Variable Rate Spraying

Area 2 – **Technologies**

Lesson 6 – **Variable Rate Technology**

Sequence ID – **21**

UPM

SPARKLE

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A2.L6.T3 Variable rate spraying

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Achieving Variable Rate Spraying

$$Rate_{application}(L/ha) = \frac{Rate_{flow}(L/\min) \cdot 600}{width_{working}(m) \cdot speed_{forward}(km/h)}$$

To vary application rate:

Variation in working width is not usually carried out

Variation in forward speed could compromise the quality of the operations and the working capacity [ha/h]

Variation in flow rate through actuators in the meter system

Achieving Variable Rate Spraying

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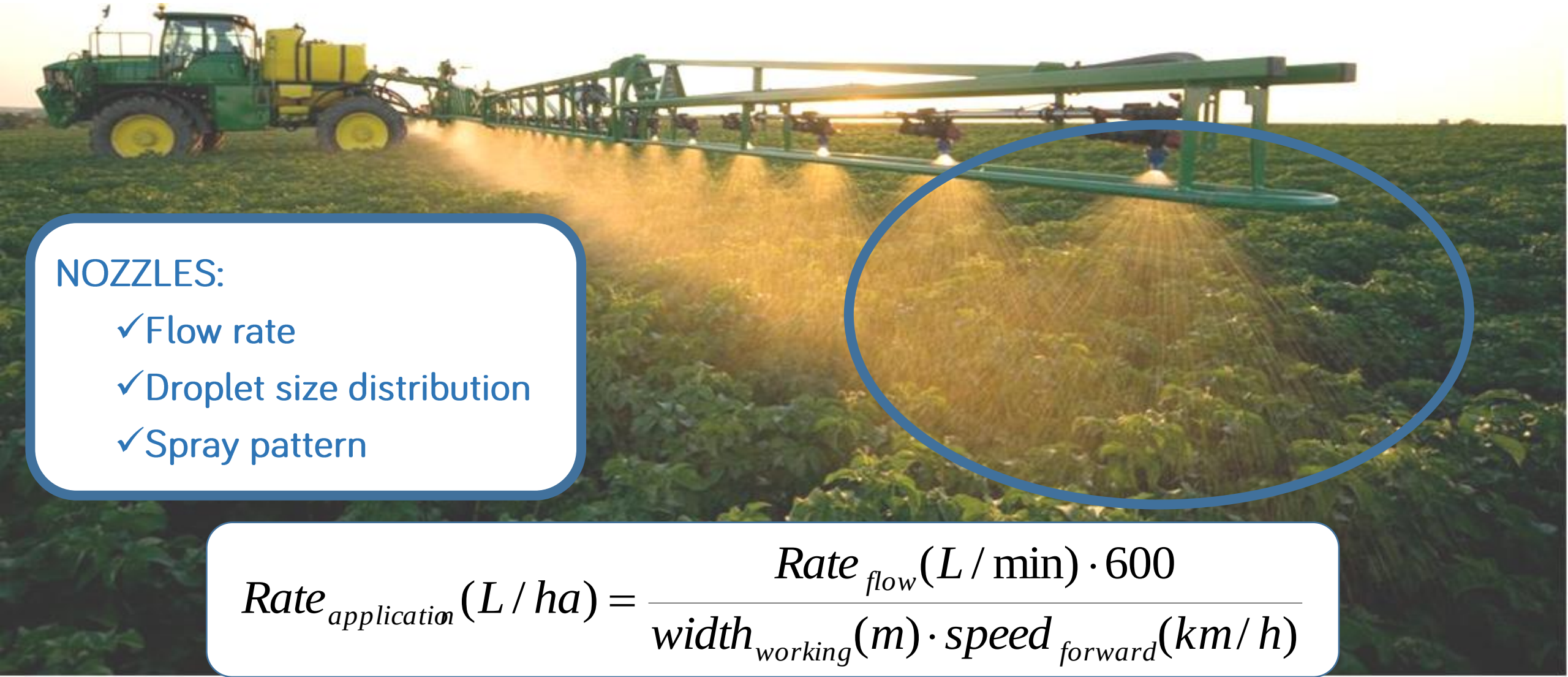

