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ADVANCED TECHNOLOGIES APPLIED TO HOSE REEL RAIN-GUN MACHINES: NEW PERSPECTIVES TOWARDS SUSTAINABLE SPRINKLER IRRIGATION

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ABSTRACT The paper describes some outstanding technological innovations and improvements of hose reel rain-gun machines related to working characteristics, application efficiency, distribution uniformity, energetic performance and economic profitability. During time, electronics and control units evolved, and the improved quality of polyethylene enables the industrial production of bigger and longer pipes. Increased efficiency of pumps, hydraulic turbines and transmission systems, results in substantial reduction of energy requirement per unit of irrigated land and supplied water. New rain-gun sprinklers allow high water distribution uniformity and minimal effects of drops on crop and soil. Operating capacity of modern medium-high machines allows irrigating of 50 ha and more of horticultural and industrial crops during peak period under sub-humid climate. Comfort and safety of labour take advantage of the remote control of several operations. Machine handiness is facilitated by hydraulic control systems, resulting in time and labour saving. Fertigation can be practised, allowing significant crop yield increases. Interfacing transmission control of pipe rewinding, field mapping, Global Positioning System (GPS) technology, sprinkler rotation speed and wetting angle, gives the possibility of precision agriculture, also increasing irrigation efficiency. The latest rain-gun machines can practice precision farming, having the chance to irrigate irregular field shapes. Precision irrigation has high potential, due to new technologies, for the future.

Keywords: hose reel machines, precision agriculture, irrigation efficiency, energy saving, fertigation.

INTRODUCTION Early hose reel rain-gun machines (RGMs) were conceived for complementary irrigation of cereals and fodder crops, cultivated in large and regular fields of sub-humid regions. The effectiveness of the prompt irrigations allowed by those machines, did not prevent them from the criticism of some working characteristics. The quite high energy required, the "no higher than fair" average uniformity of distribution, the impact of big drops on crop and soil, were considered as peculiar to the rain-gun machines. Due to these reasons, and probably to the increasing diffusion of micro irrigation, the hose reel machines were often stereotyped because of their limits by sector literature and popular beliefs. Since modern irrigation must pay attention to water saving and energy efficiency, taking care of farmer's income in the framework of resource sustainability, all parts of the RGM took advantage of available technology during time, overcoming most limits affecting former models. Working performance of modern RGMs can match agronomical, economical and environmental request of today's irrigation practice worldwide. In spite of this, prejudice on RGMs (i.e., political tendency, disinformation) still affect correct information to potential users.

HISTORICAL REMARKS Hose reel machines appeared in France during early '70s, and in Italy few years later. First models were quite simple and profitably destined to aid sowing in regions affected by dry spring (Bassez et Dubalen, 1987). Due to the original agronomic use, little attention was paid to hydraulic, irrigation and energy performance. Execution and control of irrigation-related activities was labour and time consuming, and two or more persons were requested for transporting and positioning one machine. Comfort and safety of the working conditions were critical, and problems such as tipping of the rain-gun trolley could happen during irrigation without any alarm communication. Towards the end of the '80s, RGMs were equipped with simple control units, in order to regulate some working parameters, such as the rewinding speed of the hose. The support given to users by electronic devices, together with the political guidelines regulating the agricultural sector, fostered the spreading of RGMs. At the beginning of the current Century, control units developed more functions, enabling farmers to get further working information and improve the management of irrigation parameters. Units were able to suspend irrigation when excessive pressure drop took place, then restart it after a new programme was rearranged, i.e., accounting for scheduled irrigation dose or irrigation time. Information communication, such as alarm, irrigation stop and re-start, was allowed. Maximal length and external pipe diameter of widespread machines were 400 m and Ø 125 mm respectively (Mathieu et al., 2007). Rewinding speed of the hose/sprinkler unit was usually chosen accounting for the irrigation dose and the application rate, the latter depending on working pressure, nozzle diameter and wetting radius, as reported in the technical brochures. Pressure falls may occur due to pumping problems, leakage or other reasons, reducing throw length, drops atomization, and speed rewinding, therefore affecting amount and uniformity of the supplied water. In order to overcome such frequent incident, systems able to control and manage automatically the hose rewinding under modified working conditions were studied, carried out and developed during time. Collaboration between engineering Industries and hose reel Factories, developed modular automated transmissions allowing precise different water supplies along the irrigated area during hose rewinding. Electronic devices, applied to the modern machines, allow additional functions to the remote control, such as start and adjustment of the pump engine interfacing the control unit. Towards the end of the current decade, plastic quality allowed bigger and longer polyethylene pipes, increasing the working capacity of the machines. Technological progress also concerns rain-gun sprinkler performance and operation. Recently, the combined action between sprinkler and transmission, supported by the GPS technology and the wireless communication, was studied and implemented in order to practice precision agriculture. This innovation is an important step towards the use of RGMs in precision irrigation.

