International Journal of Sciences: Basic and Applied Research (IJSBAR)

ISSN 2307-4531
(Print & Online)

http://gssrr.org/index.php?journal=JournalOfBasicAndApplied

Assessment of Low-head Drip Irrigation Systems Uniformity of Application

Samwel Odoyo Opar[a]*, Francis Gichuki[b], Stephen Conrad Ondieki[c]

[a]Department of Environmental and Biosystems Engineering, University of Nairobi P.O Box 30197, Nairobi 00100, Kenya

[b]Department of Environmental and Biosystems Engineering, University of Nairobi P.O Box 30197, Nairobi 00100, Kenya.

[c]Department of Environmental and Biosystems Engineering, University of Nairobi P.O Box 30197, Nairobi 00100, Kenya

[a]Email: odopar@yahoo.com

[b]Email: gichukifrancis@gmail.com

[c]Email: scondieki@uonbi.ac.com

Abstract

Water application uniformity (EU) is an important performance criterion that must be considered in the design, operation and management of irrigation systems for increasing agricultural productivity. This research study was as a result of the previous studies done by [5,6,7], which reported about poor/non-uniformity of water application by low-head drip irrigation systems. The study identified systems widely adopted by the smallholder farmers alongside low-cost green housing technology, categorized them based on layout configuration, height of water tank, lateral length, type, size and number of emitters and assessed their water application uniformities as recommended by the American Society of Agricultural Engineers (ASAE) Standards of 2003 using ASAE standards 1996(a) performance rating. This was done in order to compare their performances and diagnose constraints to enhance agricultural productivity.

---

* Corresponding author.

E-mail address: odopar@yahoo.com.

This research was done in Trans Nzoia West Sub-County, Kenya. Four replications of each category in operation were selected by simple random sampling and water discharges filling a 10 ml cup (medicine dispenser) were timed from each of the thirty sampled emitters of each system. The data collected was processed and statistically analyzed to determine the sample mean, the confidence interval for the single mean and tested for significance difference between the sample mean of EU for the categorized systems. The result obtained together with the information gathered through semi-structured interviews was used in the conclusions of the report.

The result from this study showed that uniformity of water application performance rating for common low-head drip irrigation systems are marginally fair (71%) on average except for the two categories with double emitters whose performances are not acceptable (< 60%). Choice of designs having fair or good water application uniformity coupled with proper installation and management is needed for the enhancement of agricultural productivity. The categories whose performance ratings are not acceptable should not be promoted by extension providers and are recommended for further hydraulic uniformity test.

Keywords: Drip irrigation systems; Low-head; Water application uniformity.

1. Introduction

Drip/trickle/micro irrigation is the application of water at a slow, controlled rate to plant root zones through emitters spaced at pre-determined intervals. The emitters are normally spaced at intervals of 15, 20, 30, 45 and 60 cm along the laterals. The author in [1] recorded that line-source emitter spacing of 30 cm for close growing crops is most common. The water supply is done through a set of interacting components forming an integrated whole referred to as a system. In agriculture, irrigation is done for the purpose of achieving increased agricultural productivity (quality and yield improvement). For low-head drip irrigation systems, water pressure is created by raising the supply container or connecting the drip system to a low pressured water supply. Compared to other irrigation systems, the authors in [2] found that drip irrigation has the highest efficiency (90 to 95%) and is the obvious choice for crop production in areas with little rainfall or scarce water.

The authors in [3] noted that water application uniformity (EU) is an important performance criterion that must be considered during the design and evaluation of irrigation system recommended by ASAE Standards of 2003. It is a measure of how evenly the volumes of water are applied. An efficient drip irrigation system should apply/emit water uniformly along a drip line/tape (dripper). Drip tapes, unlike drip lines have thin walls. Low emission uniformity leads to either over irrigation and or under irrigation along different sections of the laterals. The authors in [4] found that EU equal to 90 percent are typically used for new system design and could be designed for values up to 95 percent, but field topography can cause the design values to be as low as 75 percent.