NOZZLES:

- ✓Flow rate
- ✓Droplet size distribution
- ✓Spray pattern

$$Rate_{application}(L/ha) = \frac{Rate_{flow}(L/\min) \cdot 600}{width_{working}(m) \cdot speed_{forward}(km/h)}$$

At each individual nozzle (1/2)

flow rate (l/min) = K · A (mm²) · √pressure (bar) / density(kg/l)

At constant pressure:

A larger metering orifice size (A) a higher flow rate

At constant metering orifice size:

A higher pressure a higher flow rate

Example of flow rate chart for technical pressure range:

Pressure (bar)	1.5	2.0	2.5	3.0	4.0	5.0
ISO size/colour	flow rate (l/min)					
0075-Pink	0.21	0.24	0.27	0.30	0.35	0.39
01-Orange	0.28	0.33	0.37	0.40	0.46	0.52
015-Green	0.42	0.49	0.55	0.60	0.69	0.77
02-Yellow	0.57	0.65	0.73	0.80	0.92	1.03
025-Lilac	0.71	0.82	0.91	1.00	1.15	1.29
03-Blue	0.85	0.98	1.10	1.20	1.39	1.55
04-Red	1.13	1.31	1.46	1.60	1.85	2.07
05-Brown	1.41	1.63	1.83	2.00	2.31	2.58
06-Grey	1.70	1.96	2.19	2.40	2.77	3.10
08-White	2.26	2.61	2.92	3.20	3.70	4.13
10-Light blue	2.83	3.27	3.65	4.00	4.62	5.16

At each individual nozzle (2/2)

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At constant pressure:

A larger metering orifice size
a higher droplet size

At constant metering orifice size:

A higher pressure
a lower droplet size
and a higher angled spraying pattern

HARDI ISO F-110
Standard flat fan nozzles

bar	1.5	2.0	2.5	3.0	4.0	5.0
ISO size/colour	l/min					
0075-Pink	0.21	0.24	0.27	0.30	0.35	0.39
01-Orange	0.28	0.33	0.37	0.40	0.46	0.52
015-Green	0.42	0.49	0.55	0.60	0.69	0.77
02-Yellow	0.57	0.65	0.73	0.80	0.92	1.03
025-Lilac	0.71	0.82	0.91	1.00	1.15	1.29
03-Blue	0.85	0.98	1.10	1.20	1.39	1.55
04-Red	1.13	1.31	1.46	1.60	1.85	2.07
05-Brown	1.41	1.63	1.83	2.00	2.31	2.58
06-Grey	1.70	1.96	2.19	2.40	2.77	3.10
08-White	2.26	2.61	2.92	3.20	3.70	4.13
10-Light blue	2.83	3.27	3.65	4.00	4.62	5.16

HARDI ISO LD-110
LowDrift nozzles

bar	1.5	2.0	2.5	3.0	4.0	5.0
ISO size/colour	l/min					
01-Orange	0.28	0.33	0.37	0.40	0.46	0.52
015-Green	0.42	0.49	0.55	0.60	0.69	0.77
02-Yellow	0.57	0.65	0.73	0.80	0.92	1.03
025-Lilac	0.71	0.82	0.91	1.00	1.15	1.29
03-Blue	0.85	0.98	1.10	1.20	1.39	1.55
04-Red	1.13	1.31	1.46	1.60	1.85	2.07
05-Brown	1.41	1.63	1.83	2.00	2.31	2.58

Droplet size*:

Fine	Coarse
Medium	Very coarse

* Droplet size does not depends on the ISO colour

Variable Rate Spraying Strategies

I. VR spraying based on changing pressure

II. VR spraying based on changing metering orifice size

III. VR spraying based on pulse width modulated flow control

Effects on droplet size and spraying pattern

- Important in pesticices
- Less important in liquid fertilizers

No effects on droplet size and spraying pattern

I. VR spraying based on changing pressure

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❑ Method based on the pressure control according to forward speed to adjust the flow rate that assures an application rate (DPAE).

❑ In VR Spraying, DPAE system connected to a GPS or to a soil/crop sensor allows modifying the application rate on-the-go.

