Current trends in the development and efficiency of irrigation systems

I. R. Nafikov, *R. R.* Lukmanov*, *M. A.* Lushnov, *R. K.* Khusainov, and *I. I.* Kashapov

Kazan State Agrarian University, 65, K. Marx Str., Kazan, 420015, Republic of Tatarstan, Russian Federation

Abstract. The article presents research methods for the developed irrigation systems, for increasing the efficiency of water use in the agricultural sector. Based on an analysis of literature and patent sources, the authors present ways of modifying irrigation systems, such as physical and hydraulic barriers and magnetic treatment of irrigation water. The article also presents the results of laboratory tests of the proposed drip irrigation system. It investigates five different types of drip trays to quantify hydraulic performance. Researchers obtained dependencies of uniformity of water flow through the drip trays when changing the operating pressure in the system.

1 Introduction

The main task of the agro-industrial complex is to provide the population with quality and inexpensive foodstuffs, and the processing industry with the necessary types of raw materials. The efficient use of both individual machine-tractor aggregates (MTAs) and the entire machine-tractor fleet (MTF) of agricultural enterprises plays a major role in solving this problem [1–3].

The efficient use of machinery and tractors means producing the required quantity and quality of agricultural products with low labour and monetary costs, which requires crop irrigation [4–6].

Agriculture is by far the largest consumer of fresh water, with about 70% supplied by rivers and lakes, and in some developing countries consumption is as high as 90%.

Due to continued population growth in developed countries, there is a growing irrigated area for food supply [7–9]. Underground drip irrigation helps the plant's root system absorb moisture better. The main objective of subsurface drip irrigation is to produce food with less water and energy. Hence, the application of technologies to save water in irrigated agriculture is an urgent task [10].

Subsurface drip irrigation (SDI) is the most modern method of irrigation. Underground drip irrigation of various crops is carried out through plastic drip tubes containing emitters (drip trays) placed at certain distances (Figure 1).

Using SDI systems improves the efficiency of irrigation water and fertiliser use. The SDI systems allow irrigation and application of nutrients directly to the root zone of the plant, not on the surface. This reduces the loss of moisture due to evaporation from the soil surface and achieves efficient use of fertilizer.

Fig. 1. Subsurface drip irrigation.

The advantages of subsurface irrigation also include longer system life due to the reduced effect of solar radiation; easier ploughing and other mechanised work; and fewer weeds and fungal diseases.

Despite the numerous benefits listed above and the high efficiency of water use, the use of SDI is very limited. This is mainly because existing underground drip irrigation systems, have serious drawbacks. These disadvantages include the higher cost of the system, clogging of the drip trays, system breakage due to penetration of plant roots, and the difficulty of detecting and repairing leaks.

Another disadvantage of subsurface drip irrigation is that the soil structure can reduce water flow through the drip trays due to the intra-soil pressure near the drip tray during irrigation. Changing the flow rate can seriously

* Corresponding author: look-rus@mail.ru

affect irrigation uniformity. In addition, in loose soil, some moisture can seep below the root system due to the underground location of the drip lines.

At the seedling stage, the distance to the subsurface irrigation line is large and decreases as the root system of the plants increases. Therefore, there was a suggestion to put a waterproof polyethylene film below the drip lines. Polyethylene film 60 cm wide, 0.06 mm thick was laid to a depth of 30 to 40 cm. This method is called a physical barrier and significantly increases the amount of moisture retained in the root system area, either from drip line or rain, and limits deep percolation (seepage).

To improve soil moisture distribution in underground drip irrigation, a secondary drip line was laid below the primary drip line. This method depends on the factor that water moves faster into dry soil (due to a higher head gradient) than into wet soil. Thus, when the secondary drip line moistens the soil below the primary line and the water from the upper line is redistributed upwards, and this method is called a hydraulic barrier.

The results showed that when applied in the field, the hydraulic barrier increased potato yields by 12% and 48%, and the 'physical barrier' by 131% and 138% respectively. These results prove the advantage of using such methods to improve crop yields.