ADVANCED ITEMS Technological progress allowed the overcoming of most limits which affected the performance of RGMs in the past. Modern models take advantage of a number of technological improvements, able to increase the overall effectiveness due to both individual and coordinated performance.

Fertigation During recent research projects (2005-2010) carried out by the University of Florence in irrigated farms located in Central and Northern Italy, many farmers stated that system selection was influenced by the possibility of practicing fertigation, and that fertigation was not (profitably) allowed by rain-gun machines. Modern RGMs can be equipped with fertigation systems, as illustrated in Figure 1.

Figure 1. Hose reel machines equipped with fertigation system.

Field experiences on fertigation, carried out comparing rain-gun hose reel, boom hose reel, solid set and drip lines, were executed on Tomatoes (Tassi and Gatti, 2008). According to the results, best performance in terms of yield and gross income per hectare was given by the RGM.

Pipes and working capacity The improvement of plastic quality permits big and long pipes. Today, polyethylene pipes up to Ø 140, 150 and 160 mm in external diameters, can be 700, 500 and 480 meters long, respectively. Bigger diameters can support improved energetic efficiency and working capacity. Under cropping conditions typical of sub-humid climates, i.e., 30 mm irrigation depth, 7 days irrigation interval, and assuming 22 working hours per day, the irrigation capacity of a machine 300 m hose length, external pipe diameter Ø 125 mm, nozzle diameter Ø 32 mm, operating at 500 kPa in pressure, is 470,000 m^2. Under the same conditions, machines equipped with pipes Ø 140 and 150 mm in diameter can irrigate 590,000 and 660,000 m^2 respectively (25 and 40% more), using nozzle diameters Ø 36 and 38 mm respectively (Taglioli, 2008). The daily working time, close to 24 hours, depends on both the high degree of automation and remote control allowed by the new electronic applications, and the rapidity in the execution of transfer and setting operations permitted by the hydraulic support (Figure 2).

Figure 2. Pipes and control sticks of the hydraulic devices.

Differently from the past, the request of manual labor is minimal today, depending on factors such as field size, machine characteristics and farm infrastructures. According to current field surveys (University of Florence, 2009, in progress), one person is able to displace and position one RGM for the irrigation of sectors from 20,000 to 60,000 m^2, by working 45 minutes on average.

Sprinklers (rain-gun) Working capacity and water distribution characteristics of modern RGMs are affected by the performance of watering devices. A broad range of rain-guns is available today. Big models can operate at pressures up to 1,000 kPa, throwing water to about 100 m, and delivering more than 70 litres per second over a wetted area of about 30,000 m^2. Besides the extreme working values, modern high flow sprinklers are provided by relevant operational characteristics. Distribution uniformity of former RGM models (i.e., 10 to 20 years old), defined by the Christiansen coefficient of uniformity (CU), is generally from 70 to 80% (Smith et al., 2003), yielding the typical distribution pattern illustrated in Figure 3 (Ghinassi, 2008).