❑ This system is relatively simple. Common elements are:

- GPS (for location and speed computation) or sensor (for soil/crop properties)
- servo valve for pressure control (thus, flow rate) with and electronic controller
- flow-meter (to assure flow rate precision independent of the state of use of the nozzles)
- groundspeed sensor (when no GPS is implemented) such as a radar- or wheel-based speedometer
- microprocessor that uses information on working width and prescribed application rate to calculate the appropriate flow rate for the current groundspeed

❑ Flow rate changes across the boom as quickly as the control system can respond to a new rate command and the fluid flows along the whole length of the boom (Christmas-tree pattern spraying).

Servo valve for pressure control

Flow-meter

To nozzles

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Main on/off electro-valve

Strainer

Section on/off electro-valves

Application rate (L/ha)

Console

Safety valve

Tank

Controller

Pump

Strainer

GPS antennae

Groundspeed sensors

I. VR spraying based on changing pressure

MAIN DRAWBACK

Small increments of flow rate require large pressure increments due to the square root relationship between both parameters

$$\frac{\text{Flow rate}_{new}}{\text{Flow rate}_{current}} = \sqrt{\frac{\text{Pressure}_{new}}{\text{Pressure}_{current}}} \Rightarrow 2 \cdot \frac{\text{Flow rate}_{new}}{\text{Flow rate}_{current}} = \sqrt{4 \cdot \frac{\text{Pressure}_{new}}{\text{Pressure}_{current}}}$$

HIGHER PRESSURE

- Finer droplet size
- More drift-prone
- Higher fan angle, poorer pattern uniformity
- Out of technical range posibility
- When flow rate increment requires more than 3-fold pressure change ⇨ prescribed application rate is achieved by reducing forward speed or by using a nozzle with larger metering orifice

LOWER PRESSURE

- More coarse droplet size
- More sliding-prone
- Lower fan angle, less overlap, poorer pattern uniformity
- Out of technical range posibility

II. VR spraying based on changing metering orifice size

II.A. Variable orifice size nozzles

A flexible material deforms slightly with pressure providing a variable diameter orifice that produces a wider range of flow rates than a conventional nozzle system over the same pressure range. A single nozzle allows for a wider range of application rates and/or forward speeds.

Used for liquid fertilizer applications as spraying pattern is less important than in pesticides applications.

II.B. Multiple active nozzles

Individual or multiple nozzles are activated and deactivated to provide flow rate simultaneously according to total needs.

Nozzle activation involves variations in pressure so that nozzle combination has to be carefully selected by the controller system.

II. VR spraying based on changing metering orifice size

II.A. Variable orifice size nozzles

- Elastomer (EPDM) variable orifice (1/2)
  - Pressure directly varies metering orifice
  - No springs or moving parts

