FIELD EVALUATION OF SOIL PHYSICAL, CHEMICAL AND HYDRAULIC PROPERTY CHANGES CAUSED BY SURFACE WATER APPLICATION: A CASE STUDY OF RUAHA-MBUYUNI IRRIGATION SCHEME, IRINGA, TANZANIA

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An assessment of the factors influencing soil physical and hydraulic property changes under a surface irrigated onion crop was made at Ruaha-Mbuyuni farmer-managed irrigation scheme in Iringa region. A total of 60 plots in three different locations were used in the study. Results show significant variability in soil physical and hydraulic properties between locations. Generally, the soils had low structural stability mainly due to low organic matter content (1.1 – 3.1%). The irrigation water had moderate salinity (ECw between 0.9 and 1.5) and low sodicity (SAR between 4.0 and 7.7 me/l) throughout the season. Accordingly, this water poses no or only slight permeability problems although in the long run, salinity levels may affect crop water availability. The concentration of suspended sediments in the irrigation water (0.4 – 16.2 g/l) is considered high and this could be one of the main agents for the observed decrease in basic infiltration rate and saturated hydraulic conductivity over the season with consequent reduction in total and specific yields. This situation can be redressed through appropriate soil and water management practices within the scheme itself and the catchment area at large.

Keywords: *Infiltration rate, hydraulic conductivity and suspended sediment load*

INTRODUCTION

Surface irrigation is unique among irrigation systems in that infiltration, not the system hardware, essentially determines the systems application rate and strongly influences water distribution (Trout, 1991; Foroud *et al.*, 1996). Although it is a widely used method for applying water to crops (accounting for more than 95% of the world's irrigated land), surface irrigation can never be described as a "simple" method if it is to be used efficiently. Good control of the highly variable nature of water movement across a soil surface and its infiltration into the soil over a season is extremely difficult to achieve and would seem to make this one of the most complex methods of applying water ever devised (Kay, 1990). Infiltration characteristics under surface irrigation may vary considerably within a season (Eisenhauer *et al.*, 1992). Farmers' response to such variation is normally to over-irrigate by either extending the application time or increasing the volume of water applied. Such measures may however lead to runoff and deep percolation

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losses, salinity and other problems such as poor aeration and crop diseases.

Most soils in arid and semi-arid areas are characterized by a reduction in infiltration rate and hydraulic conductivity when low salinity or sodic water is used (Abu-Sharar and Salameh, 1995). These soils are also characterized by poor aggregate stability and soil sealing due to crust formation at the surface. Soil sealing is one of the major factors that affect water intake and its movement and is influenced by particle size distribution and aggregation. McNean *et.al.*, (1982) observed that hydraulic conductivity decreased from 7.13 to 0.52 cm/h with an increase of clay content from 5.7 to 48.5 percent, respectively. Flocculation/dispersion conditions may influence soil sealing directly or through their effect on aggregate stability (Heil *et al.*, 1997). Aggregate stability has been related directly to the organic matter content. A soil with low organic matter content (less than 5%) may contain aggregates that are relatively unstable which can easily be dispersed (Heil *et al.*, 1997).

About one third of the total area of Tanzania can be classified as semi-arid and occupies much of the central plateau (Hatibu *et al.*, 1995). This area is characterized by low and erratic rainfall (Linsley *et al.*, 1988; Hatibu *et al.*, 1997). Ruah-Mbuyuni (the study area) lies in this zone. Surface irrigation, upon which crop production in the area largely depends, has been practised for over 40 years. Paddy rice, maize and beans are mainly grown as food crops while some horticultural crops are raised as cash crops (TIP, 1991). However, there has been a noticeable steady decline in the yield of some irrigated crops, specifically onions (TIP, 1992) the cause of which is not yet clear. Onions are sensitive to water deficit with yield response factor (ratio of relative yield decrease to relative evapotranspiration deficit), ky of 1.1 (Doorenbos and Kassam, 1979). Hence a reduction in water availability due to decreased infiltrability and impaired redistribution will significantly affect crop development leading to yield reduction.

The suitability of water from a quality standpoint is determined by its potential to cause problems and is related to the special management practices needed or the yield reduction caused. The amount and nature of ions present determine the quality of a given water for irrigation. The most common problems that result from using poor quality irrigation water include salinity, permeability, toxicity and physiological problems. This study was therefore aimed at establishing the sources of the problems experienced at the scheme and provide solutions where possible.

MATERIALS AND METHODS

Description of the study area

The study was carried out at Ruaha-Mbuyuni traditional irrigation scheme, Kilolo District in Iringa Region (Figure 1) with an area of 240 ha. The scheme is located at latitude 7°29'S and longitude 36°33'E, with a mean altitude of about 1000 m above mean sea level. The climate is semi-arid with mean annual rainfall of 465 mm and mean daily temperature ranging from 18.1° C to 31.2° C. The area has one growing season with rains starting around mid November and ending around mid April. The relative humidity ranges from 22.5% during the dry season to 87.9% during the rainy season.

The cambisols derived from Great Ruaha and Lukosi river alluvial deposits cover much of the scheme area. Soils of this area have considerable variation in texture but generally they range from coarse textured sandy-loam to heavy cracking clay.