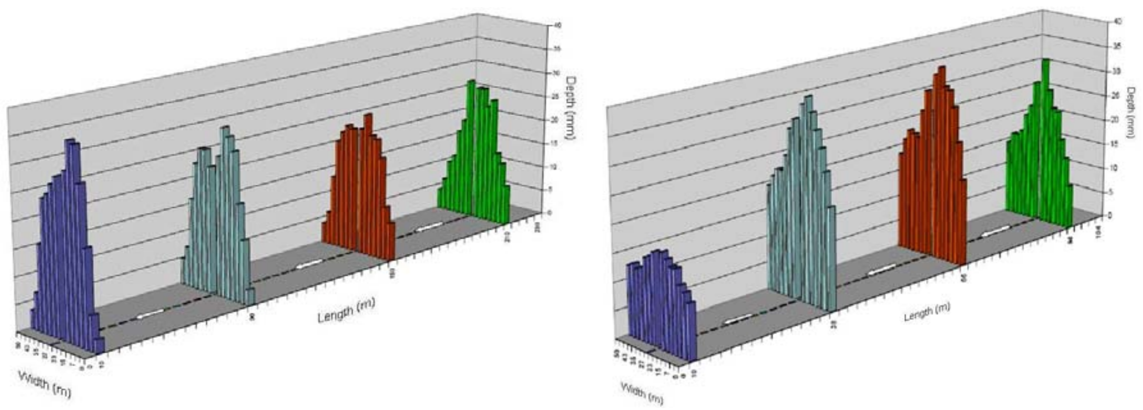

Figure 3. Distribution patterns of old RGM models.

According to the sketch, much water is supplied along and beside the traveling line, whereas the edge of the wetted area receives little water. Moreover, irrigation of the farthest side of the field, where RGM irrigation starts, is critical. Some modern rain-gun models are able to reverse automatically the irrigation direction after a preset irrigation time (Figure 4), enabling the increase of irrigation efficiency.

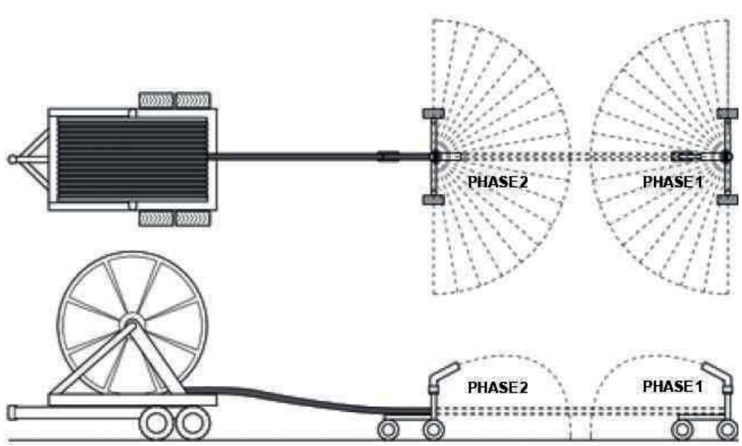

Figure 4. Schematic representation of the automatic reverse of irrigation direction.

Late big rain-guns can combine efficiency, working capacity and safe water distribution. Moreover, some of them can help overcoming local constraints, such as irregular field shape and wind, thanks to the possibility of varying the jet angle (Figure 5).

Figure 5. Jet atomization (left) and sprinkler with variable jet angle (right).

Field test carried out on a rain-gun supplying about 100 m^3/h of water, under moderate wind (<1.2 m/s) and “free flow” nozzle (flow breaker off), yielded CU values varying from 81% to 85% under jet angle from 15° to 35°. According to the same test, the distribution efficiency, defined as the ratio between measured and expected supplied volumes, ranged from 75% to 99%, depending on working pressure, jet angle and nozzle diameter (Taglioli, 2006). From the practical point of view, this is a relevant support to precise field water supply.

Control units New control units can allow complete information on hose reel machines, interfacing user during the irrigation execution. Controlled functions refer to working information and to irrigation program. Remote control allowing farmers to monitor and adjust some working process, such as irrigation start, stop and restart, is available due to modem GSM technology (Figure 6).

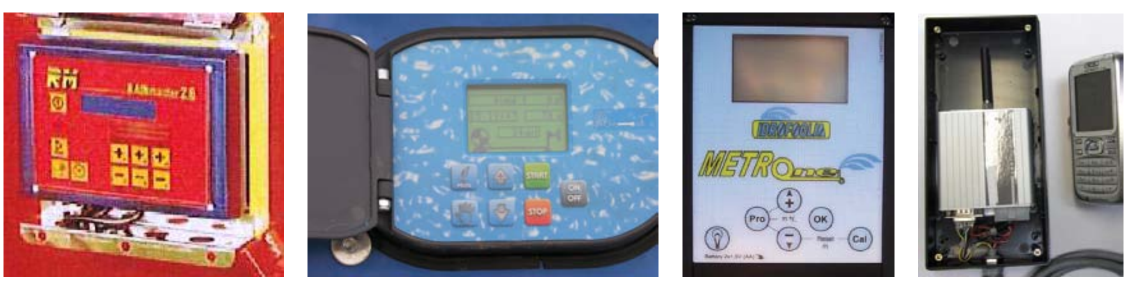

Figure 6. Control units and modem GSM for remote control.