Teejet SJ7A-VR and SJ3-VR lines of Variable Rate Fertilizer spray nozzles

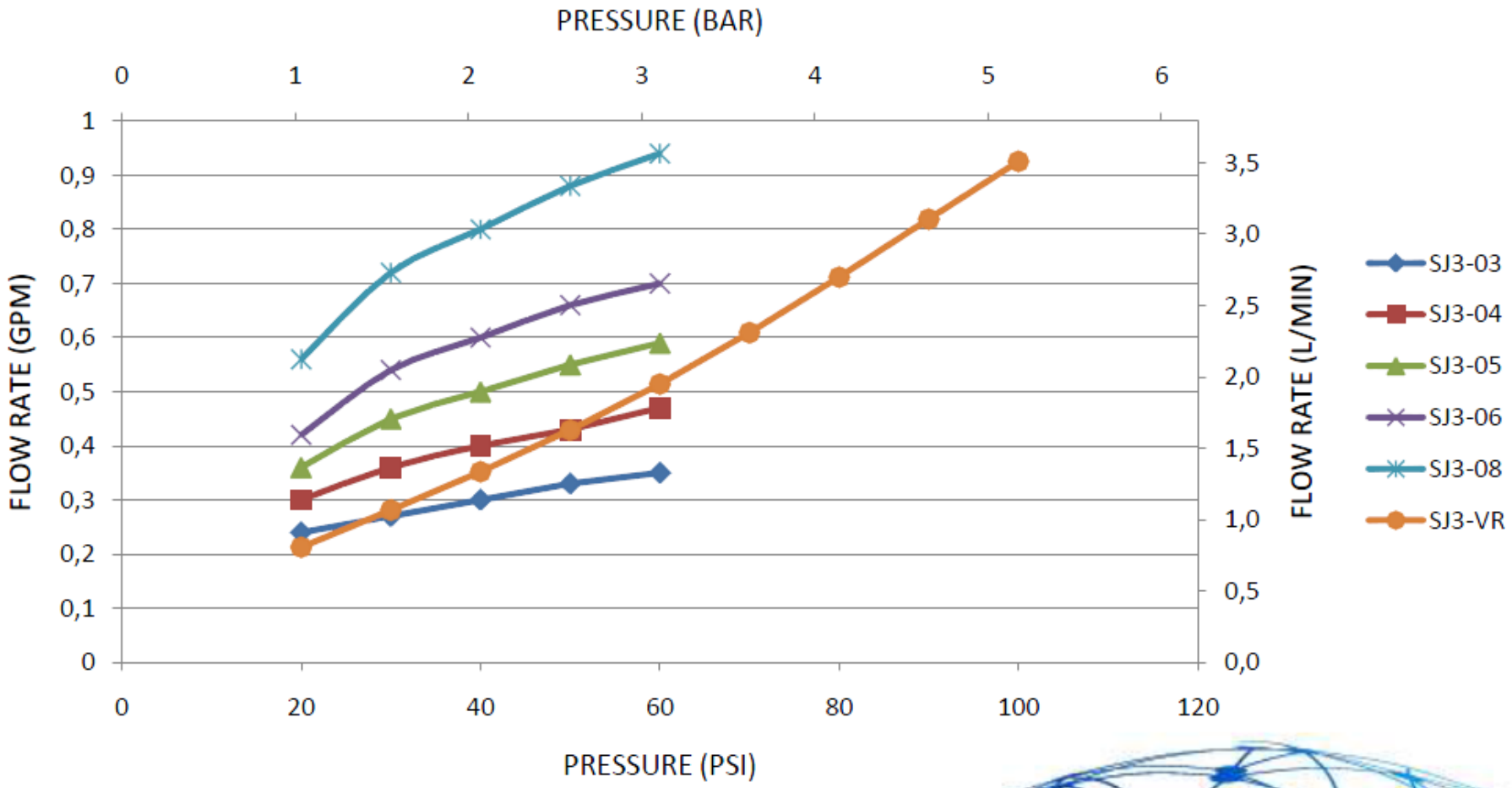
Nozzle	Liquid Pressure in bar	Capacity 1 Nozzle in l/min
SJ7A-VR-X0.5	2.0	0.59
	2.5	0.67
	3.0	0.76
	3.5	0.85
	4.5	1.07
	5.5	1.33
SJ7A-VR-X1.0	2.0	1.01
	2.5	1.20
	3.0	1.42
	4.0	1.94
	5.0	2.58
	5.5	2.94
SJ7A-VR-X2.0	2.0	2.62
	2.5	3.00
	3.0	3.42
	3.5	3.87
	4.5	4.84
	5.5	5.92

Nozzle	Liquid Pressure in bar	Capacity 1 Nozzle in l/min
SJ3-VR-X0.5	1.5	0.51
	2.0	0.58
	3.0	0.71
	4.0	0.87
	5.0	1.06
	6.0	1.28
	7.0	1.55
SJ3-VR-X1.0	1.5	0.84
	2.0	1.02
	3.0	1.41
	4.0	1.84
	5.0	2.33
	6.0	2.86
	7.0	3.44
SJ3-VR-X2.0	1.5	2.19
	2.0	2.58
	3.0	3.36
	4.0	4.11
	5.0	4.85
	6.0	5.58
	7.0	6.29