Figure 2 shows that below the soil surface there is film 1 (hydraulic barrier), then two drip lines 2 and 3 at 15 and 25 cm depth and a physical barrier 4 at 30 cm depth. There were vertical multi-sensor probes 5 used to measure soil moisture at distances of 4, 20 and 25 cm from the drip lines.

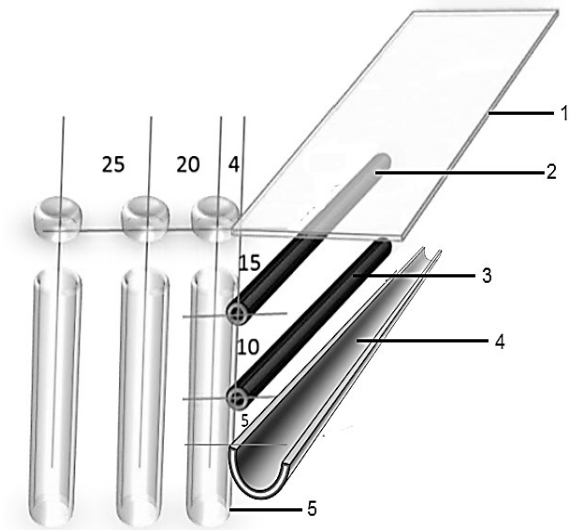
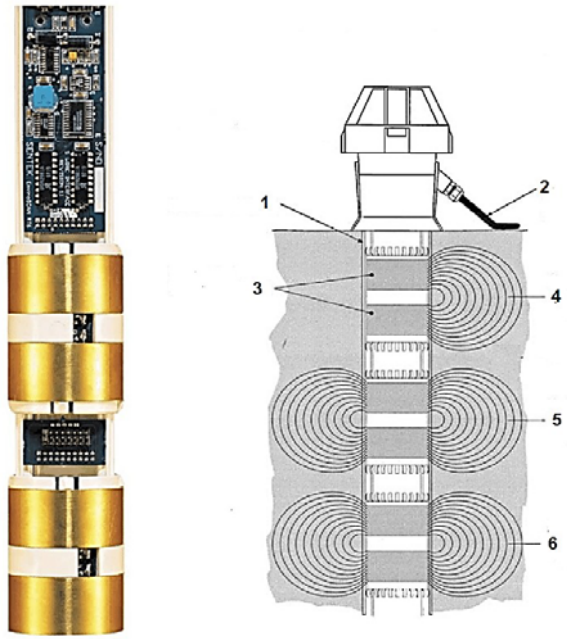


Fig. 2. Subsurface drip irrigation with physical and hydraulic barrier.

A capacitance-type moisture detector also has a use for measuring water movement in the soil (Figure 3). The soil moisture measurement system consists of vertical tube 1, three sensor electrodes 3, cable 2, which transmits the soil moisture information to the control unit. Soil moisture sensors 4, 5 and 6 of the EnviroSCAN brand (Australia) are placed at 10 cm intervals from each other [11].



(a) (b)

Fig. 3. EnviroSCAN sensors (a) – general view; (b) – diagram of the location and operation of the sensors at depth.

2 Materials and methods

2.1 An alternative method of subsurface drip irrigation

The developed alternative method of subsurface drip irrigation avoids most of the above disadvantages. This system is being introduced in the south of Spain to irrigate olive orchards. It consists of installing a water distribution network and drip trays on the soil surface. The system works as follows: drip trays positioned above the soil surface feed water into a perforated plastic pipe positioned vertically in the ground (Figure 4). In this way, it formed moisture distribution inside the soil, right at the bottom of the perforated tube. If the depth of the perforated tube is large and its diameter small enough, evaporation losses from the soil surface can be considered negligible.