The introduction of low pressure drip lines/tapes in the market coupled with green housing technology and their combined attractive attributes has led to widespread adoption of low-head/cost drip irrigation systems by the smallholder farmers. Emphasis is being put on their use as a way of increasing agricultural production and attaining food sufficiency. Despite the high rate of adoption, the authors in [5, 6] some portions of drip irrigation systems receive little or no water discharges leading to poor crop yields. Due to non-uniformity in water application plants are either over or under-irrigated. The authors in [7] found that lack of knowledge by farmers on amount of water to apply, uneven water distribution, bias by technical staff to crop extension rather than irrigation are major constraints. The study recommended further research to address the technical constraints pertaining to the adoption and use of low cost drip irrigation technology in order to enhance agricultural productivity. The author in [8] concluded that the combined effects of water head, land slope and lateral length affect the performance of low-head drip irrigation systems. The uniformity of water application from micro irrigation system is affected both by the water pressure distribution in the pipe network and by the hydraulic properties of the emitters used. There are three useful tests recommended by authors in [9] to evaluate the performance of drip irrigation system: (1) overall water application uniformity, (2) hydraulic uniformity or pressure variation, and (3) emitter performance variation. These tests should be performed in the order indicated because, if the overall water application uniformity is high, there is no need for further tests. In evaluating the EU, the two most important variables in consideration are a measure of the flow rate and pressure. The equations which have been used by authors in [3, 8-11] in the evaluation of EU if the average discharge rate is chosen as a design parameter and flow variation (CV) in drip irrigation are as follows;

$$EU = (1 - 1.27CV)100Q_{min}/Q_{avg} \quad (1)$$

$$CV = 1 - Q_{min}/Q_{max} \quad (2)$$

Where Q_{max} = maximum average 1/6 of the number of emitter discharge

Q_{avg} = average of all sampled emitter discharge

Q_{min} = the minimum average 1/6 of the number of emitter discharge

CV = statistical coefficient of variation of emitter discharge.

The general performance evaluation criteria for EU values, adopted from author in [10], are > 90%, excellent; 80-90%, good; 70 - 80%, fair 60 - 70%, poor and < 60%, not acceptable. The general criteria for CV values recommended by author in [11] for line-source emitters are: ≤ 10%, good; 10 - 20%, average; and ≥ 20%, not acceptable. Since it is not easy to collect the discharge from all the emitters along the drip laterals, sampling of the data points is necessary for estimation of EU. The author in [9] recommended that to accurately determine uniformity, the data points should be made of a minimum of eighteen points located throughout the irrigation zone. More may be required for greater accuracy and computation is simplified if the number of points is measured as a multiple of six.

The purpose of this study was to assess water application uniformity of common low-head drip irrigation systems as a way of checking and comparing the level of performance and diagnosing constraints to help improve agricultural productivity. The scope of the study was concerned with identifying and selecting common low head drip irrigation systems in the farmers' fields, categorizing the systems, selecting replicates of each category, developing data point sampling pattern guide, sampling individual emitters (data points) and collecting data to obtain the flow rates for analysis. Also some information was obtained through semi-structured interviews.

2. Materials and Methods

2.1 Area of study

This research was conducted in Trans Nzoia West Sub-County of Trans Nzoia County, Kenya. The area is about 380 km North West of Nairobi and is agriculturally high potential. Many smallholder farmers in the area have adopted the use of low-head drip irrigation alongside low-cost green house farming technology.

2.2 Sampling design

Low-head drip irrigation system with lateral emitter spacing of 30 cm in operation in the smallholder farms were identified using a list drawn from the field by the help of agricultural extension officers. Categorization of the systems was done on the basis of layout configuration, height of water tank, lateral length, type, size and number of emitters. Six categories were obtained and coded as shown in table 1.

Table 1. Categorized low head drip irrigation systems

Description	T1	T2	T3	T4	T5	T6
Type of lateral	Drip line	Drip tape	Drip line	Drip tape	Drip tape	Drip tape
Size of lateral (mm)	8	16	8	16	16	16
Emitters per spacing	1	2	1	1	2	1
Length of lateral	15	15	12	30	30	22
Tank height (m).	1.5	2	1.5	2	2.5	2.5
Number of emitters	552	1104	888	1104	2208	1216
Layout reference in	Fig. 1	Fig. 1	Fig. 2	Fig. 1	Fig. 1	Fig. 3
Appendix B	(8mx15m)	(8x15)	(8x24)	(8x30)	(8x30)	(11x24)

Note: All categories have twelve laterals except T6 which has sixteen.