The source of irrigation water for Ruaha-Mbuyuni scheme is Lukosi river which is a tributary of Great Ruaha river. The river has a large catchment area south of Iringa and consequently the discharge is considerable (TIP, 1992). The scheme is divided into two fields namely Mhinzi and Ilongo (Figure1). Paddy rice, onions and maize are major crops while beans and sweet pepper are minor crops. During the irrigation season (May to October) onion cultivation covers about 75% of the cultivated land. In October the canal is often dry because the river flow is at its minimum (TIP, 1992) and therefore only about 10% of the area is cultivated between September and October.

Plot layout and sampling procedure

A total of 100 plots of 2m by 5m were constructed in each of the three selected locations within the Ilongo block of fields (Figure 2). Selection of these locations was based on soil type and the position relative to the field canal. Twenty plots in each location were randomly selected for discharge and yield measurements. From the 20 plots in each location, three sampling sites were randomly selected from where soil hydraulic conductivity and infiltration rate measurements were taken. Soil samples were also taken from the same sites for determination of soil bulk density, particle size distribution, electrical conductivity and some chemical properties such as sodium, calcium and magnesium ion concentration.

Determination of hydraulic, physical and chemical properties of soil and water

Standard procedures were used to determine the hydraulic, physical and chemical properties of both the soil and water as shown in Table 1.

Crop performance assessment

Onion (*Allium cepa*) var. Red Bombay was the crop used in all the three locations. Land and seed-bed preparations as well as sowing, transplanting,

