Assessment of environmental and economic impacts of trickle irrigation system

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Abstract. The systems of trickle irrigation offer the potential influential irrigation to increase crop yields and have been proven reasonable according to the engineering and agricultural opinion particularly in barren areas. Trickle irrigation systems that have been offered comparatively lately in Arab countries have demonstrated to save huge amounts of water and enhance crop yield. The computational program (Trickle Irrigation System Design, TISD) connected with the economic procedures were used to research the environmental and economic conditions of the agriculture system. The conditions of environment comprised the type of soil, the topography of land, the climate areas, the water quantum and quality, and the dimensions of land. The conditions of economic included the interest rates of nominal and real, the principal price of land, and the rates of labor and energy escalation. The research deemed the ratio of B/C indicating the effects of environmental and economic parameters applying the system of trickle irrigation. The research presented the crop rotation of tomato-sesame as a line-source, and the point-source was represented by citrus trees. The research results revealed a significant impact on the ratio of B/C for the parameters; soil type, land topography, and water quality. The other parameters evidenced a variety impacts among considerable, small, and negligible on the B/C ratio. The study represents a worthy perception for institutional considerations in agricultural economics.

1. Introduction
The study in [1] has shown the importance of the efficacy of irrigation due to the increase of 50\% required for watering by 2025. The understanding for the economic and environmental site conditions is deemed for the systems of trickle irrigation. The studies in [2-11] revealed that in spite of these systems could be well designed environmentally, the lack of considering the economic conditions may conduct to a system deficiency. The selection of the system has been controlled centrally by the economic efficiency. The economic analysis is depending on two general categories, site and system [3]. The economic factors of the site implicate; rate of interest, costs of labor, costs of energy, inflation of energy, taxes for equipment, costs of water, value of land, and the return for each crop. The rate of interests could be classified into nominal or real. The nominal rate is considering the current rate providing the inflationary and interest components. The real rate is nearly considering free of inflation which is used to define the expenditures of capital. Further, the system factors implicate; costs of components of system; life of components of system, costs of labor, costs of energy and maintenance. The study in [12] comprised the economic effects of drip method of irrigation (DMI) on planting of sugarcane. The cultivation cost was operationally decreased in weeding, intercultural and labor cost of irrigation. The
B/C ratio without subsidy condition ranged from 1.98 to 2.02 while it ranged from 2.07 to 2.10 for 30% subsidy. Zero sales tax measures have been proposed to reduce the drip set cost. The experimental study in [13] revealed the effect of planting, quality and economic return on guava yield under DMI. The guava had been planted at 6x6m (I) and 5x5m (II). The yield outcomes in (II) was greater than in (I) over the years of planting. The effect of salt on soil physical, chemical, and biological characteristics with maize cropping was investigated in [14] under DMI. The results revealed an enhancement in soil environment and nutrients state. The study in [15] inspected the soil effect and climate changes on consumption of a subsurface drip irrigation (SDI) for cropping tomatoes and peppers using sensors. The measurements of climate parameters were registered by two weather stations. The evapotranspiration was estimated using a software. The outcomes demonstrated a considerable raise in crop yield when using SDI system rather than the normal DMI. Another study for cropping pattern under DMI [16] has a significant effect in resource savings, cultivation cost, yield profitability of crops and farm. Furthermore the study of cropping several vegetables and fruits using the DMI with the solar aid [17] has been investigated. The results showed the B/C was high for solar powered drip system. The research presented in [18] pursued to evaluate the technical and feasibility of irrigation systems that rely on pumping solar and wind energy. The research, first, used the program CROPWAT to evaluate two types of crops (common and fruit cash). The study considered three types of pumping systems (solar, wind, and diesel). The study compared the costs of three irrigation systems (surface, sprinkler and drip). The economic analysis deemed the B/C ratio through twenty years. The study demonstrated the windmills were the best solution and the solar came in the second position. The study in [19] investigated the climate impact on the production of tomato using the DMI. The climate changes considered three different levels of combinations (50, 75, and 100% of the water needed for the crop) and two types of mulches (black polyethylene and paddy straw). The highly production for each mulch was attained when applying 50% of the required water. The production using the straw-mulched was higher than those of polyethylene-mulched under 100% of water application. With 50% water application, the highest water use efficiency was acquired under polyethylene mulch. The impacts of economic and resource on drip irrigation including B/C manner using the survey data of okra cultivation have been studied in [20]. The study of the drip irrigation usage demonstrated that it can decrease nearly 15% of planting cost to save up to 47% of electrical energy and water quantity, and boost 49% of okra yield. The farmers who grow okra using the trickle irrigation got an additional income compared to those who do not use the trickle irrigation. The author in [21] proceeded the economic analysis using the trickle irrigation program TISD [22] on sixteen crops and vegetables based on the environmental and economic conditions. The economic analysis was B/C ratio and net returns amounts. The study presented some suitable rotations. For most crop rotations, the net returns were attained to high values and B/C ratio varied from 1.5 to more than two. The authors used in [23] the TISD program [22] linked with the economic procedures [21] to research the impact of the configurations and orientations of laterals for planting fruit trees on some economic bases. The research has been proceeded the environmental and economic states for eleven fruit trees. The trees considered in the research were: pears, olives, mangoes, guavas, grapes, figs, dates, citrus, bananas, apples, and apricots. The results demonstrated that the configured drip irrigation system has a worthy effect on both the capital cost and the energy cost whereas the system has a reasonable effect on the maintenance cost.