The experimental design was a completely randomized design and four replications of each categorized system were selected by simple random sampling. In every sample thirty individual emitters (data points), to increase accuracy, were sampled along the laterals using numbered marker pegs following the developed sampling pattern guide shown in fig. 1 below.

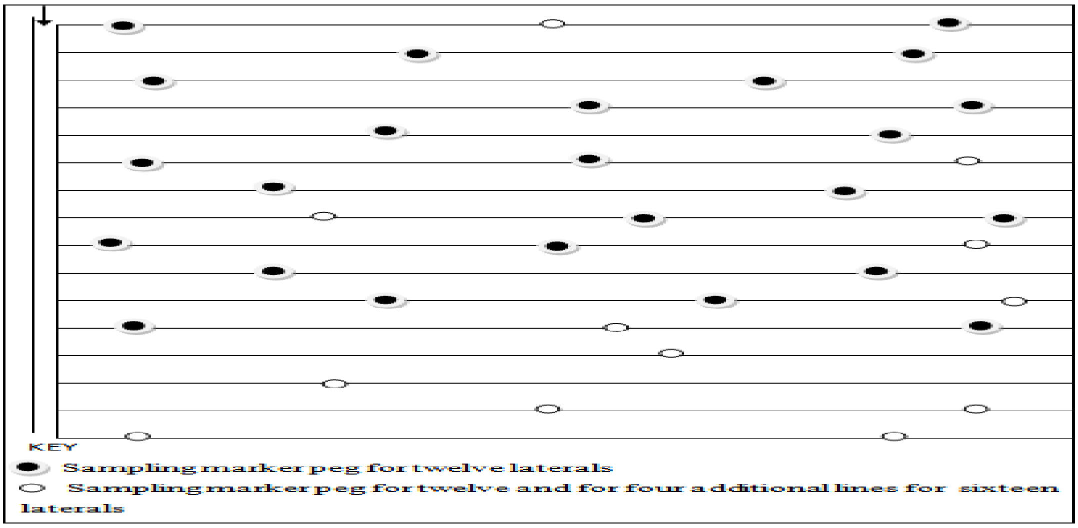

Fig. 1. Sampling pattern guide

The marker pegs were fixed in the sampled emission points without following any numbered order before turning on the system's water supply to avoid biasness. The first emitter in the direction of water flow was the data point for systems laterals with double emitters.

2.3 Data collection

This study involved timing the period, in seconds, taken by water discharges from sampled emitters of sampled systems to fill 10 ml catch cans (medicine dispensing cups) using a stop watch. Some primary information was obtained using informal semi-structured interviews listed in the data collection sheet in Appendix A. Data points were marked with numbered marker pegs using the guide for sampling pattern. The system's water supply was turned on and timing the period taken to fill a 10 ml cup with discharges from each sampled emitter using a stop watch started five minutes later. Any point which was completely blocked was recorded zero. To avoid over irrigation due to many data point, two assistants were trained and helped in data collection.

2.4 Data analysis

The recorded time taken to fill the 10 ml cup for every data point of each sampled system was arranged in ascending order using an excel spreadsheet. The outliers', the very smallest and longest time not consistent with the rest of the recorded time were left out. A period of thirty seconds time lag from the rest of consecutive ranked data was used to identify the outliers from the sampled points. With the help of spreadsheet, the average time and average flow rate (Q_{avg}), in milliliters per second, was calculated. The following steps were used to calculate the maximum and minimum discharges;

1. Calculated 1/6 of the number of emission data points measured i.e 30/6 = 5.
2. From the set of ordered data, the average time for the five slowest data points, leaving out the

outliers, was used to calculate the average minimum discharge (Q_{min}).

3. From the set of ordered data, the average time for the five fastest data points was used to calculate the average **maximum** discharge (Q_{max}).

The values obtained were used to calculate CV and finally EU using equation 2 and 1 respectively. The average EU for every treatment was used to assess the water application uniformity according to the ASAE performance standard criterion for line-source emitters. The EU was also statistically tested for significant difference between the samples means using a One-way ANOVA and the estimation of the confidence intervals at 95% level.

3. Results

The identified common low head/cost drip irrigation systems in the smallholder farms adopted alongside green housing technology are shown in table 1 above. Their design layouts are as illustrated in figs.4, 5 and 6 in appendix B. The summary of analyzed data and data used for statistical analysis are shown in tables 4 and 5 respectively in appendix C. The result for average values for CV and EU are as illustrated in fig. 2 below.

