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RESEARCH PAPER

Determination of the working performance of a new fertigation system developed for hose reel irrigation machine

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Abstract

The aim of this study is determining of the working performance of the a new fertigation system (TURPO CLK FS) that developed for hose reel irrigation machines (HRIM). As a liquid fertilizers nitrogen and phosphorus were used. The HRIM was operated under two different irrigation water pressures (5 and 2.5 bar) conditions. The dosing pump was operated for two different frequencies (150 and 300 pulse/min). Field experiments were realised by using two different liquid chemical fertilizers and measured of pH, electrical conductivity (EC), and total dissolved solids (TDS) values. According to evaluation when using nitrogen fertilizer pH values ranged between 8.40 - 8.59, EC values 602.92 - 915.83 µS/cm, and the TDS values 294.17 - 451.25 mg/L at all sets. When using phosphorus fertilizer, pH values ranged between 7.13 - 8.03, EC values 485.42 - 519.58 µS/cm, and TDS values 236.25 - 252.92 mg/L. And then the Christiansen Coefficient of Uniformity (CCU) was calculated over 24 samples in each set. The CCU values were founded between 95.02% - 99.95%. As the result it has been concluded that the TURPO CLK FS could be used together with HRIM during fertigation applications.

Introduction

Irrigation is one of the two critical cultural processes and the other is fertilization, aimed at reducing the unit product cost by increasing yield and quality in crop production. In a general definition, irrigation and fertilization is the application of water and plant nutrients that plants need and cannot be met naturally to the plant root zone or directly to the plant (Çetin & Tolay, 2020). While fertigation was used in horticulture and greenhouse agriculture in the past, it has started to be used in field agriculture as a result of technological developments in irrigation machines in recent years. Due to the synergy created by the use of fertilizer and water, there is an increase in yield and quality in plant production where fertigation is applied (Imas, 1999). The use of HRIMs has become quite common in recent years. Water usage efficiency is high and application methods are easy. In this study, an HRIM with fertigation system developed by us was used. Here, the function of the dosing pump is to mix the fertilizer into the irrigation water line in a uniform and homogeneous phase. The mixing of the fertilizer with the irrigation water is done according to a predetermined ratio. Dosing pumps are manufactured in many different types and powers and are generally used with a control unit. In this study, a dosing pump was used together with an electronic control unit

The amount of fertilizer to be mixed into the irrigation water is determined by controlling the frequency of the dosing pumps. In the fertigation technique, synergy is achieved by applying irrigation water and fertilizer together to the plants. Thus, required labor costs of fertilizer distribution are also reduced. Chemical or organic fertilizers used in fertigation systems should be either in liquid form or dissolved in water. There are problems the supplying of electricity to the electronic control units during the fertigation in the field. For this reason, it is important that feeding of dosing system by a source independent of the grid, such as solar energy. Thus, dosing pump that fed by photovoltaic panel system was used in the study.

Materials and Method

Materials

Study field

The field experiments of this study was done in research area belonging to the Field Crops Central Research Institute- İkizce Research and Application Farm of Agriculture and Forest Ministry. This research area is a field has barley stubble and no slope.

In order to finish the experiments related to irrigation water mixed with fertilizer in a short time, attention was paid to the fact that the selected field was close to the laboratory where the measurements would be made. A hydrant was used to feed HRIM on the field where the study was carried out. The pressure can be adjusted by different values through valve of hydrant. Another reason why the study was carried out on a field with stubble is transporting easily the water collection containers (WCC) placed in the machine work area are from the mud formed after irrigation to the field without stubble. The field where the study was done is shown in Figure 1.

Figure 1. Study field

Hose reel irrigation machine

HRIM is trailed type agricultural machine that makes sprinkler irrigation and works with pressurized water. Its main components consist of a trailer, bodywork, drum, polyethylene pipe with a length of 400 m and a diameter of up to 125 mm, turbine-gear box mechanism and water distributor (boom or gun). The use of machine is simple and its water use efficiency is extremely high.

The "turbine-gearbox combined mechanism" on the HRIM converts the kinetic energy of the pressurized irrigation water to the work and moves the water distributor carrier and provides conveying water with the polyethylene pipe.