The present research endeavours to assess the trickle irrigation system environmentally and economically based on the program of Trickle Irrigation TISD [22]. The program assigned includes the elaborated design of trickle irrigation system. The design measures include the system components of (ports, tubes, fittings, pump unit, and line-point sources of trickle systems). The main target of the study is to evaluate the impacts of environmental and economic factors on farming using TISD program of trickle irrigation system. The environmental conditions selected are: type of soil, topography of land, conditions of climate, and conditions of water resource. The economic conditions are: rates of nominal and real interests, raw land price, and energy and labor escalation rates. The study used the crop rotation of tomato-sesame as a line-source, and the point-source was represented by citrus trees. The study deemed the only B/C ratio for comparing the results.
2. Methodology

To assess the impacts of environment and economic states on the trickle irrigation system, the program TISD [22] linked with the economic analysis [21] has been used to estimate the B/C ratio for selected crops and fruits (tomato-sesame and citrus). The trickle system configurations of TISD program are shown in figures 1 and 2. Figure 3 can show simply the flowchart of TISD program. The data for environmental conditions are; the type of soil [24-29], topography of the land area [30-31], location and type of water source, quantity and quality of irrigation water [32-34], and climate area [35-37]. The data for economic conditions comprise; price of land [38], rates of nominal and real interest [12, 39], cost of type of energy source [40-43], factor of energy inflation, costs of labor, factor of labor inflation, costs of all components of the trickle system used. The crops and fruits selected have to be convenient to environmental agronomical conditions. These conditions could be chosen as soil texture type, conditions of the area of climate, water salinity. The TISD program can estimate the costs and returns of the trickle system of irrigation and then to define the different bases of the selected parameters. The costs of the trickle system implicate; assemblies, operational processes, system maintenance, land purchasing or hiring, water availability (surface or ground), crops production factors (land accommodation, cultivation, manuring, weeding, pest control, harvesting, and transportation). The methodology uses a base run of the farm depending on the parameters of environment and economic conditions. All comparisons of the following runs are referred to the base run. Therefore, TISD program runs the base farm run data for both tomato-sesame and citrus using the configured the trickle system with laterals’ orientation. The various parameters are varied one by one meanwhile the others remain as the same of the base run. So, the discussion can be attained by estimating the effect of every parameter of the environmental and economic states on the B/C ratio.

![Figure 1](image1.png)

**Figure 1.** The system of tickle irrigation configuration [1].

![Figure 2](image2.png)

**Figure 2:** The system of tickle irrigation configuration [2].
2.1. **Base farm run**

The base farm shape and topography is shown in figure 4 to conduct the processes analysis. Table 1 includes the environmental and economic data of the base farm run. In addition, the crop conditions based on the agricultural statistics in Egypt [44] and the selected rotations (tomato-sesame) and fruits (citrus) in 2018 are shown in table 2. The TISD program suggests the appropriate production and costs of the selected crops as in [21] and [23].

