system is presented in Table 3.

Drain discharge (DD)

The drain discharge or drainage water outflow varied from 0.75 to 1.21 mm day^{-1} with a mean value of 0.94 mm day^{-1}. Mallika (2017) [8] reported the average drain discharge during *kharif* 2015 and 2016 ranged from 0.08 to 0.75, 0.11 to 0.85, 0.12 to 0.99, mm d^{-1} in the M_1 (60 m spacing), M_2 (50 m spacing), M_3 (40 m spacing), respectively at Mallapur village (Middle region of TLBC) site. Similarly, at Chagabhavi village (Tail region of TLBC), the drain discharge varied from 0.19 to 1.22, 0.18 to 1.18 and 0.20 to 1.28 and mm d^{-1} in 60, 50 and 40 m spacing respectively.

Salt output

The salinity of the drainage effluent along with drainage coefficient indicates the rate of saline land reclamation. The product of these two parameters at any given stage reveals the quantum of salt output from the treated area. The salt output varied from 40.6 to 22.4 kg ha^{-1} with a mean value of 28.0 kg ha^{-1}.

In SSD system, on an average, 3.5 t ha^{-1} of salt load was removed through drainage water at 50 m lateral spacing SSD system, indicating that the rate of reclamation was faster in the SSD system reported by Karegoudar *et al.* (2019) [6].

Table 3: Drain discharge, salt output, NO_3-N concentration in the drain discharge and nitrogen loss as influenced by SSD with 60 m lateral spacing.

Date of sampling	Drain discharge (mm day^{-1})	Salt output (kg ha^{-1})	NO_3-N (mgL^{-1})	NO_3-N (kg/ha)
04/2/2021	1.21	40.6	9.92	0.12
08/2/2021	1.10	30.5	7.44	0.08
11/2/2021	1.01	29.1	8.68	0.09
15/2/2021	0.84	26.2	9.92	0.08
18/2/2021	1.01	29.1	8.68	0.09
22/2/2021	0.75	22.4	12.40	0.09
25/2/2021	0.94	27.3	13.02	0.12
01/3/2021	0.90	26.2	9.92	0.09
04/3/2021	0.75	29.1	7.44	0.06
08/3/2021	1.01	22.4	11.78	0.12
12/3/2021	0.94	27.3	6.20	0.06
15/3/2021	0.90	27.5	5.58	0.05
18/3/2021	0.97	29.7	6.20	0.06
23/3/2021	0.87	26.6	8.06	0.07
25/3/2021	0.84	26.3	11.53	0.10
Maximum	1.21	40.6	13.02	
Minimum	0.75	22.4	5.58	
Average	0.94	28.0	9.12	

Nitrate nitrogen (NO_3-N)

The magnitude of drainage outflow has the impact on the total nitrate load (Sands *et al*., 2008; Nangia *et al*., 2010) [16,11]. The NO_3-N concentrations in drain discharge varied from 13.02 to 5.58 with a mean value of 9.12. However, Manjunath *et al*. (2019) [10] reported that the mean NO_3-N content of all the water samples in natural stream were less than 5 mg L^{-1} during *kharif* season. The concentration of nutrients such as NO_3-N was shown to be a function of rainfall, irrigation and time of fertilization (Calvert, 1975) [3].

The total seasonal NO_3-N loss was 5.07 kg ha^{-1} $season^{-1}$. Whereas, Karegoudar *et al*. (2019) [6] reported that the average seasonal nitrogen loss of 11.2 kg ha^{-1} in SSD with 50 m spacing during *kharif* season in the initial period of experimentation.

Conclusion

In general, EC, RSC, SAR, and SSP values appear to be the main constraints as far as the feasibility of drain water for its reuse. Hence, it could be concluded that even 7 to 8 years after the implementation of subsurface drainage system with 60 m lateral spacing, drain water samples were not suitable for reuse as irrigation water to paddy in the R/S season as per the classification particularly for poorly drained black soils in the TBP command area.

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