In our study, an equipment with a fertigation system named TURPO CLK FS with a boom designed for HRIMs and a 400 m long PE water pipe was used (Figure 1). The TURPO CLK FS, which has a photovoltaic panel, can fertilize independently from the electricity grid in field conditions (Figure 2).

Figure 2. HRIM equipped TURPO CLK FS with PV

Portable pH, EC, TDS, and temperature meter (HI9811-5)

A multifunctional portable measuring device HI9811-5, which can measure four values (pH, EC, TDS, temperature), is used. The aforementioned device is easy to use and has the ability to measure with high precision. Measurements were made using a combined probe connected to the device with an 8-pin DIN connector (from the User's Manual). The measured values were read on the liquid crystal display of the device as EC μS/cm and TDS mg/L. The accuracy of the instrument is ±2% for EC, ±2% for TDS and ±0.1 for pH. Figure 3 shows the portable HI9811-5.

Figure 3. Portable HI9811-5

Dosing pump and liquid chemical fertilizers

In the TURPO CLK FS built on HRIM, there is an ENELSA-ANTECH brand NOVA-D model volumetric dosing pump with 0.555 ml stroke. The pump has a solenoid coil and a teflon diaphragm. Suction and discharge pipes with an outer diameter of 8 mm and an inner diameter of 6 mm were used to connect the dosing pump to the fertilizer tank and the pressurized irrigation water pipe. Since the cross-sectional areas of the pipes used are small, liquid fertilizers were preferred in order to avoid clogging in the system during operation. The dosing pump can be operated at different frequencies by using the adjustment buttons on the electronic control unit integrated into the pump.

In the experiments, UAN 32 fertilizer containing 32% nitrogen (8% NH_4, 8% NO_3, 16% NH_2) and micronutrients (boron, copper, iron, manganese, zinc and molybdenum) and phosphorous fertilizer containing 61% phosphorus pentoxide (P_2O_5) in acidic character (CLEANPHOS) was used. One of the reasons why the aforementioned fertilizers are preferred is that no clogging occurs in the nozzles. Figure 4 shows photographs of the dosing pump used in this study.

Figure 4. Dosing pump

Water collection containers

In the study, a boom with nozzles, which is an organ of HRIM, was used. There are 34 nozzles with 8 mm hole diameter and impact plate placed at 140 cm intervals on the lower part of the boom, which has a working width of approximately 50 m. During irrigation, samples were taken from the outlet of the nozzles with water collection containers placed in the field under the nozzles. While placing the water collection containers (WCC) under the boom, care was taken to have them both directly under and between the nozzles. The samples taken contain a mixture of water and fertilizer. 6 WCC with a cross-sectional area of 1200 cm2 and a volume of 30 L were used. After the boom had passed through the sampling points, the lids of the WCC were quickly closed to prevent evaporation losses. Figure 5 shows the WCC lined up under the boom.

Figure 5. WCC lined up under the boom

Method

In the arrangement of the experiment plots, 6 plots with 4 replications were created with 2 different fertilizers. Samples were obtained from each of the 8 experimental sets with the help of 24 WCCs with lockable lids. According to the experiment plan, HRIM was operated at two different pressures, the first being 5 bar and the second being 2.5 bar. Adjustment is made using the slider of the hydrant valve. Two different liquid chemical fertilizers (UAN 32 and CLEANPHOS) containing nitrogen and phosphorus were given to the pressurized water line at two different frequencies, 150 pulses/min and 300 pulses/min, with a 0.555 mL stroke volume dosing pump. The dosing pump can be operated at different frequencies by using the adjustment buttons on the electronic control unit integrated into the pump. Repeated experiments were made by opening the 200 m irrigation pipe of the HRIM placed in the study area. In order to collect the samples mixing fertilizer into the irrigation water, 6 WCC were placed under the boom.

In order to transmit the water-fertilizer mixture to the boom at a distance of 400 meters at the first time start-up of the HRIM, the hydrant valve was opened until the machine was supplied with water, and the pressure value of 5 bar was read from the manometer on the machine. It was observed that after the valve was opened, water sprayed from the nozzles in 120 seconds for a pipe length of 400 m. Thus, it has been determined that the velocity of the water in the pipe can reach up to 12 km/h.