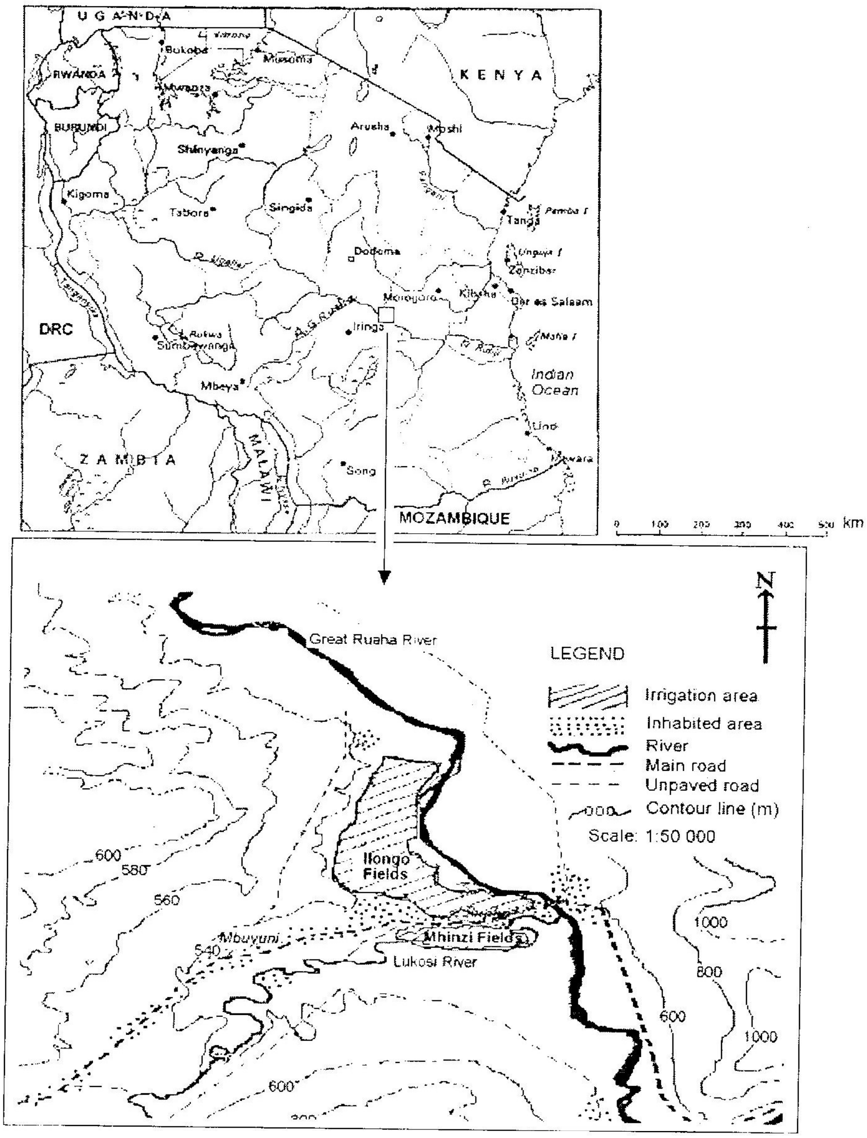

Figure 1: Location map of Ruaha-Mbuyuni Irrigation scheme

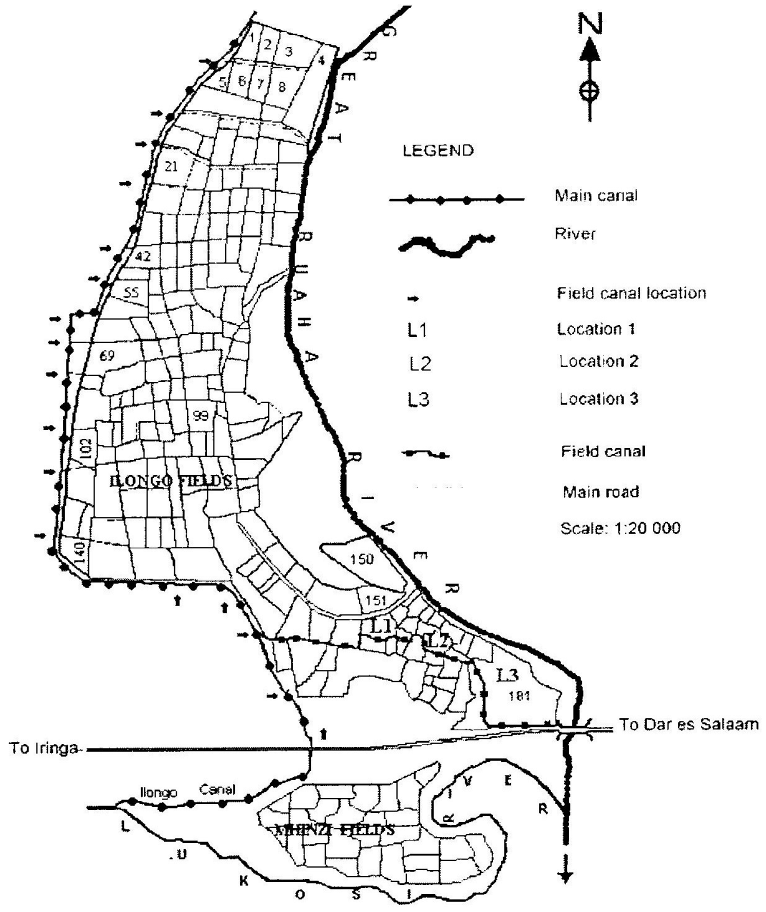

Figure 2: Canal and field layout of Ruaha-Mbuyuni irrigation scheme

weeding and harvesting were done manually. The seedlings were transplanted at a spacing of 10 cm x 10 cm. Water was applied at an interval of seven days during the first and second stages of crop development i.e. 1 - 65 days followed by an interval of 14 days during the third and fourth stages i.e. 66 - 95 days. Irrigation was stopped two weeks prior to harvesting. Other cultural practices were applied as per recommendations.

Crop performance was assessed by yield per unit area (tonnes per hectare) and water utilization efficiency (Ey) or specific yield (yield per unit volume of water used) (kg/m^3). Yield was determined by weighing the harvested bulbs in each basin while water utilization efficiency was calculated from the yield and volume of water used in each basin.

Data analysis

Statistical analyses were carried out using available statistical computer packages in order to determine the significance of the measurements taken and derive relationships between different variables. Specifically, analysis of variance (ANOVA), Duncan's multiple range test, correlation, simple linear regression analysis and Chi-squared tests were performed on the data collected.

RESULTS AND DISCUSSION

Table 2 shows the mean basic infiltration rate and saturated hydraulic conductivity (K_S) measured from three locations and their corresponding soil texture while Figures 3 and 4 show the variation of basic infiltration rate and saturated hydraulic conductivity over the season respectively. Appendices 1 and 2 show the spatial and temporal variation of basic infiltration rate and saturated hydraulic conductivity over the season respectively.

The infiltration rate and hydraulic conductivity varied significantly between locations (Table 2). According to Bai (1979) as cited by Landon (1991), the basic infiltration rate can be rated as moderately rapid, moderate and slow for sandy loam, sandy clay loam and clay soils respectively while saturated hydraulic conductivity is moderately low for sandy loam and sandy clay loam and very low in clay soils. The infiltration rate ranges in all soils are within acceptable values for surface irrigation (3 to 65 mm/h) (Landon, 1991).

Table 1: Methods for determination of hydraulic, physical and chemical properties of soil and water samples

Hydraulic/Physical/Chemical property	Method
Soil bulk density	Core method (Blake and Hartge, 1986)
Particle size distribution	Pipette method (Gee and Bauder, 1986)
Electrical conductivity of soil extracts and water samples	Temperature compensating conductivity meter (Rhoades, 1972)
PH of soil and water	Electrometric method (MacLean, 1982)
xchangeable bases (Na^+, Ca^{2+}, mg^{2+}) for soil and water samples	Ammonium acetate method (Thomas, 1982)
Soil organic carbon	Walkley and Black method (Nelson and Sommers, 1982)
Soil organic matter	Obtained by multiplying organic carbon by a factor of 1.742 (Nelson and Sommers, 1982)
Sodium adsorption ratio (SAR)	Equation given by Ayers and Westcot (1989)
Infiltration rate	Double ring infiltrometer method (Musgrave and Holtan, 1964)
Saturated hydraulic conductivity	Inverted auger hole method (Landon, 1991; Smedema and Rycroft, 1983)
Sediment concentration in irrigation water	Method by Lundekvan and SkΘien (1998)

Basic infiltration rate and saturated hydraulic conductivity decreased by 50 and 55% on average respectively over the season. This trend was similar in all locations (Figures 3 and 4). There was a high correlation (R = 0.92, 0.94 and 0.85 for location 1, 2, and 3 respectively) between basic infiltration rate and saturated hydraulic conductivity. In fact, if the soil profile is homogeneous and structurally stable, the basic infiltration rate or steady-state infiltrability is practically equal to the saturated hydraulic conductivity (Hillel, 1980). The soils of the study area had low aggregate stability due to low organic matter content (3.1%) (Appendix 5). Heil, *et al.* (1997) observed that a soil with low organic matter (<5%) contains aggregates which are relatively unstable and can not withstand the dispersion effect when water is applied. This low aggregate stability could be one of the factors which contributed to the observed decreasing trend

Table 2: Infiltration rate and saturated hydraulic conductivity for different locations

Location	Mean basic infiltration rate (mm/h)	Mean K_s (mm/h)	Textural class
1	52.5 a	17.7 a	SL
2	36.0 b	15.2 a	SCL
3	3.75 c	1.3 b	C