Under critical working conditions, such as excessive pressure drop or wind speed, irrigation can be stopped automatically. When problems are solved, the control unit will carry out irrigation according to the preset priorities, that is irrigation depth in most cases. Due to improved transmission systems, sensors and electronic technology suitable to field applications, further operations can be managed through new functions allowed by the control units, the number of which increased through time, yielding accurate information on operating performance (Taglioli, 2006). Control units can display the machine working speed and working time, the scheduled water application depth, the time delay at start and end position, the water flow and other information. Connecting the unit with a GSM modem, information on problems related to pressure, working speeds and other mechanical or setting failures, will be sent to preset mobile phone numbers. Moreover, remote pump start and adjustment of water pressure is allowed by controlling the pump engine thanks to advanced clutch transmission technology. Control is permitted by both mobile sms and web connection (Figure 7).

Figure 7. Control unit and communication devices for adjustment of water pressure.

Transmission Hose rewinding is allowed by the hydraulic energy of the water flow caught by a turbine and transferred to the reel through a gear transmission. Hose winding round the reel would increase the rewind speed without any regulating equipment. First “speed compensators” appeared during early ‘80s, acting mechanically on the turbine bypass. Electronic was applied to the speed control at the end of the same decade. The kinematics layout of former transmission systems was composed of a Pelton type turbine connected to the driving gear shaft by a belt, resulting in rewinding speed no higher than 40-60 m/h. High water pressures were requested at the machine inlet (more than 600-700 kPa), due to both pipe diameters unsuited to delivered discharges, and low energetic efficiency of the turbine (friction losses up to 100 kPa and more). In new transmission systems, the turbine is fastened to the driving gear shaft, abating frictions this way. Increase of energetic performance allows low pressure working conditions (i.e., 150 kPa when connected to booms, Figure 8) and higher rewind operation.

Figure 8. Low pressure hose reel booms.

Working speed of the machine can be managed automatically by the control unit acting on the turbine bypass. The speed variation range is about 20-30 m/h, allowing to shift the field into sectors (i.e., different water requirements along the field) by programming up to four combinations of field length and working speed along the field (Figure 9).

Figure 9. Automated variable transmission. Turbine is fastened on the driving gear shaft.

Other automatic transmission systems allow wider traveling speed ranges (i.e., 20 to 150 m/h) by both selecting gear speed and managing turbine bypass.

Precision agriculture Latest updates concern the combined use of wireless and Global Positioning System (GPS) technology, intended for the intelligent irrigation process. According to the new approach, irrigation water is supplied by an integrated and interacting system (IIS) consisting of Personal Digit Assistant (PDA), GPS unit, sprinkler controlled electronically, and automated hose rewinding transmission (Figure 10). The rain-gun is located by the GPS, and both irrigation angle and rotating speed are governed by the control unit according to the field shape and the preset irrigation scheduling. The field-shape map is plotted by the user and stored in the PDA unit.

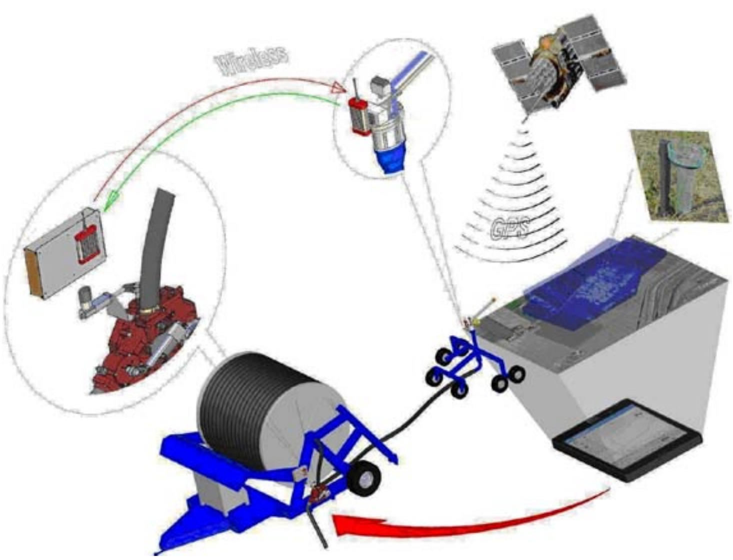

Figure 10. Integrated RGM irrigation system (courtesy: Comer Industries S.p.A., *modif.*).