The turbine gearbox mechanism, which is the main part of HRIM, converts the kinetic energy of water into mechanical energy. The peripheral speed of the drum can be adjusted by changing the cross-sectional area where the water enters the turbine. The adjusted speed value can be easily read from the speedometer on the HRIM. Drum circumferential speed, which is a linear speed, also determines the speed of the boom in the field during irrigation. Thus, in all sets and repetitions of the experiment, it was ensured that the boom passed over the WCCs in the field at a constant speed of 30 m/h. The images of the manometer and speedometer on the HRIM during operation are shown in Figure 6.

Figure 6. Manometer and speed meter on the HRIM

After measuring the instantaneous and average wind speed with an anemometer on the boom, the experiments were started. In order to make accurate measurements, the work was suspended on windy and rainy days. HRIM with TURPO CLK FS was placed next to the hydrant and 6 WCC were placed 8 m back from the boom. The boom with a feed rate of 30 m/h reached the WCC lined axis after about 15 minutes. The boom then completed its passage over the WCC and the lockable covers of the WCC were immediately closed.

For each set, 24 WCCs were placed in the experiment area. Measurements were made using the calibrated portable HI9811-5 and recorded in the pre-prepared observation log. Immediately after the measurements in one set were completed, the WCC and its lids were cleaned by flushing with adequate tap water. In this way, erroneous measurements that may occur due to WCC contamination of liquid chemical fertilizers applied at different doses in different sets are prevented.

Result and Discussion

Working performance of TURPO CLK FS was determined by measuring the pH, EC, and TDS values of the irrigation water mixed fertilizer in WCC in different sets and making the CCU calculation. Irrigation water samples taken without fertilizer mixing were used to determine the mean values of pH, EC and TDS before fertigation and were determined as 8.7, 560 µS/cm and 270 mg/L, respectively. After nitrogen fertilizer application, average pH values for different dosage pump frequencies at different irrigation water pressures are between 8.40 and 8.59, EC values were between 602.92 and 915.83 µS/cm, and TDS values are between 294.17 and 451.25 mg/L. After using phosphorus fertilizer, pH values were between 7.13 and 8.03, EC values were between 485.42 and 519.58 µS/cm, and TDS values were between 236.25 and 252.92 mg/L for different dosage pump frequencies at different irrigation water pressures.

HRIM is a turbine driven, automatic rewind and water saving irrigation equipment. In order to use the kinetic energy of the water, the pressurized water coming from the hydrant comes to the turbine-gear box mechanism. The rotation of the water turbine-gearbox mechanism realizes the rotation of the drum that pulls the PE pipe and the boom carrier car. In the meantime, pressurized water is transmitted through the PE pipe to the nozzles on the boom and sprinkler is carried out. The system can be used in different areas of irrigation projects for water saving purposes.

Plant nutrients to be used in fertilization should be mixed homogeneously into the irrigation water. For this reason, the working performance of the systems that mix fertilizer into the irrigation water in fertigation applications is extremely important. The performance of the systems is determined by measuring whether the fertilizer-water mixture is homogeneous. In addition, the phase of the fertilizer to be mixed with the irrigation water also affects the homogeneity of the fertilizer-water mixture. More homogeneous fertilizer-water mixtures are obtained by mixing liquid fertilizers with irrigation water instead of solid fertilizers.

In a study, the nitrogen ratio taken from the fertilizer applied with the drip irrigation method in tomato production was determined and compared with other fertilizer application methods. In the aforementioned study, drip and furrow irrigation method was applied by applying 6 different sets of fertilizer to the irrigation water and plant row during planting and flowering periods. In the soil analyzes made after the study, it was seen that most of the nitrogen fertilizer applied in the application with the drip irrigation method was removed from the plant and fertilizer was given to the plant row, but if nitrogen fertilizer was mixed with the irrigation water, such a problem did not occur. It has been shown that the efficiency of fertilizer use in nitrogen applications made by adding fertilizer to the irrigation water with the drip irrigation method is higher than the nitrogen applications made by adding fertilizer to the plant row with the furrow irrigation method (Miller et al., 1976).