Note: *SL = Sand loam; SCL = Sand clay loam; C = Clay*
Means followed by the same letter are not significantly different at P<0.05

Table 3: Correlation between soil particle proportions and infiltration rate and K_s

Hydraulic property	Correlation coefficient	
	% Sand	%Clay
Basic infiltration (mm/h)	0.9998	-0.9958
Saturated hydraulic conductivity (mm/h)	0.9837	-0.9942

in infiltration rate and hydraulic conductivity with time throughout the season in all locations (Figures 3 and 4). Dispersed soils usually have low permeability, they tend to shrink, crack and become hard on drying and plastic on wetting (Michael, 1978)

According to Smedema and Rycroft (1983), infiltration rate and hydraulic conductivity under saturated conditions are well correlated with soil texture and structure. Size and configuration of soil particles determine how much water can enter and flow through the matrix. Soils in location 1 and 2 are coarser than those in location 3 and hence the observed differences in basic infiltration rate and saturated hydraulic conductivity. This is further supported by the correlation between soil particle proportions and either the basic infiltration rate or saturated hydraulic conductivity (Table 3). These results agree with the findings of McNean *et al.* (1982) and Tarimo (1995).

The mean bulk density ranging from 1.28 to 1.51 g/cm^3 across locations is considered suitable for agricultural production (Landon, 1991). The observed differences in bulk density between locations are due to differences in soil texture. Soils which have high percentages of sand, had the highest bulk density as compared to soils which are dominated by clay. According to Musgrave and Holtan (1964), soils with high percentage of clay have low bulk density, low infiltration rate and low hydraulic conductivity. Bulk density is also associated with organic matter content - the higher the organic matter content the lower the bulk density (Uriyo *et al.*, 1979). The increase of bulk density with depth as observed in all the locations could be attributed to a decrease in organic matter content and compaction of soil at lower depths (Hatibu *et al.*, 1995; Mahoo, 1992).

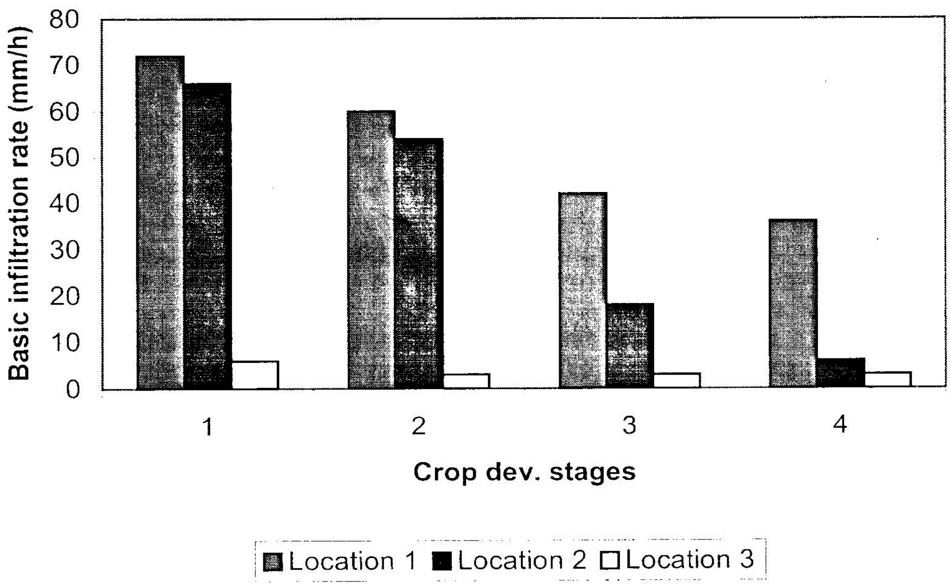

Figure 3: Basic infiltration rate at different stages of crop development

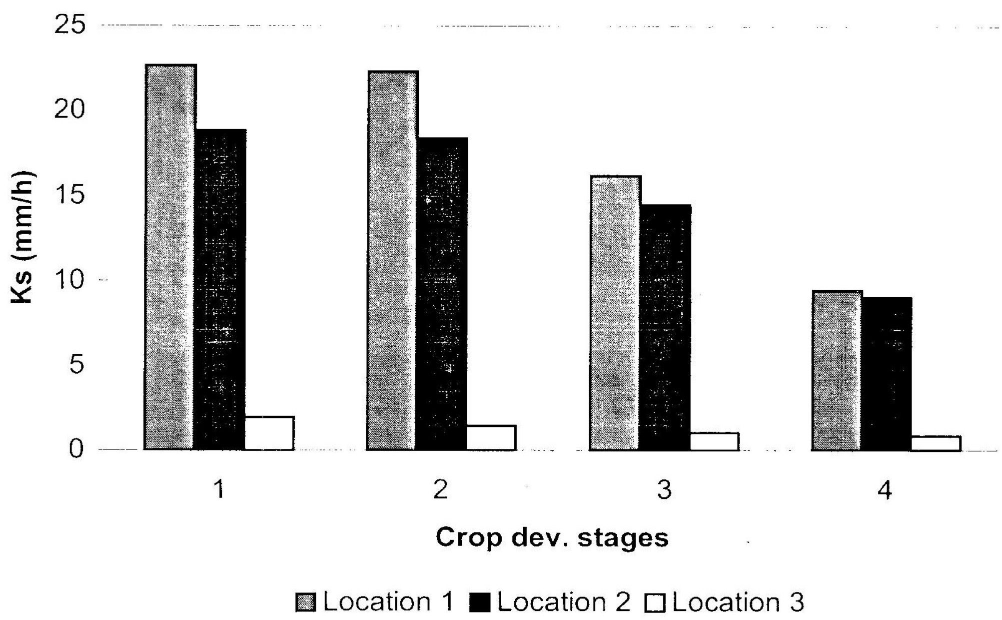

Figure 4: Saturated hydraulic conductivity at different stages of crop development

The observed difference in bulk density before field operations (mean of 1.35 g/cm^3) and after field operations (mean of 1.41 g/cm^3) can also be attributed to compaction of the soil. Similar results have been observed by Kayombo and Lal (1993) and Hatibu *et al.* (1995).