II. VR spraying based on changing metering orifice size

II.A. Variable orifice size nozzles

SJ3-VR vs STANDARD SJ3



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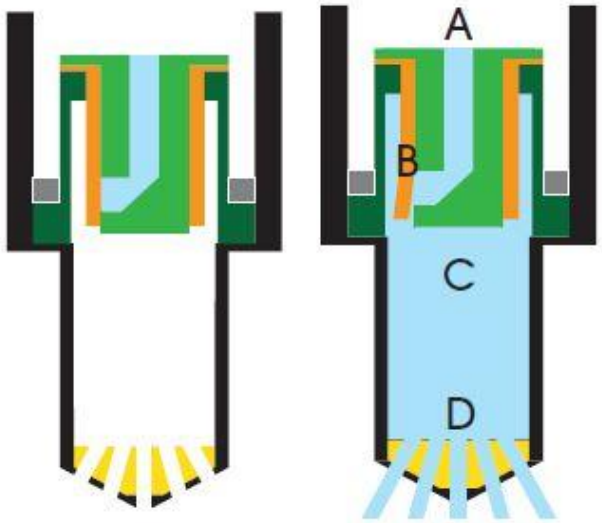
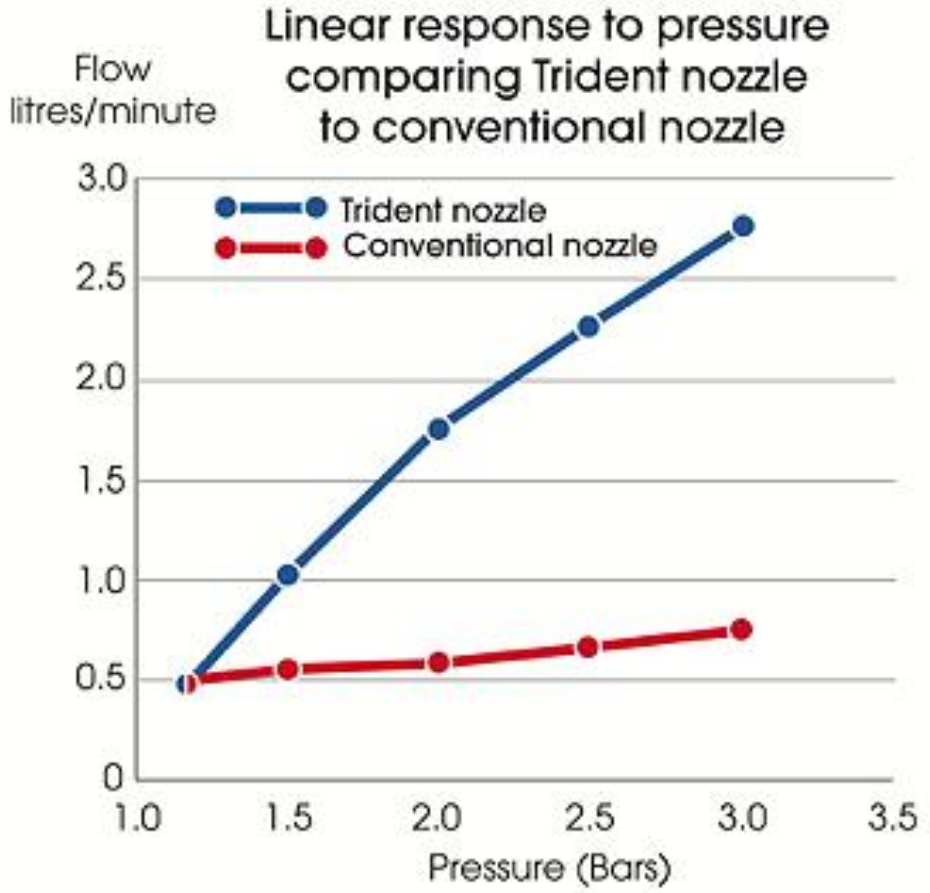
II. VR spraying based on changing metering orifice size

II.A. Variable orifice size nozzles

- Elastomer (EPDM) variable orifice (2/2)