In a study comparing the sprinkler irrigation method and irrigation with a gun, the water distribution in the soil and on the surface during and after irrigation was investigated. As a result of the study, it was determined that the distribution of the amount of water entering the soil at the sampling points showed unacceptably large differences. Since the amount of water entering the soil is less than the amount of water applied, it has been stated that ponds occur on the soil surface and in small and inclined areas of surface runoff. The CCU equation was used to calculate the uniformity of the distribution of water distributed over the soil surface and entering the soil. In the calculation made using the amount of water applied and the amount of water collected, it was seen that the irrigation efficiency was 80%. It has been reported that both the amount of water per unit area and the water uptake rate of the soil should be taken into account in systems where components that apply water only once through the area where it acts, such as a movable sprinkler gun, will be used (Cook, 1983).

In an article published on the future of the irrigation industry, it is reported that in the systems to be designed in the future, advanced equipment that mixes plant nutrients into irrigation water according to the need to increase crop yield will be available and applications called fertigation technique will become widespread (Burt, 1995).

In a study, the effects of wind speed and operating pressure on the water distribution uniformity of linear irrigation motion systems were investigated. It is stated that circular and linear irrigation systems have become widespread in Southeastern America in recent years. It has been pointed out that mobile irrigation systems are used in large areas and it is stated that there is a need for measurable information about the performance of sprinkler equipment in working conditions. Two types of sprinkler nozzles were tested in the study. One of these nozzles is a fixed rib plate LDN (low drag nozzle), and the other is IWOB (rotating plate nozzles and swinging diffuser nozzles), allowing the water to diffuse away from the center by shaking it. It has been stated that LDN nozzles are designed to prevent droplet drift by producing large droplets in irrigation works carried out in low pressure and windy conditions. In LDN nozzles used to prevent droplets from entrainment, irrigation water is distributed through a fixed plate with a certain number of grooves on it. It has been stated that the design of IWOB nozzles is to provide high water distribution homogeneity regardless of the pressure and flow rate of the water. It has been explained that a movable distributor rotates around a center in IWOB nozzles, which are used to provide high water distribution homogeneity. It is stated that the use of both LDN and IWOB sprinkler nozzles in linear and circular motion irrigation systems has become widespread (Dukes, 2006).

In the study conducted for the distribution of cattle manure used in corn production, the feasibility of the fertigation system, which is a new technique because it is more environmentally friendly, was evaluated. Thus, conventional fertilizer distribution systems and fertigation systems used with HRIM were compared. It was noted that nitrogen losses in the form of nitrates were less in the water and air samples taken from the fertigation application area. It has been reported that the unused nitrogen lost due to low-efficiency practices in agricultural areas increases the algae density in water resources such as lakes, ponds, estuaries, and rivers, reducing oxygen, and as a result, it causes the death of many microorganisms. This oxygen reduction leads to eutrophication. In order to prevent the pollution that occurs in this way, it has been explained that fertilizers should be given when the plants need it, in the right amount and with the right technique (Bortolini & Bisol, 2008).

In a study conducted in field conditions, it was stated that the fertigation technique was an effective method and was recommended to farmers. It has been claimed that, thanks to fertigation in many plants, an increase in efficiency between 20% and 60% is achieved, and a savings of between 20% and 70% can be achieved in water use. It has been stated that fertigation is a useful technique that increases the efficiency of water and fertilizer use, has a high technological level and cost, but is beneficial. It has been explained that solid fertilizers and liquid fertilizers can be used in fertigation application. It is reported that fertigation is important for the effective use of fertilizer and water, especially in arid and semi-arid regions (Biswas, 2010).

In a study conducted in soilless environment (hydroponic farming) in two different modern greenhouses equipped with NMC-PRO and DARES brand fertigation systems. Equipment costs and water and fertilizer use efficiency were compared in different fertilization systems. It has been reported that the cost and water use efficiency of the NMC PRO fertilization system is higher than the DARES fertilization system. It has been stated that the fertilizer use efficiency is equal in both systems (Chen et al., 2014).