**Figure 3.** Flowchart of TISD program.

**Figure 4:** Size and topography of base farm run.
Table 1. Environmental and economic data for base farm run.

| Environmental Conditions                  |
|------------------------------------------|
| Soil type: Soil texture (loamy or fine or coarse sands); text. code = 2 |
| Climatic conditions: Hot (Egypt); CLZ = 3; wind speed, WS = 3 mph |
| Farm shape: Figure 4                     |
| Crop conditions: Plant spacing, root depth, shaded area; water & leaching [24, 45-48] |
| Source of water: Groundwater; suction head, Hs = 6 m; water electrical conductivity = 1 dS.m⁻¹ |

| Economic Conditions                      |
|------------------------------------------|
| Raw land value: RAW = 1000 US$/ha⁻¹ |
| Real interest rate: RIR = 6% |
| Nominal interest rate: NIR = 10% |
| Electric energy [49]: Energy cost = 1/10 US$.kW⁻¹.hr. (2018); energy escalation rate = 27% (2018) |
| Labor [50]: Labor cost = 4 US$.man⁻¹.hr. (2018); labor escalation rate = 5% (2018) |
| Erection elements: PVC = DIN (15 US$.kg⁻¹, 2018); Alum. and steel pipe [3], ports’ prices [51] |

Table 2. Economic information of the base farm run crops [44, 2018].

| Crops   | Prod. price (US$.ha⁻¹) | Aver. production (ton.ha⁻¹) | Aver. price (US$.ton⁻¹)² |
|---------|------------------------|-----------------------------|--------------------------|
| Tomato  | 4064                   | 41                          | 99                       |
| Sesame  | 1184                   | 1.3                         | 915                      |
| Citrus  | 3726                   | 24                          | 155                      |

²[44, 2017].

2.2. Proposed changes in environmental and economic data of base farm run

Table 3 and 4 shows the proposed changes of the environmental and economic data of the base farm run. The base farm run is equally divided in length and/or width into two, four, six, and eight to be able to search the effect of area of the farm on the B/C ratio. The different agricultural areas presents the dimension ratios, L/B, (9.4, 7.1, 6.8, 5.1, 4.7, 3.4, 2.4, 1.8, 1.7, 1.3, and 1.2). Further, the farm dimension ratios, L/B, with the same farm area are; 3, 2.5, 2, 1.5, and 1. The flowchart of the methodology is shown in figure 5.

Table 3. Proposed changes of base farm run environmental parameters.

| Crop Rotations | Soil structure | Land topography | Climate conditions | Water conditions |
|----------------|----------------|-----------------|--------------------|-----------------|
|                | Codea          | DZ%             | DZ1%               | CLZ Codeb       | WS (mph)        | EcW (dS.m⁻¹) | Hs   |
| Tomato-sesame  | 5, 4           | 16, 8, 4, 2     | 12, 6, 3, 1.5     | 5               | 12, 6, 3       | 8, 2         | 30   |
| Citrus         | 6, 4           | 16, 8, 4, 2     | 12, 6, 3, 1.5     | 5, 2            | 12, 6, 3       | 4, 2         | 30   |

ᵃCode 4: silt loams, loams, and very fine sandy loams; Code 5: sandy clay loams, silty clay loams, and clay loams; Code 6: clays, silty clays, and sandy clays.
ᵇCode 2: Moderate climate; Code 5: High desert climate.

Table 4. Proposed changes of base run economic parameters.

| Crop Rotations | Economic conditions |
|----------------|---------------------|
|                | Raw land value | Nominal and real interest rates | Energy escalation rate |
|                | RAW US$/ha | Nominal % | Real % | ESCR % | LASCR % |
| Tomato-sesame  | 2000, 4000, 8000 | 8, 12 14 | 4, 8, 10 | 3, 5, 9 | 2, 6, 8 |
| Citrus         | 2000, 4000, 8000 | 8, 12 14 | 4, 8, 10 | 3, 5, 9 | 2, 6, 8 |
3. Results and discussion

The program of TISD was run applying the crops tomato-sesame and citrus using the configured trickle irrigation system knowing the data of the environmental and economic base farm run (Table 3 and 4). The laterals are arranged normal on the North for tomato-sesame while they may be arranged parallel to or normal on the North. According to [22], some notes may be introduced as follows:

- DP1: the laterals are directed parallel to North with configuration #1 (the pump is at the farm center),
- DP1: the laterals are directed parallel to North with configuration #1 (the pump is on the long side),
- DP2: the laterals are directed parallel to North with configuration #2,
- DN1: the laterals are directed normal on North with configuration #1 (the pump is at the farm center),
- DN1: the laterals are directed normal on North with configuration #1 (the pump is on the long side),
- DN2: the laterals are directed normal on North with configuration #2,
- DN2: the laterals are directed normal on North with configuration #2,