By definition, water quality refers to the characteristics of a water supply that will influence its suitability for a specific use. In irrigation water evaluation, emphasis is placed on the chemical and physical characteristics of the water and only rarely are other factors considered important (Ayers and Westcot, 1985). The electrical conductivity of irrigation water (EC_w) ranged from 0.9 dS/m to 1.5 dS/m while sodium adsorption ratio (SAR) ranged from 4.0 to 7.7. The detailed spatial and temporal variation of ECw, SAR and other chemical elements over the season are shown in Appendix 3. According to the guidelines for interpretation of water quality for irrigation (Ayers and Westcot, 1985), this water poses no or only slight permeability problems (Figure 5) although the level of salinity may affect crop water availability in the long run. It was also noted that the EC_w tended to increase over the season. The cause for such a trend is unclear but could probably be due to leaching of soils in the catchment area with the leachate appearing later as subsurface flow containing higher concentrations of salt.

The concentration of the suspended sediments ranged from 0.41 to 16.21 g/l over the season with mean values of 6.0, 6.6 and 7.0 g/l for location 1, 2 and 3 respectively. When the mean irrigation water applied for the same locations of 425.7, 638.6 and 538 mm is considered, it shows that a total of about 25.5, 42.2 and 37.7 t/ha of sediment were deposited over the season in the respective locations. Such amounts are relatively high and due to the fineness of the suspended sediments, sealing of the water conducting pores is inevitable. This would appear to be one of the main reasons for the observed decrease in infiltration rate and saturated hydraulic conductivity over the season in all the locations (Figure 3 and 4) as salinity and SAR levels of the irrigation water are such that permeability is not seriously impaired.

Ayers and Westcot (1985) observed a reduction in permeability and soil surface crusting when irrigation water of rich sediments was applied. Abu-Sharar and Salameh (1995) reported a 15% decrease in infiltration rate and 20% decrease in hydraulic conductivity when turbid water of 0.07% fine soil particles was used. On the other

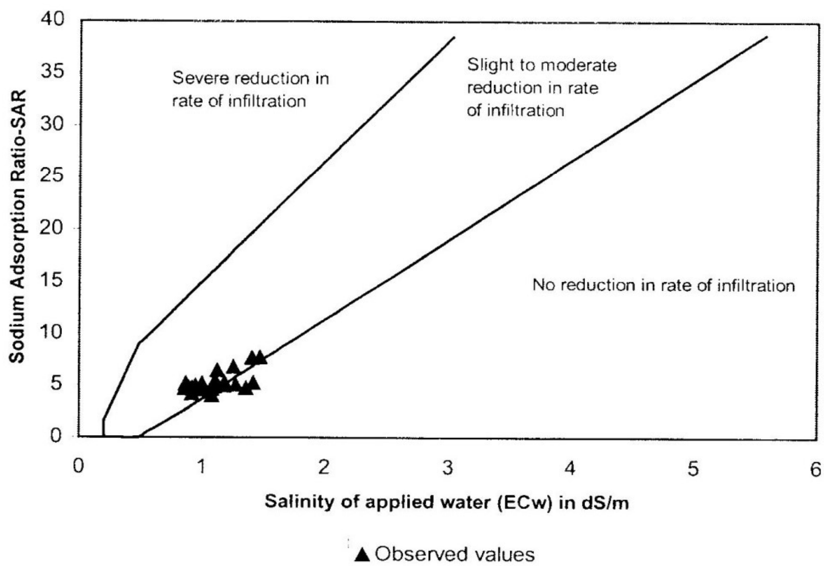

Figure 5: Effect of ECw and SAR on infiltration rate and hydraulic conductivity

hand, a reduction in cumulative infiltration of 50% due to surface sealing caused by irrigation water was reported by Trout (1991).

The variation of suspended sediments with time is shown in Figure 6 and Appendix 4. At the beginning of the season, the sediment load is considerably higher than towards the end of the season. This could be attributed to the fact that at the beginning of the season, surface runoff dominates the river flow. Surface runoff especially from degraded catchments contains large amounts of soil surface materials including fine soil