In a study, fertigation equipment used in drip irrigation systems was tested in gardens and the advantages of fertigation application were explained. These advantages are savings in water and energy and fertilizer application labor, reduction of possible pollution in both soil and groundwater due to not washing the pesticides and fertilizers used, the fertilizer use efficiency being up to 80%, and the reduction of water and fertilizer losses in sloping and uneven lands. In addition, after fertilization, it is another advantage to use irrigation systems that only address the root zone by reducing the density of weeds without the need to spare time for irrigation, adding some fertilizing equipment to the old irrigation systems (Sovaiala et al., 2017).

In a study conducted with HRIM for fertigation, an external system was designed using a pump that does not need electrical energy and works with the proportional dosing principle. In order to determine the working performance of the system, food coloring was mixed into the irrigation water instead of fertilizer. Then laboratory and field experiments were carried out. In the experiments, the amount of residue on the filter papers placed in the HRIM study area during irrigation was measured by colorometric method and statistical analyzes were made. It has been suggested that the use of HRIM and dosing pumps can increase the fertilizer use efficiency. It has been claimed that when the fertilizer is mixed with the irrigation water by dosing pump, the coefficient of variation (CV) of the fertilization distribution homogeneity is between 21-38% and is at an acceptable value (Demircioğlu & Çelen, 2020).

The uniformity of HRIM's water distribution is important to the performance of fertigation applications. The reason for this is that the amount of fertilizer applied per unit area in fertigation applications is a function of the amount of irrigation water mixed with fertilizer per unit area. In this study, it was tried to determine whether the fertilizer mixed with irrigation water was uniform or not.

In this study, a set was formed with the samples taken with the help of 24 water collection containers placed in the HRIM study area. CCU values were calculated using pH, EC and TDS values as percentages. CCU values, which are an indicator of fertilization performance of the TURPO CLK FS. At the end of the calculations, it was found that each of the 8 sets of CCU values for pH, EC and TDS varied between 95.97% and 99.95%, between 95.02% and 98.71%, and between 95.12% and 98.87%, respectively.

The average pH, EC and TDS values obtained by using the TURPO CLK FS for nitrogen fertilizer at different irrigation water pressures and different dosing pump frequencies are given in Table 1.

Table 1. Average pH, EC, and TDS values in nitrogen fertilizer use

Irrigation water pressure (bar)	Dosing pump frequency (pulse/min)	Average pH	Average EC (µS/cm)	Average TDS (mg/L)
5	150	8.58	602.92	294.17
	300	8.58	690.42	339.17
2.5	150	8.59	694.17	341.67
	300	8.40	915.83	451.25

EC: Electrical conductivity, TDS: Total dissolved solids

The average pH, EC and TDS values obtained by using the TURPO CLK FS for phosphorus fertilizer at different irrigation water pressures and different dosing pump frequencies are given in Table 2. The experiment was carried out by measuring the average values of pH, EC and TDS measured in irrigation water mixed with liquid chemical fertilizer. The experiment plan consists of 8 sets and two different irrigation water pressures, two different fertilizers and two different dosing pump frequencies were used as factors. While pH, EC and TDS values differ between sets, they show high homogeneity in 24 irrigation water samples mixed with liquid fertilizer in the same set.

Table 2. Average pH, EC, and TDS values in phosphorus fertilizer use

Irrigation Water Pressure (bar)	Dosing Pump Frequency (pulse/min)	Average pH	Average EC (µS/cm)	Average TDS (mg/L)
5	150	8.03	519.58	252.92
	300	7.53	503.75	244.17
2.5	150	7.58	504.58	244.17
	300	7.13	485.42	236.25

EC: Electrical conductivity, TDS: Total dissolved solids

In Table 3, the pH, EC and TDS values measured in 24 irrigation water samples mixed with nitrogen fertilizer in each set are given together with the calculated CCU values. In Table 4, the pH, EC and TDS values measured in 24 irrigation water samples mixed with phosphorus fertilizer in each set are given together with the calculated CCU values.