3.1. Environmental conditions impacts on the B/C ratio

3.1.1. Soil type and climate conditions. The impacts of several soil structures for tomato-sesame and citrus on the B/C are shown in Figure 6. The figure shows the B/C ratio changes to the base farm run due to changes of soil texture as in Table 3. It is revealed that the soil texture changes on the B/C ratio is considerable (up to 15% for line-source, tomato-sesame) and is negligible (up to 2% for point-source, citrus). In the medium soil the best B/C may be attained. The configuration type and laterals’ direction has no effect for changing soil type when planting citrus (less than 0.5%). The improvement in the B/C ratio, for planting tomato-sesame is considerable due to changing the soil from coarse to medium and the others are negligible.
Moreover, the impacts of changes of climate areas (CLZ) and wind speed (WS) on B/C ratio are shown also in figure 6. It is noted that the climate and wind speed impacts on B/C values are trivial for both tomato-sesame and citrus (up to 3.0%). Therefore the trickle is deemed the best irrigation system for hot climate and high wind speeds.

![Figure 6. B/C ratio against the soil texture and climate conditions.](image)

3.1.2. Land Slopes. The impacts of various slopes of the land on the B/C ratio of tomato-sesame and citrus are shown in figure 7. It is noted that land slope impacts on B/C ratio are depending on both slope and pump position (configuration #1). The B/C ratio retardation can be avoided by positioning the pump on the upper side of the farm. For citrus (point source), the laterals may be preferably arranged in the small slope. The increase of land slope by up to 2% can improve the B/C ratio (Configuration #2).

![Figure 7. B/C ratio against the land topography.](image)

3.1.3. Water Conditions. The impacts of water quantity and quality on the B/C ratio of tomato-sesame and citrus are shown in figure 8. As far as known, the production of the crops is affecting by the maximum salt tolerance range [52-55], then, the trickle system costs increase and the crop yield decreases [56-59]. The decrease in B/C reaches more than 45% against electrical conductivity of 8 dS/m for tomato-sesame and attains greater than 30% against electrical conductivity of 4 dS/m for citrus. The B/C ratio decreases up to 5% to 35% due to enlargement of suction head from 6 to 30 m. In addition, the impact of water quality source was negligible on the configured system and laterals orientation.
3.1.4. Farm sizing and partition. The impacts of various farm sizing on the B/C ratio of citrus trees are shown in figure 9. It is noted that the impacts of farm size on the B/C ratio for citrus are small (up to 4%). The results revealed a good enhancement in the B/C ratio with L/B ratio within 1.2-1.3 and area of farm within 8.8-13.2 ha. In addition, the configured system and directive laterals has nearly not affected by the farm partition whereas the B/C changed by less than 1% for farm areas changed between 6.6 and 26.5 ha. In the opposite figure 10, the area of base run is still conserved at 53 ha and the farm dimension ratio L/B is changed. It is noted that the selection of system configuration and laterals’ direction has not been affected by the farm dimension ratio.
3.2. Effect of Different Economic Conditions on the B/C Ratio

3.2.1. Real and Nominal Interest Rates. The current rates of interest, that charged by lending institutions including inflationary component, are called nominal rates [60-61]. The real rate is free of inflation. Therefore, the nominal rate is considered greater than the real rate by the inflation rate for long-term. For planting tomato-sesame and citrus, the impacts of nominal and real rates on the B/C are shown in figure 11. It is noted that, the nominal and real rates on the B/C ratio is depending on their values. The B/C ratio increases as the nominal and real interest rates decreases. The configured and directive laterals has not been affected by the nominal and real rates. The B/C ratio has been highly affected by the nominal rate rather than the real rate according to the high values of erection elements comparing the land price.

![Figure 11. B/C ratio under against nominal and real interest rates.](image)

3.2.2. Raw Land Price. The impacts of raw land price on the B/C ratio for tomato-sesame and citrus are shown in figure 12. It is noted that the B/C ratio is adversely proportioned with the raw land price. The configured and directive laterals has not been affected by the raw land price. The B/C ratio is affected equally by the raw land price for all selected crops as 2.6% for each increasing increment 1000 US$/ha.

![Figure 12. B/C ratio against the raw land value.](image)

3.2.3. Inflation Rates for Energy and Labor. The impacts of energy and labor escalation parameters on the B/C ratio for tomato-sesame and citrus are shown in figure 13. It is noted that B/C ratio has been depended on the values of the energy and labor inflation rates. The B/C ratio is adversely proportioned with the inflation rate of energy and labor. The configured trickle system has not been affected by the energy and labor inflation. The B/C ratio has not been affected by the labor inflation. The B/C ratio is slightly affected by the energy inflation as 1% for each 1% of the inflation rate.
Figure 13. B/C ratio against the energy and labor escalation rates.