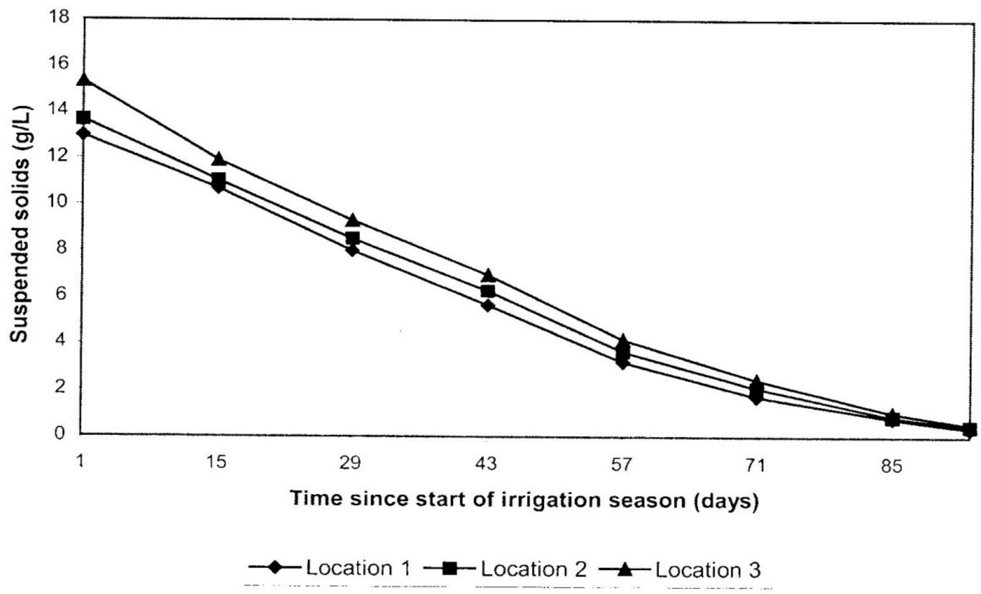

Figure 6: Variation of suspended sediments with time

Table 4: Crop yield

Location	Yield (t/ha)	Specific yield (kg/m^3)
1	13.270 c	3.11 b
2	31.295 a	4.98 a
3	26.845 b	5.05 a

Note: *Means followed by the same letter are not significantly different at P<0.05.*

particles, which are easily eroded (Linsley *et al.*, 1988). After the rainy season, river flow is dominated by subsurface flow and groundwater runoff which contain little amount of suspended materials (Linsley *et al.*, 1988; Oad and Levine, 1985).

The mean crop yields from all locations were low (Table 4) compared to the optimal range of 35 to 45 t/ha (Doorenbos and Kassam, 1979). The crop yield differed significantly (P<0.05) between locations. The observed variation of yield between locations can be attributed to differences in soil properties, infiltration rate and saturated hydraulic conductivity. The soils in location one are coarse, while location two are medium textured soils and location three soils are fine textured (Table 2). An onion crop requires a medium textured soil which has moderate infiltration rate and hydraulic conductivity for optimum yields (Landon, 1991; Ayers and Westcot, 1985). Thus soils in location 2 which had moderate infiltration rate and hydraulic conductivity were more favourable for onion production.

The observed mean specific yields, which ranged from 3.11 to 5.05 kg/m^3 were generally lower than the normal range of 8 to 10 kg/m^3 (Doorenbos and Kassam, 1979). Location 1 had significantly lower (P< 0.05) specific yield compared to locations 2 and 3 (Table 4). This implies that most of the applied water was not used by the crop. The variation of specific yield between locations is possibly due to differences in water retention capacities of the different soil types. Location 3 soils had a better water retention capacity due to relatively high clay content and showed higher specific yield while location 1, having the lowest amount of clay content, and hence low water retention capacity had the lowest water utilization efficiency.

CONCLUSIONS

The soil physical and hydraulic properties of the study area vary with the season. However, the quality of the Lukosi river water in terms of chemical composition is within acceptable standards. The only reason for the observed decrease in basic infiltration rate and saturated hydraulic conductivity over the season seems to be due to the sealing effect of the suspended sediments in the irrigation water, a fact that is exacerbated by the poor structural stability of the soils in the area. Hence the observed low yields and water utilization efficiencies are a reflection of an inherent soil and water management problem in the area as well as the catchment in general. In order to redress the situation, steps need to be taken to improve the organic matter content of the soil and arrest the degradation process of the catchment.

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REFERENCES

1. Abu- Sharar, T.M. and A.S. Salameh, *Reduction in hydraulic conductivity and infiltration rate in relation to aggregate stability and irrigation water turbidity*. Journal of Agricultural Water Management, Vol 29, pp 53 – 62, 1995.
2. Ayers, R.S. and W.D. Westcot, *Water Quality for Agriculture. FAO Irrigation and Drainage*

Paper No. 29 Rev. 1. FAO, Rome, pp 174, 1985.

3. Blake, G.R. and K.H. Hartge, *Bulk density*. In: Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods (Ed. Klute, A.). American Society of Agronomy Inc./Soil Science Society of America Inc., Madison. pp 363-375, 1996.

4. Doorenbos, J. and A.H. Kassam, *Yield Response to Water*. FAO Irrigation and Drainage paper No. 33. FAO, Rome, pp 174, 1979.

5. Eisenhauer, D., D.F. Heermam, and A. Klute, *Surface sealing effects on Infiltration with surface Irrigation*. Journal of Irrigation Engineering Vol. 35 No.6, pp1799 – 1807, 1992.

6. Foroud, N., E. S. George, and T. Entz, *Determination of infiltration rate from border irrigation advance and recession trajectories*. Journal of Agricultural Water Management Vol. 30, pp133-142, 1996.

7. Gee, G.W. and J.W. Bauder, *Particle size analysis*. In: Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods (Ed. Klute, A.). American Society of Agronomy Inc./Soil Science Society of America, Madison. pp 383 – 409, 1986.