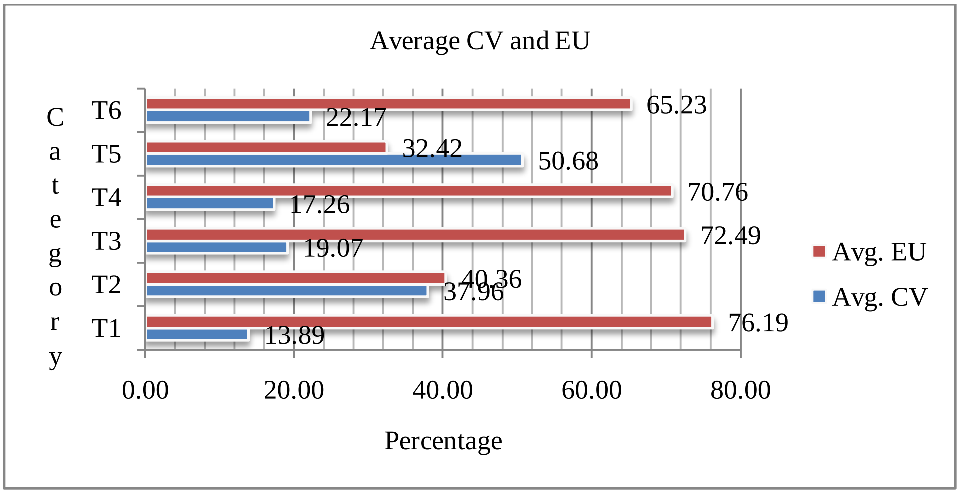

Fig. 2. Average CV and EU

Table 2. Assessment of EU based on ASAE standard criterion

Category	% CV	Performance	% EU	Performance
T1	13.89	Average	76.19	Fair
T2	37.96	Not acceptable	40.36	Not acceptable
T3	19.07	Average	72.49	Fair
T4	17.26	Average	70.76	Fair
T5	50.68	Not acceptable	32.42	Not acceptable
T6	22.17	Not acceptable	65.23	Poor

The table shows that low head drip irrigation system designs adopted by small scale farmers have either not acceptable, poor or fair water application uniformities.

Table 3. One-Way ANOVA

Source of variation	d.f	SS	MS	F-ratio	F-Table (5% level)
Treatment	5	6852.81	1370.56	44.51	(5,18) = 2.77
Error	18	554.19	30.79		
Total	23	7407			

The table shows that the calculated F-ratio >> F-table at 95% confidence interval.

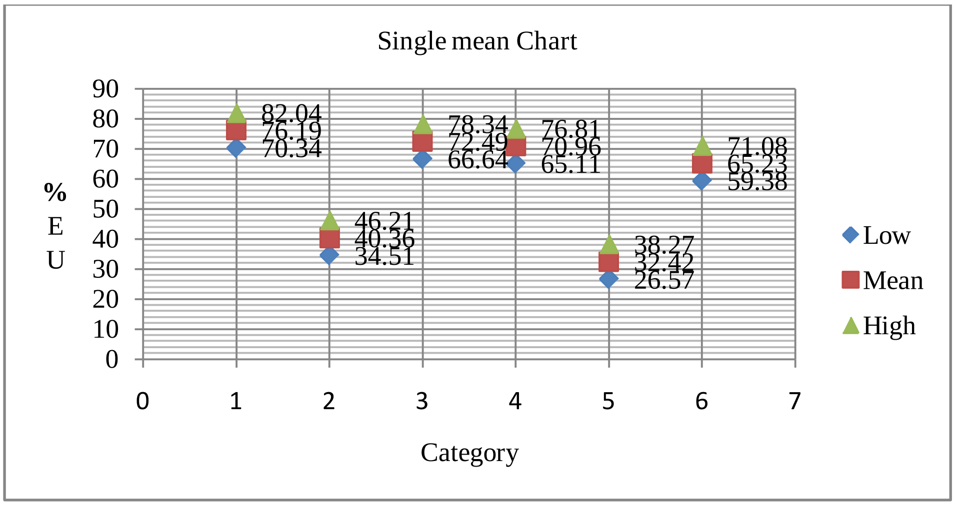

Fig. 3. Confidence interval for single mean

The figure shows that the upper limit for category T1 is in the good performance range. T2 and T5 with double emitters have very poor application uniformity.