BFS Trident line of Variable Rate Fertilizer spray Nozzles





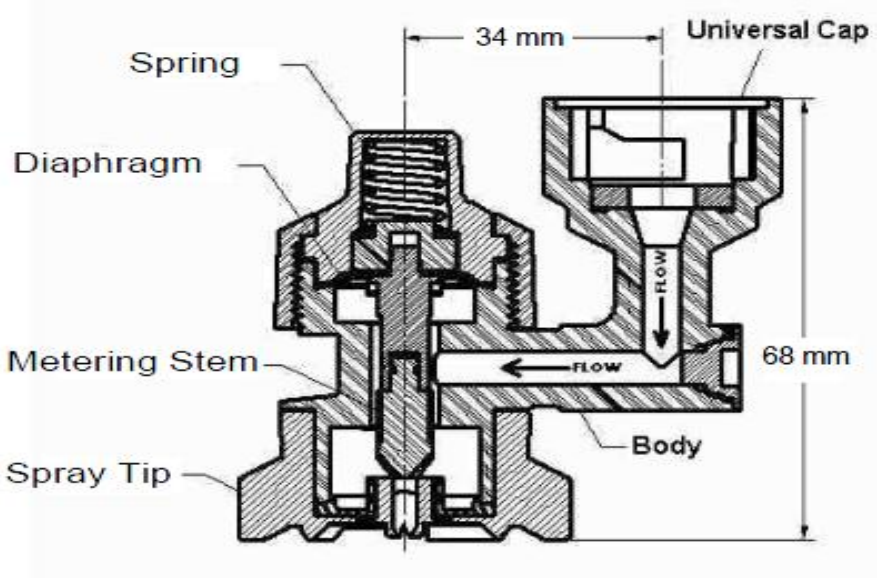
II. VR spraying based on changing metering orifice size

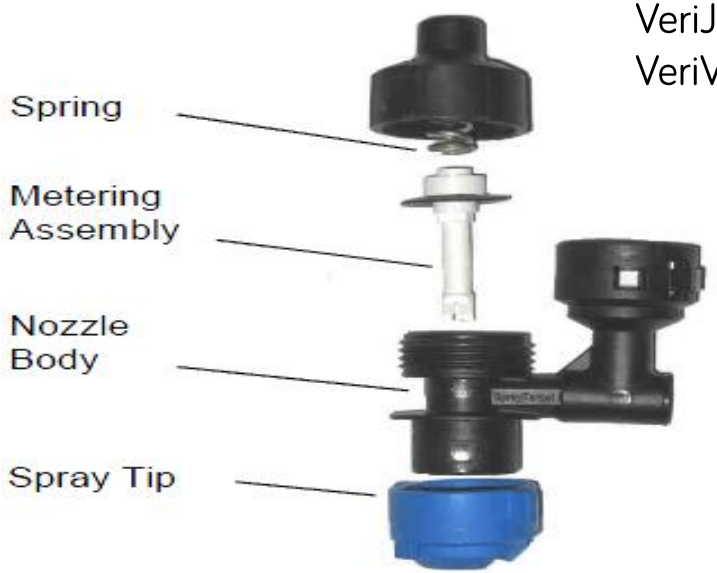
II.A. Variable orifice size nozzles

❑ **Pressure-activated springs on flexible metering assembly**

- The nozzle comprises a flexible spray tip that is automatically deformed by a flexible metering assembly in response to changes in liquid pressure

SprayTarget line of Variable Rate Fertilizer spray Nozzles





VariTarget : 0.10 – 0.80 GPM
Hi-VariTarget : 0.25 – 2.50 GPM
VeriJet : 0.15 – 1.20 GPM / 0.25 – 2.50 GPM
VeriVolume : 2.0 – 12.0 GPM

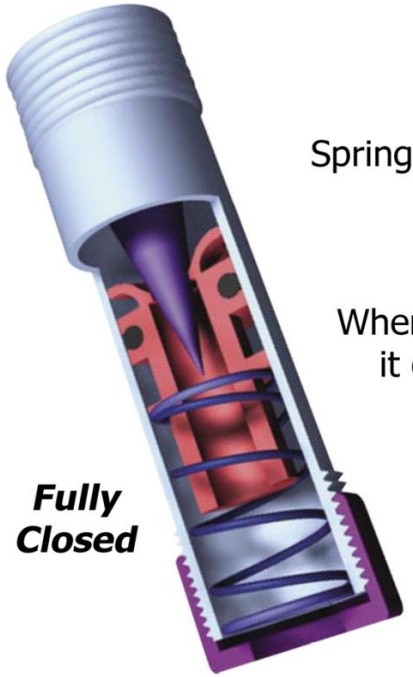
II. VR spraying based on changing metering orifice size

II.A. Variable orifice size nozzles

❑ Pressure-activated springs on moving assembly (1/2)

- The nozzle comprises a fixed cone inside a moving cylindrical assembly that provides different sections of the metering orifice.