8. Hatibu, N., H.F. Mahoo, B. Kayombo, E. Mbiha, E.M. Senkondo, D. Mwaseba, and D.A. Ussiri, *Soil-Water Management in Semi-Arid Tanzania*. Final Technical Report. Sokoine University of Agriculture, Morogoro, Tanzania, pp 87, 1995.

9. Hatibu, N., H.F. Mahoo, B. Kayombo, and O. Mzirai, *Evaluation and Promotion of Rain Water Harvesting in Semi-arid Areas of Tanzania*. Final Technical Report. Sokoine University of Agriculture, Morogoro, Tanzania, pp 74, 1997.

10. Heil, J.W., A.S.R. Juo, and K. J. McInnes, *Soil properties influencing surface sealing of some sandy soils*. Journal of Soil Science Vol.162, pp 459 – 469, 1997.

11. Hillel, D., *Applications of Soil Physics*. Academic Press, New York, pp 385, 1980.

12. Kay, M., *Recent developments for improving water management in surface and overhead irrigation*. Agricultural Water Management, Vol. 17, pp 7 – 23, 1990.

13. Kayombo, B and R. Lal, *Tillage Systems and Soil Compaction in Africa*. Soil and Tillage Research. Vol. 27, pp 35 – 72, 1993.

14. Landon, J. R. (Ed.), Booker *Tropical Soil Manual*: A hand book for soil survey and agricultural land evaluation in the tropics and subtropics. Longman Scientific and Technical. Essex. pp 474, 1991.

15. Linsley, R. K., M. A. Kohler, and J. L. H. Paulhus, *Hydrology for Engineers*. McGraw-Hill Book Company, London. pp 492, 1988.

16. Lundekvan, H and S. SkΘien, *Soil Erosion in Norway. An overview of measurements from soil loss plots*. An International Journal of British Society of Soil Science, Vol. 14 No. 2, pp122, 1998.

17. Mahoo, H., *Deforestation of a Tropical Humid Rainforest and Resulting Effects on Soil Properties, Surface and Subsurface Flow, Water Quality and Crop Evapotranspiration*. Ph.D Thesis, Sokoine University of Agriculture, Morogoro, Tanzania. pp 227, 1992.

18. McLean, E.O., *Soil pH and lime requirement*. In: Methods of Soil Analysis, Part 2: Chemical and microbiological properties. (Eds. Page, A.L., Miller, R.H. and Keeney, D.R.). American Society of Agronomy Inc./Soil Science Society of America Inc., Madison. pp 199 – 224, 1982.

19. McNean, B. L., G. J. Hoffman, and N.T. Coleman, *Effect of soil texture on hydraulic conductivity*. Soil Science Society of America Proc. Vol. 30, pp 308 –312, 1982.

20. Michael, A.M., *Irrigation: Theory and practice*. Vikas Publishing House PVT Ltd. New Delhi. pp 801, 1978.

21. Musgrave, G.W., and H.N. Holtan, *Infiltration*. In: Handbook of Applied Hydrology: A compendium of water-resources technology. (Ed. Chow, V.T.). McGraw-Hill publishing company. New York, Section 12, 1964.

22. Nelson, D.W. and L.E. Sommers, *Total carbon, organic carbon and organic matter*. In: Methods of Soil Analysis, Part 2: Chemical and microbiological properties. (Eds. Page, A.L., Miller, R.H. and Keeney, D.R.). American Society of Agronomy Inc./Soil Science Society of America Inc., Madison. pp 539-579, 1982.

23. Oad, R. and G. Levin, *Distribution of water in Indonesian irrigation systems*. Transactions of ASAE Vol. 28 No.3-4, pp 1166-1172, 1985.

24. Rhoades, J.D., *Quality of water for irrigation*. Journal of Soil Science Vol. 113, pp 277 – 284, 1972.

25. Smedema, L.R. and D.W. Rycroft, *Land Drainage: Planning and design of agricultural drainage systems*. B.T. Batsford Ltd. London. pp 376, 1983.

26. Tarimo, J.E.R., *Soils of Mtibwa Sugar Estate: Some physical and chemical properties and their effect on crop performance under sprinkler irrigation*. M.Sc. Dissertation, Sokoine University of Agriculture, Morogoro, Tanzania. pp 9 – 20, 1995.

27. Thomas, G. W., *Exchangeable cations*. In: Methods of Soil Analysis, Part 2: Chemical and microbiological properties. (Eds. Page, A.L., Miller, R.H. and Keeney, D.R.). American Society of Agronomy Inc./Soil Science Society of America Inc., Madison. pp 159-165, 1982.

28. TIP, *Mahenge Division Traditional Irrigation Improvement Programme*. Annual Report. Iringa, Tanzania, 1991.

29. TIP, *Irrigation between the baobabs. Inventory study of Mbuyuni irrigation system*. pp 43, 1992.

30. Trout, T.J., *Surface seal influence on surge flow furrow infiltration*. Journal of Irrigation Engineering Vol. 34, pp 66 – 71, 1991.

31. Uriyo, A.P., H.O. Mongi, Chowdhury, B.R. Singh, and J.M.R. Semoka, *Introduction to Soil Science*. Tanzania Publishing House. Dar es Salaam. pp 232, 1979.