Table 3. CCU values for pH, EC, and TDS in nitrogen fertilizer use

Irrigation Water Pressure (bar)	Dosing Pump Frequency (pulse/min)	CCU Values for pH (%)	CCU Values for EC (%)	CCU Values for TDS (%)
5	150	99.95**	97.36	97.05
	300	99.62	98.71	98.87
2.5	150	99.72	95.02*	95.12
	300	99.95	96.57	96.65

CCU: Christiansen Coefficient of Uniformity, EC: Electrical conductivity, TDS: Total dissolved solids

Table 4. CCU values for pH, EC, and TDS in phosphorus fertilizer use

Irrigation Water Pressure (bar)	Dosing Pump Frequency (pulse/min)	CCU Values for pH (%)	CCU Values for EC (%)	CCU Values for TDS (%)
5	150	95.97	96.87	96.72
	300	99.09	98.61	97.72
2.5	150	98.24	97.62	97.67
	300	99.10	98.18	97.80

CCU: Christiansen Coefficient of Uniformity, EC: Electrical conductivity, TDS: Total dissolved solids

Another factor affecting the working performance of the developed TURPO CLK FS is HRIM water distribution homogeneity. In this study, both nitrogen and phosphorus liquid chemical fertilizers were used together with irrigation water. The amount of nitrogen mixed with irrigation water (ANWCC- kg) and the amount of phosphorus (APWCC- kg) were obtained from the samples collected in the water collection cups placed under the boom. The average values calculated for the CCU for HRIM water distribution homogeneity in all sets where the operation is performed at different irrigation water pressures and different dosing pump frequencies are given in Table 5. When Table 5 is examined, it is seen that the HRIM water distribution homogeneity used in the study is at least 80.06% and at most 88.91%.

Table 5. Average and CCU values for ANWCC and APWCC

Measurements	5 bar 150 pulse/min	5 bar 300 pulse/min	2.5 bar 150 pulse/min	2.5 bar 300 pulse/min
	ANWCC			
Average (kg)	5.40	5.39	4.35	4.27
CCU (%)	88.91	85.30	83.88	84.95
	APWCC			
Average (kg)	5.75	5.69	4.41	4.43
CCU (%)	85.35	88.38	86.69	80.06

ANWCC: The amount of nitrogen mixed with irrigation water (kg), APWCC: The amount of phosphorus mixed with irrigation water (kg), CCU: Christiansen Coefficient of Uniformity, EC: Electrical conductivity, TDS: Total dissolved solids

Conclusion

In the study, the working performance of the TURPO CLK FS developed for HRIM was determined. The main component of the TURPO CLK FS is a dosing pump fed from a photovoltaic panel. The pump was operated at different frequencies. With the help of the developed system, liquid chemical fertilizers can be applied to irrigation water in field conditions, independently of the electricity network. The homogeneity of the fertilizer mixed irrigation water was determined by calculating the CCU. 24 different CCU values were calculated for pH, EC and TDS values in 8 sets of experiments. Calculations showed that the the lowest CCU value was 95.02% and the highest CCU value was 99.95%. In the TURPO CLK fertigation system, there is no mixing component (mixer, etc.) for homogeneous mixing of liquid chemical fertilizers with irrigation water, that is turbulence. Although it is not a mixing component, the CCU values calculated to determine the operating performance of TURPO CLK FS revealed that the fertilizer-water mixture showed a high level of homogeneity.

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Author Contributions

TP: Conceptualization, Data Curation, Formal Analysis, Funding Acquisition, Investigation, Methodology, Project Administration, Resources, Supervision, Validation, Visualization, Writing-Original Drafting, Writing-Rewie and Editing; **AÇ:** Theoretical Management of Thesis, Conceptualization, Data Curation, Formal Analysis, Funding, Review, Methodology, Project Consulting, Resources, Audit, Verification, Visualization, Writing-Original Drafting, Writing-Reviewing and Editing; **MAD:** Formal Analysis, Methodology, Visualization and Writing-Examination, Orientation and Arrangement; **HA:** Formal Analysis, Methodology, Visualization and Writing-Examination, Direction and Editing.

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Credit

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