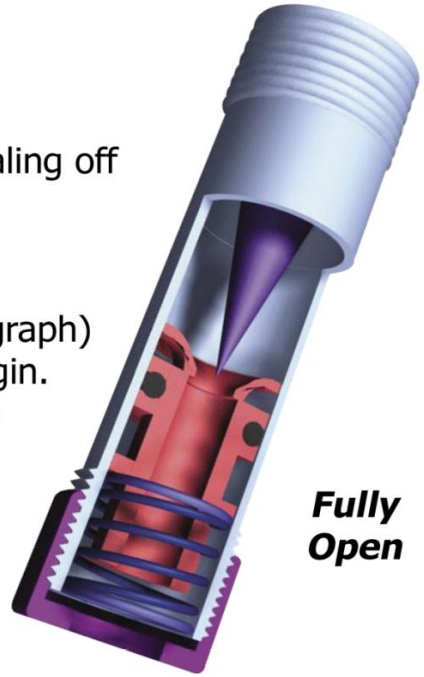
Spratronics line of O-Nozzle Variable Rate Fertilizer spray Nozzles



Fully Closed O-Nozzle
Spring pushes orifice assembly tightly against cone, sealing off liquid flow with no dripping.

Partially Open O-Nozzle
When system pressure is increased to 1-16 PSI (see graph) it overcomes spring resistance, allowing flow to begin. Spring continues to compress proportionately to control system pressure. Orifice allows flow rate corresponding to PSI (see graph).

Fully Open O-Nozzle
When spring is nearly fully compressed, flow rate reached maximum 12-14 GPM.



Fully Closed

Fully Open

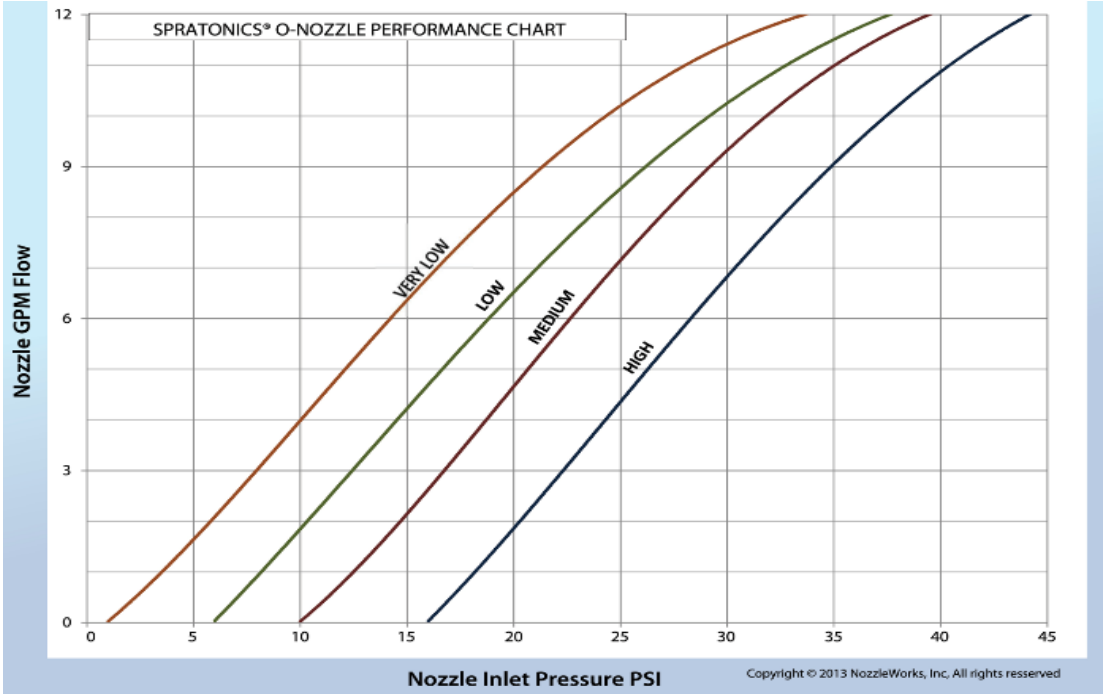
II. VR spraying based on changing metering orifice size

II.A. Variable orifice size nozzles

❑ Pressure-activated springs on moving assembly (2/2)

- The nozzle comprises a fixed cone inside a moving cylindrical assembly that provides different sections of the metering orifice.