Table 5 summarized all the studied environmental and economic impacts on the B/C ratio for the trickle irrigation system for tomato-sesame as a line-source and citrus as a point-source. Table 5 lists the significance effect of the different parameters of environmental and economic configured and directive laterals trickle irrigation system.

4. Conclusion
The study presented in this research is to assess the environmental and economic impacts on the trickle irrigation system. To fulfill these goals, the environmental and economic parameters of cultivating farms were introduced using the software TISD (Trickle Irrigation System Design). The trickle system’s configuration could be selected by TISD program to meet the desired B/C ratio. There were two types of cultivation; tomato-sesame rotation (line-source) and citrus trees (point-source). The selected environmental parameters are: soil type, land slopes, wind speed, climate, water source and quality, and farm partition. The selected economic parameters are: real and nominal interest rate, raw land price, and energy and labor inflation. The soil type impact on the B/C ratio was considerable for line-source and trivial for point-source. The impact of soil type had a trivial on the system configurations. The slope direction with laterals and pump position were considered the land slope parameters to affect the B/C ratio. Accordingly, the best orientation of laterals for point-source is on short slope and the pump position is on the upper farm side. The configured trickle system has been affected by the land slope, especially with high slope. The B/C ratio has not been affected by the high wind speed. The B/C ratio for the configured orientated laterals has also not been affected by the climate for line-point-source. The effect of water salinity is negligible on the B/C ratio to the minimum salt tolerance of the crop. The B/C ratio for the configured orientated laterals has a small changing due to water head suction effect. So, the groundwater sources is deemed the best use for trickle irrigation system. The small effect on the B/C ratio has been found for the farm partition with configured trickle irrigation system. The B/C ratio for the configured system has been depending on the values of real and nominal interest rates. Further, The B/C ratio has been affected highly by the nominal rate than the real rate due to the higher cost of the system installation. The B/C ratio has been affected by land value for the configured orientated laterals. The B/C ratio has not nearly been affected by the energy and labor inflation rates for the configured orientated laterals system. The small influential on the B/C ratio of the line-point-source trickle systems for the energy inflation rate. There is no effect for the labor escalation rate on the B/C ratio of drip systems. The influence of energy escalation rate on the B/C ratio of the line-point-source trickle systems is small.
| No. | Parameters                  | System type | System impact | Conf. impact | Laterals’ dir. impact |
|-----|-----------------------------|-------------|---------------|--------------|-----------------------|
| 1   | Soil texture                | L-source    | High          | No           | -                     |
|     |                             | P-source    | V. small      | Silly        | -                     |
| 2   | Land topography             | L-source    | Small         | Small        | -                     |
|     |                             | P-source    | High          | High         | High                  |
| 3   | Climate zone                | L-source    | Silly         | Silly        | -                     |
|     |                             | P-source    | Small         | Silly        | Small                 |
| 4   | Wind speed                  | L-source    | No            | No           | -                     |
|     |                             | P-source    | No            | No           | -                     |
| 5   | Water quality               | L-source    | V. small      | No           | -                     |
|     |                             | P-source    | V. small      | Silly        | Silly                 |
| 6   | Water source type           | L-source    | Small         | No           | No                    |
|     |                             | P-source    | Small         | Silly        | -                     |
| 7   | Farm Area                   | L-source    | V. small      | Silly        | -                     |
|     |                             | P-source    | Small         | V. small     | Small                 |
|     |                             | L-source    | Silly         | Silly        | -                     |
| 8   | Farm dimension              | P-source    | V. small      | Silly        | Silly                 |
|     |                             | L-source    | Small         | No           | -                     |
| 9   | Interest rates              | P-source    | Considerable  | Silly        | Silly                 |
|     |                             | L-source    | Small         | No           | -                     |
| 10  | Raw land cost               | P-source    | Considerable  | Silly        | Silly                 |
|     |                             | L-source    | Small         | Silly        | -                     |
| 11  | Energy escalation           | P-source    | Small         | Silly        | -                     |
|     |                             | L-source    | V. small      | Silly        | -                     |
| 12  | Labor escalation            | P-source    | Silly         | Silly        | Silly                 |

Silly 0 < Impact < 1 % Considerable 5 < Impact < 10 %
V. small 1 < Impact < 2 % High 10 < Impact < 20 %
Small 2 < Impact < 5 % Very high Impact > 20 %

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