4. Conclusion

This research identified six categories of low-head drip irrigation systems used in low-cost green houses in the field as shown in table 1. The result shows that T1, T3 and T4 have fair EU. T1 showed the best water application uniformity with the upper limit in the good performance range at the confidence interval of 95% shown in fig. 3. The performances of systems with double emitters per spacing on the laterals, T2 and T5, with increased total rate of water supply and probability of water discharges to plant root zones in case of clogging, are not acceptable. T1 and T2 are the same in length but differ in the number of emitters, type of lateral and water head. T1 and T3 have the same water head, size and type of lateral but different in layout and the number of emitters. Since their performances are almost the same, T3 has an advantage over T1 in terms of area or number of plants that can be raised. Even though T5 is at higher water head compared to T4, its performance rating is not acceptable. This is an indication that the performance of T2 and T5, with double emitters is attributed to poor hydraulics in the systems design. The poor performance of T6 (65.23%), even though is at a higher water head and shorter laterals compared to T4, is attributed to additional number of laterals for increasing the irrigated area.

A one-way analysis of variance procedure was used to statistically test whether there is a significant difference between the sample means at a confidence level of 95% as shown in table 3. Since the calculated F-ratio (44.51) is greater than the F-table (2.77), there is a significance difference between the sample means. Also, the calculated F-ratio is much larger than one (44.51 >> 1) which gives a clear indication of the location effects. The location effects is as a result of poor installation, differences of water depths in the tank at the time of running the tests, differences in field topography, aging of the systems and management levels.

The result from this study showed that uniformity of water application performance rating for common low-head drip irrigation systems are marginally fair (71%) on average except for the two categories with double emitters whose performances are not acceptable (< 60%). One category, T1, however has a performance rating with an upper limit in the good range (80 to 90%). Choice of designs having fair or good water application uniformity coupled with proper installation and management is needed for the enhancement of agricultural productivity. The two categories whose performance ratings are not acceptable should not be promoted by extension providers and are recommended for further hydraulic uniformity test.

While conducting the study, the major constraints/limitations encountered were variations in topography and water depths in the tank from one sample to the other for every category which resulted into the significant location effect. Also a conclusive performance comparison could not be made due to differences in water head, number of emitters per spacing and lateral sizes and lengths used for categorization.

Acknowledgements

We pay special tribute to Dr. C.T Omuto for helping in understanding research methodology and continuously following up on the progress of the study. We would also like to thank the Ministry of Agriculture (Directorate of Agricultural Engineering Services) for granting leave and financial support and Mr. Isaya V Sijali of Kenya Agricultural Research Institute (NARL) for providing valuable related study materials. Special thanks also go to all those who assisted us in the field.

References

[1] I.V Sijali. *Drip Irrigation: Options for smallholder farmers in Eastern and Southern Africa*. RELMA, Nairobi: In. Press, 2001, pp. 23.

[2] J. Keller and D. Karmeli. “Evaluation of a trickle irrigation system”, in *proceedings of the 2nd International Drip/Trickle Irrigation Congress*, 1974, pp. 287 -292.

[3] S. Jiang and Y. Kang, 2010. "Evaluation of micro irrigation Uniformity on laterals Considering Field Slopes**".** *Journal of Irrigation and Drainage Engineering*, Vol.136, pp. 429 –434, May, 2010.

[4] Westlands Water District (2001). "Irrigation System Evaluation". [on-line] Available: www.westlandswater.org/resources/wmh/evaluation pdf, [Jan. 8, 2013]

[5] C. Kabutha, H. Blank and B. Van Koppen . "Drip Kits for smallholders in Kenya; experience and the way forward", in *proceedings of the 6th International Micro-Irrigation Congress on "Micro-Irrigation Technology for Developing Agriculture*, 2000. Cape Town, South Africa.

[6] F.A Hassan. "Evaluation of emission uniformity for efficient micro- irrigation" Internet: www.trickle-l.com/new/archives/eeu.html [Dec. 17 2012].

[7] Z.A Nyakwara, D.W Kilambya and S.N Makokha. "Social-economic Evaluation of the Low Head Drip Irrigation Systems for Small-scale Farmers in Uasin Gishu District, Moiben Division" Presented at National Agricultural Research Laboratories, Nairobi, Kenya.