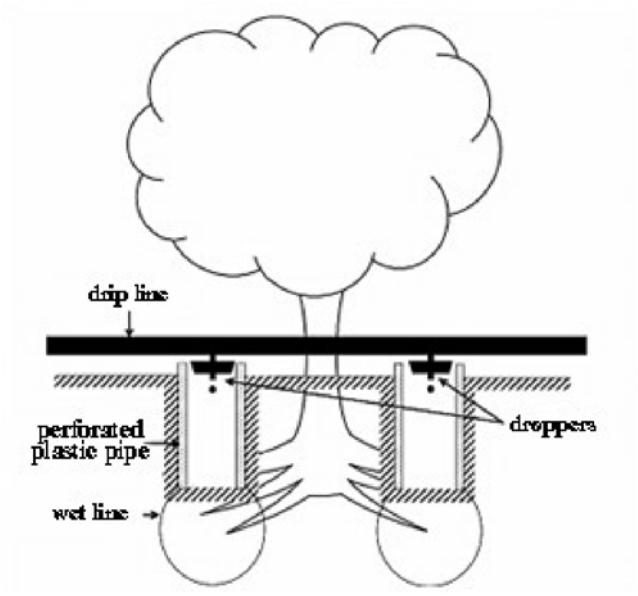


Fig. 4. Alternative method of subsurface drip irrigation.

The proposed alternative system has the following advantages This drip irrigation system is easy to install and relatively economical, with no clogging of the drip trays with soil.

The disadvantage of this system is the additional cost of installing perforated pipes under each drip tray. However, it avoids the cost of burying drip lines as with traditional subsurface irrigation.

Maintenance of the system is much easier than in underground irrigation systems, as clogged drip trays are easier to locate and replace at a lower cost.

To evaluate the effectiveness of the alternative subsurface drip irrigation method and to compare it with the surface drip irrigation method, we carried out a laboratory experiment. We have experimentally confirmed that the yield of fruit and berry crops is higher with the alternative irrigation method. The new system improved irrigation water efficiency compared to the traditional drip system and achieved water savings of up to 20% [12].

One of the most important directions of scientific and technological progress in mechanisation and electrification of agriculture, is the development of methods and technical means, considering the requirements of environmental safety, application of electrophysical ways of influence on biological objects to increase their yields. Using electromagnetic and magnetic fields in seed pre-treatment and plant exposure, as well as in preparing irrigation water in irrigation systems, can increase the yield of grain, vegetable and other crops, their resistance to disease and stimulate plant growth.

At present, there are results of experimental studies indicating a positive effect of magnetic influence of irrigation water on growth, development and yield of agricultural crops.

Piped water that passes through the magnetic field of a permanent magnet is magnetised (figure 5). The passage of water through a magnetic field changes its structure and some physical-mechanical, chemical and bacteriological properties such as density, brine capacity and the degree of sedimentation of solids.

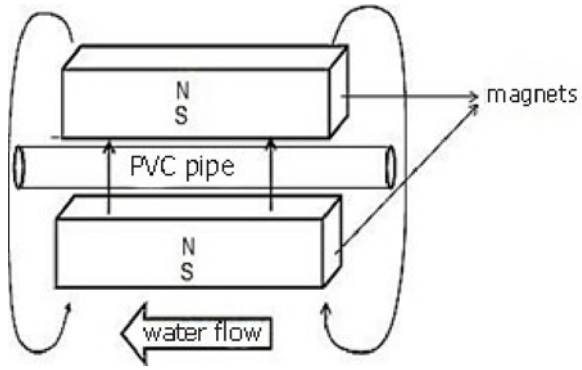


Fig. 5. Schematic diagram of magnetising water flow with magnets in a PVC pipe.

A device with a magnetic field in the range 3.5 to 136 mTl was used for magnetised irrigation water. Analysis of the data collected during the study shows that the effect of the magnetic treatment varied according to the type of plant and the type of irrigation water used. And there was also an increase in plant yield and plant water uptake.

3 Results and discussion

To improve the efficiency of drip irrigation systems, the drip irrigation unit was upgraded to include a soil moisture sensor to assess the uniformity of water distribution by drip trays at different pressures [13].

We selected five different types of Rivulis Eurodrip drip trays for the study (Figures 6 and 7), the specifications of which are shown in Table 1.

Table 1. Technical characteristics of the drip trays tested.

Type of drip tray	Series	Cover colour	Nominal flow rate, (l/h)
with pressure compensation	A	green	8
	B	black	3.85
	C	brown	2.2
without pressure compensation	D	black	4
	E	green	8

Drip trays with pressure compensation (Figure 6) compared to drip trays without pressure compensation (Figure 7) ensure uniform water supply to the active water use layer according to the manufacturer's specifications through each drip tray, and the water flow through such a drip tray does not change with pressure variations in the system.