After starting, the sprinkler can reverse automatically the irrigation direction, and wet irregular field boundaries during the rewinding travel. According to the specific needs along the field, the integrated system is able to adjust the working conditions of the sprinkler by properly combining rotation speed, irrigation angle and travelling speed, in order to match the targeted irrigation depth according to the precision agriculture approach. Field size and shape can affect the irrigation system selection, as well as shape variations and obstacles such as buildings (Figure 11).

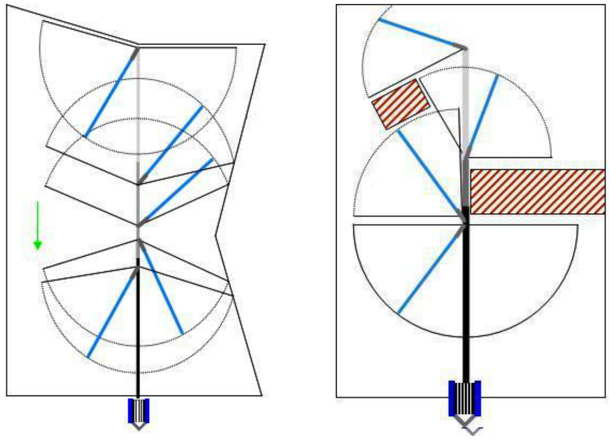

Figure 11. Improved RGM irrigation of irregular fields.

Under similar conditions, different systems (i.e., solid set, drip) would be chosen, unless developed RGM irrigation can help overcoming the external constraints. Increasing the rotation speed of the sprinkler when supplying water to the central part of the irrigated area, will result in a flattened distribution pattern (Figure 12), different from the one in Figure 3.

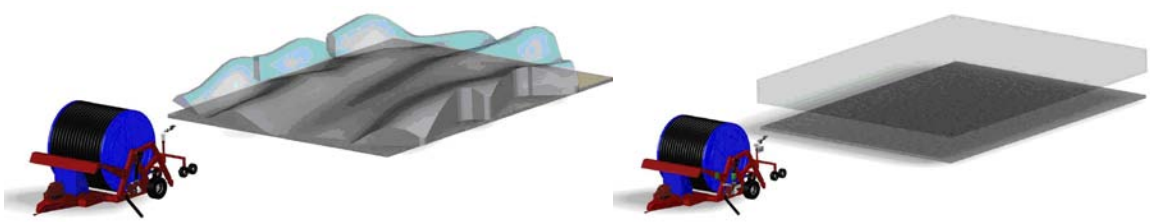

Figure 12. Typical (left) and improved (right) distribution pattern.

During preliminary field tests, flattening of the distribution profile allowed to increase up to 50% the width of the irrigated area matching the targeted water depth. Such performance enables the achievement of better field distribution efficiency (i.e., application and uniformity), and increases the RGMs working capacity by reducing the overlapping of wetted areas. Problems arising from pressure variations (i.e., reduced jet throw and discharge) can be overcome successfully by the automatic arrangement of rain-gun wetting angle and working speed. The latter chance is allowed by the most advanced transmission systems, acting automatically on both turbine bypass and gear selection. Moreover, the new IIS system has the potential to support soil and yield maps, allowing precision irrigation in the next future.

CONCLUSION Performance of RGMs improved significantly during time. The use of modern machines is simple and user friendly, and the high level of automation requires minimal human labor operating under safe and comfortable conditions. With respect to the past, the new rain-gun sprinklers are able to supply water much more uniformly and with minimal impact on crop and soil, therefore being suitable to most annual crops.

Sprinkling machines can be equipped with tools supporting precise applications of water and fertilizers. The working capacity increased with the agronomic and energetic efficiency, resulting in economical and environmental advantages. Latest machines take advantage of wireless and GPS technology, allowing the practice of precision agriculture under the support of integrated and interacting systems. Since they have the potential to support other information maps, precision irrigation is the step expected in the next future.

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