Appendix 1: Infiltration rate measurements

Location number	Stage of crop development	Measuring dates	Basic infiltration rate (mm/h)	Mean values for each stage of crop development
		13/04/99	84	
	1	25/04/99	72	72
		27/04/99	60	
		11/05/99	60	
	2	16/05/99	60	60
1		25/05/99	60	
		08/06/99	60	
		20/06/99	48	42
	3	26/06/99	36	
	4	10/07/99	36	36
		12/04/99	78	
	1	26/04/99	60	66
		02/05/99	60	
	2	10/05/99	60	
2		23/05/99	60	54
		07/06/99	42	
	3	21/06/99	18	18
		05/07/99	18	
	4	13/7/99	6	6
		11/04/99	6	
	1	25/04/99	6	6
		01/05/99	6	
		09/05/99	3	
3	2	27/05/99	3	3
		06/06/99	3	
	3	20/06/99	3	3
		04/07/99	3	
	4	17/07/99	3	3

Appendix 2: Saturated hydraulic conductivity measurements

Location number	Stage of crop development	Measuring dates	Saturated hydraulic conductivity (mm/h)	Mean values for each stage of crop development
		13/04/99	22.8	22.7
	1	27/04/99	22.6	
		11/05/99	22.6	
	2	25/05/99	22.5	22.3
		08/06/99	21.9	
1	3	26/06/99	16.2	16.2
	4	10/07/99	9.4	9.4
		12/04/99	19.2	18.9
	1	26/04/99	18.5	
	2	10/05/99	18.5	18.4
		23/05/99	18.4	
2		05/06/99	18.3	
	3	21/06/99	14.5	14.5
	4	13/7/99	9.0	9.0
	1	11/04/99	1.9	1.9
	2	09/05/99	1.4	1.4
	3	20/06/99	1.0	1.0
3	4	17/07/99	0.8	0.8

Appendix 3: Chemical analysis of irrigation water

Location number	Date	ECw (dS/m)	Ca^{2+} (me/l)	Mg^{2+} (me/l)	Na^{+} (me/l)	K^{+} (me/l)	PH	SAR (me/l)
1	13/04/99	0.86	3.42	2.63	8.12	2.21	8.04	4.67
	27/04/99	0.92	4.14	1.78	7.23	0.70	7.94	4.20
	11/05/99	1.08	4.35	2.16	7.24	0.95	7.82	4.01
	25/05/99	0.87	4.65	2.76	9.93	1.25	7.68	5.16
	08/06/99	0.95	3.50	2.67	8.73	1.00	7.64	4.97
	26/06/99	1.13	4.68	3.03	12.65	1.36	7.38	6.45
	10/07/99	1.18	4.72	2.89	10.28	1.37	7.30	5.27
2	12/04/99	0.89	2.50	2.48	7.67	0.45	8.06	4.86
	26/04/99	1.08	3.44	2.02	7.67	1.21	7.92	4.65
	10/05/99	1.08	3.50	2.23	8.17	1.21	7.86	4.83
	23/05/99	0.99	3.35	2.64	7.89	1.10	7.84	4.56
	07/06/99	1.00	3.52	2.89	9.23	1.03	7.80	5.16
	21/06/99	1.18	4.72	3.10	9.79	0.99	7.50	4.95
	05/07/99	1.26	3.96	3.20	12.80	1.29	7.32	6.77
	13/07/99	1.42	4.85	2.97	10.33	1.37	7.30	5.22
3	11/04/99	0.92	2.75	3.04	8.18	1.20	7.96	4.81
	25/04/99	1.09	3.32	2.88	9.00	1.21	7.94	5.12
	09/05/99	1.10	3.37	2.83	8.56	1.21	7.90	4.87
	27/05/99	1.12	4.62	3.12	10.29	1.36	7.85	5.23
	06/06/99	1.28	4.85	3.03	10.02	1.46	7.62	5.05
	20/06/99	1.36	5.38	3.44	9.92	0.88	7.48	4.73
	04/07/99	1.41	5.20	3.23	15.72	1.32	7.31	7.66
	12/07/99	1.48	5.75	3.03	16.10	1.40	7.30	7.69

Appendix 4: Suspended sediment load in the irrigation water

Time since start of irrigation season (days)	Location 1 (g/l)	Location 2 (g/l)	Location 3 (g/l)
1	12.5	13.4	15.9
15	10.9	10.4	11.0
29	8.2	10.7	10.5
43	7.2	7.5	8.9
57	6.7	8.0	6.7
71	1.3	1.5	1.6
85	0.9	1.0	1.0
93	0.4	0.5	0.6
Total	48.1	53	56.2
Mean	6.0	6.6	7.0

Appendix 5: Variation of organic matter content and soil texture in the three locations

Location	Site	Depth (cm)	Organic matter content (%)	Soil texture	Mean textural class per location (%)	Mean organic matter content per location (%)	Mean basic infiltration rate per location (mm/h)
1	1	0 - 15	1.05	SL			
		15 - 30	0.05	SCL			
	2	0 - 15	2.65	SCL	SL	1.13	52.5
		15 - 30	0.29	SCL			
	3	0 - 15	2.22	L			
		15 - 30	0.52	SL			
2	1	0 - 15	2.89	SCL			
		15 - 30	0.52	SL			
	2	0 - 15	3.51	SCL	SCL	2.09	36.0
		15 - 30	0.89	SCL			
	3	0 - 15	3.41	CL			
		15 - 30	1.32	C			
3	1	0 - 15	4.64	C			
		15 - 30	1.57	C			
	2	0 - 15	3.97	C	C	3.05	3.75
		15 - 30	0.33	C			
	3	0 - 15	4.68	C			
		15 - 30	3.13	C			

Note: SCL = Sandy Clay Loam, SL = Sandy Loam, C = Clay, L = Loam