Fig. 6. Pressure-compensated drip trays.

Fig. 7. Drip trays without pressure compensation.

Before starting the experiments, we vented the system and adjusted the inlet pressure of each main pipe to the required value. We placed 500 ml measuring vessels directly under each drip tray to determine the volume of water leaked in two minutes (Figure 8).

Experiments were carried out at three different pressures (P) – 0.05, 0.2 and 0.35 MPa, in triplicate.

Fig. 8. Experimental installation for drip irrigation.

The results of the experimental investigations carried out on all drip trays are shown in Figures 9 and 10 [17].

By increasing the operating pressure from 0.05 to 0.35 MPa, the volumetric flow rate of the A series droppers increased from 7.4 to 8.4 l/h, B from 3.6 to 4.9 l/h, C from 2.1 to 2.4 l/h, D from 3.1 to 8.2 l/h and E from 5.7 to 15.2 l/h (Table 2).

Table 2 shows that droppers with pressure compensation are less sensitive to changes in flow when pressure increases than droppers without compensation.

Table 2. Fluid flow rates at different pressures and deviations from the specified nominal flow rate.

Type of drip	Nominal flow rate (l/h)	Fluid flow rate at different pressures					
		0.05 MPa	Δ q %	0.2 MPa	Δ q %	0.35 MPa	Δ q %
tray A	8	7.4	-7.5*	7.9	-1.3	8.4	5.0
B	3.85	3.6	-6.5	4.3	11.7	4.9	27.3
C	2.2	2.1	-4.5	2.2	0.0	2.4	9.1
D	4	3.1	-22.5	5.9	47.5	8.2	105.0
E	8	5.7	-28.8	11.5	43.8	15.2	90.0

* A negative sign indicates the percentage of reduction

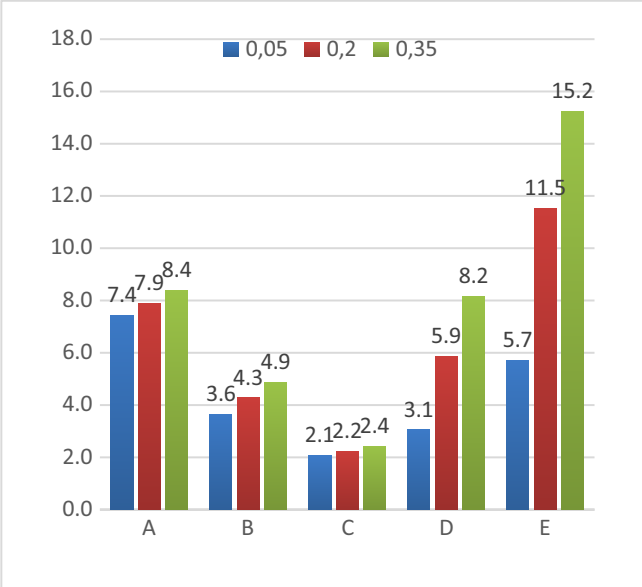


Fig. 9. Graphical dependence of liquid flow rate at different pressures.

Droppers type A and C (with pressure compensation) achieved significant uniformity of water flow and the smallest deviations from the set nominal flow rate at an operating pressure of 0.2 MPa. In type B droppers (also with pressure compensation), the uniformity of water flow decreased with increasing pressure.

Table 3 shows the coefficient of variation C_v, which expresses the uniformity of water flow through the drip trays.

The values of the coefficient of variation C_v of type D and E droppers (without pressure compensation) increased with increasing operating pressure in the system, indicating the dependence of the uniformity of flow on system pressure (Table 3).

Table 3. Coefficient of variation C_v of drip flow rate from nominal pressure.