[8] S.N Ngigi, 2008. "Technical evaluation and development of low-head drip irrigation systems in Kenya". *Irrigation and Drainage*, vol. 57, pp. 450–462, Oct. 2008.

[9] A.G Smajstrla, B.J Boman, D.Z Haman, D.J Pitts, and F.S Zazueta . "Field Evaluation of Micro-irrigation Water Application Uniformity"**.** Internet: www.edis.ifas.ufl.edu/pdffiles/AE/AE09400.pdf. Jan. 15, 2012 [Dec. 4 2012].

[10] American Society of Agricultural Engineers (ASAE). "Field evaluation of micro irrigation systems". St. Joseph, Michigan. EP405.1, 1996a

[11] American Society of Agricultural Engineers. "Design and installation of micro irrigation systems". St. Joseph, Michigan. EP409, 1996b.

Appendices

Appendix A: Data collection sheet

Data point	Time in to fill 10 ml cup in seconds	Data point	Time in to fill 10 ml cup in seconds	Data point.	Time in to fill 10 ml cup in sec
1		11		21	
2		12		22	
3		13		23	
4		14		24	
5		15		25	
6		16		26	
7		17		27	
8		18		28	
9		19		29	
10		20		30	

Source of water …………………………………..

Size of drip line/tape ………

Layout of laterals are uphill/down slope/fairly flat ……………………

When were the system installed and/or laterals replaced? ....

Is there any observed area(s) receiving no/little/more water? ... Yes/No. If yes, what do you do to solve the problem? ....

Is filter in place? Yes/No. . If yes, how often is it cleaned? ………………………

Is there any leakage(s) in the system? …... . If yes, how do you solve the problem? …...............

Appendix B: Categorized design layouts.

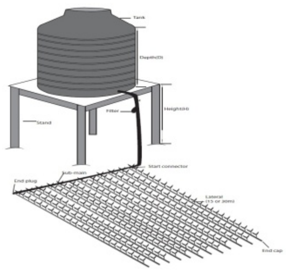

Fig. 4. Layout for T1, T2, T4 and T5 (Chapin)

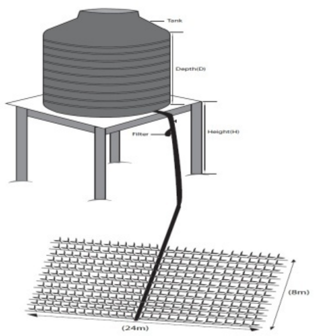

Fig. 5. Layout for T3 (Family)

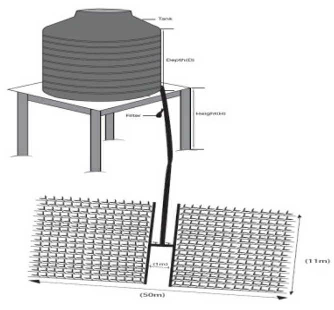

Fig. 6. Layout for T6 (Micro-Tal)

One sub unit represents the Micro-Tal systems layout

Appendix C: Analyzed data

Table 4. Summary of analyzed data

Attribute	T1	T2	T3	T4	T5	T6
Average %CV	13.6	37.96	19.07	17,26	50.68	22.17
Average % EU	76.19	40.36	72.49	70.76	32.42	65.23
Mean time (s)	41.42	68.95	42.75	56.32	55.08	50.18
Q_{avg} in ml/s	0.2424	0.1494	0.2346	0.1767	0.1817	0.2015
$Q_{avg.}$ in l/h	0.873	0.522	0.842	0.636	0.654	0.725

Conversion: Emitter flow rate in l/h.

- Emitter flow rate when x ml is discharged in t seconds to l/h ....*360/xt l/h*
- *ml/s to l/h* is .... *Q*3.6 l/h*; where Q is discharge rate in ml/s.

Table 5. EU values for one-way ANOVA

Sample	T1	T2	T3	T4	T5	T6	Total
1	66.44	35.06	68.20	75.85	32.66	64.47	342.68
2	82.38	52.91	74.79	70.07	33.68	67.58	381.41
3	81.34	42.28	72.04	68.12	35.02	61.06	359.86
4	74.61	31.19	74.91	70.19	28.32	67.80	347.02
Total	304.77	161.44	289.94	284.23	129.68	260.91	1430.97