Pressure, P MPa	C_v				
	A	B	C	D	E
0.05	0.10	0.07	0.05	0.25	0.30
0.2	0.05	0.12	0.03	0.49	0.46

0.35	0.06	0.32	0.11	1.00	0.95

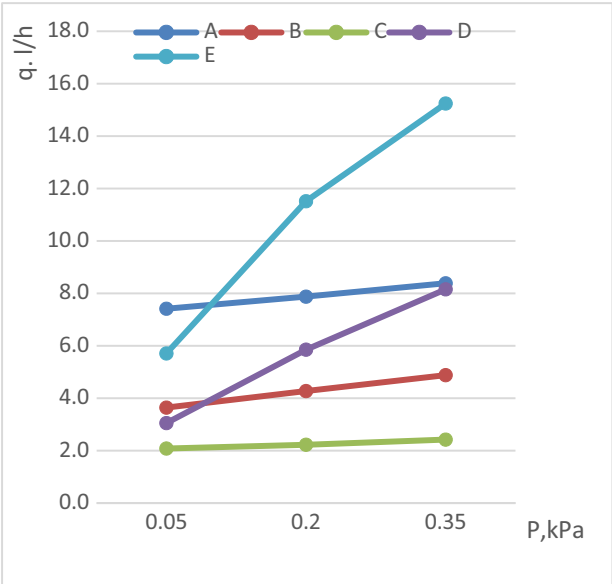


Fig. 10. Dependence of volume flow of drip trays on pressure.

We should note that for all dropper types the coefficient of variation C_v and the average deviations of the water flow rate from the specified nominal flow rate were achieved at low operating pressure in the system.

4 Conclusion

The results of these studies show that pressure-compensated drip trays are less sensitive to changes in pressure with an operating pressure of 0.35 MPa. The water consumption (q) of type A droppers increased by 5.27%, B by 27.3% and C by 9.1%. Type D and E drip trays have the lowest flow uniformity at different pressure levels. Under actual irrigation conditions, we recommend installing pressure gauges not only in the collector line, but also on the main pipes (preferably at the end of each main pipe) to determine the pressure drop and pressure loss in the system.

References

1. D. Khaliullin, I. Badretdinov, I. Naficov, R. Lukmanov, Engineering for Rural Development (Jelgava, 26–28 May 2021) **20,** 1501–1506, doi: 10.22616/ERDev.2021.20.TF321 (2021)
2. D. T. Khaliullin, et al, BIO Web of Conf. **27,** 000103, doi: 10.1051/bioconf/20202700103 (2020)
3. R. Galimov, I. G. Galiev, A. T. Kulakov, E. R. Galimov, BIO Web of Conf. **37,** 00052 (2021)
4. M. Kh. Faskhutdinov, BIO Web of Conf. **27,** 00056, doi: 10.1051/bioconf/20201700056 (2020)
5. N. M. Egorov, F. Kh. Khaliullin, S. M. Yakhin, BIO Web of Conf. **27,** 00124
6. I. Nafikov, R. Khusainov, R. Lukmanov, I. Galiyev Engineering for Rural Development (Jelgava, 26–28 May 2021) **20,** 1416–1421, doi: 10.22616/ERDev.2021.20.TF304 (2021)
7. E. R. Dalaleev, I. N. Gayaziev, B. G. Ziganshin, et al., Rural mechanic **6,** 28–29 (2017)
8. I. M. Gomaa, I. I. Kashapov, R. R. Khaidarov, et al, BIO Web of Conf. **27,** 00233, doi: 10.1051/bioconf/20201700233 (2020)
9. I. I. Kashapov, B.G. Ziganshin, Yu. A. Tsoi, et al., Bulletin of Kazan State Agrarian University **15 (3 (59),** 84–87, doi: 10.12737/2073-0462-2020-84-87 (2020)
10. B. G. Ziganshin, I. G. Galiev, R. K. Khusainov, A. Abdelfattah, BIO Web of Conf. **27,** 00119 (2020)
11. A. H. Abdelfattah, R. F. Sabirov, et al., BIO Web of Conf. **27,** 00249, doi: 10.1051/bioconf/20201700249 (2020)
12. B. Ivanov, B. Ziganshin, A. Dmitriev, et al., BIO Web of Conf. **27,** 00109
13. B. L. Ivanov, B. G. Ziganshin, et al., Bulletin of the Kazan State Agrarian University **14 (3 (54),** 103–107, doi 10.12737/article_5db969d80165a4.44685655 (2019)