Spratronics line of O-Nozzle Variable Rate Fertilizer spray Nozzles



II. VR spraying based on changing metering orifice size

II.B. Multiple active nozzles

- Multiple nozzle holders
- Individual or combination of multiple nozzles are automatically selected to provide flow rate simultaneously according to the required total flow rate and to the forward speed.

SELETRON by ARAG

✓ Spraying nozzle holders (dual/quadruple) equipped with a cutting-edge electronic shut-off nozzle valve

✓ Separated control of every single nozzle, minimizes overlap and protects buffer zone.

✓ The electronic parts control the actuator and the communication with the computer via Can-Bus, receiving the opening/closing commands and outputting the information about valve status (opening/closing time 0.4 sec).

PRESSURE EVOLUTION FROM 7 TO 20 Km/h WITH MULTISPRAY (KUHN)
Application rate 100 L/ha at 2 bar reference pressure

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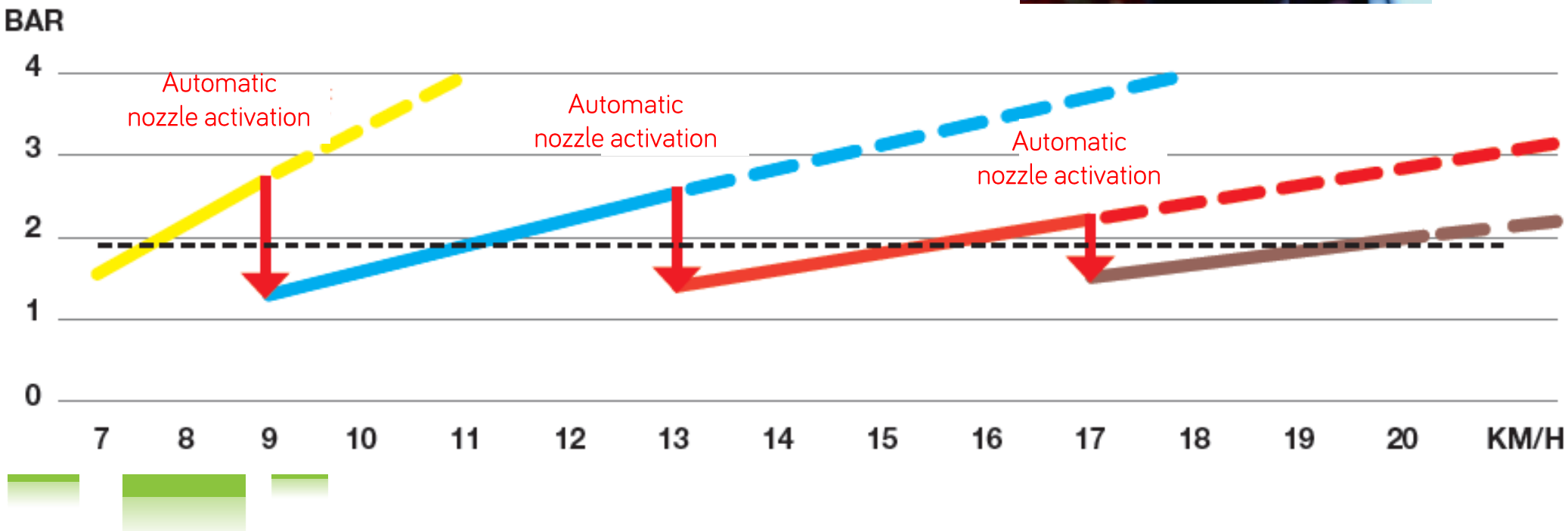
When forward speed increases

Higher flow rate is required

A nozzle with larger metering orifice is activated



ISO Colour

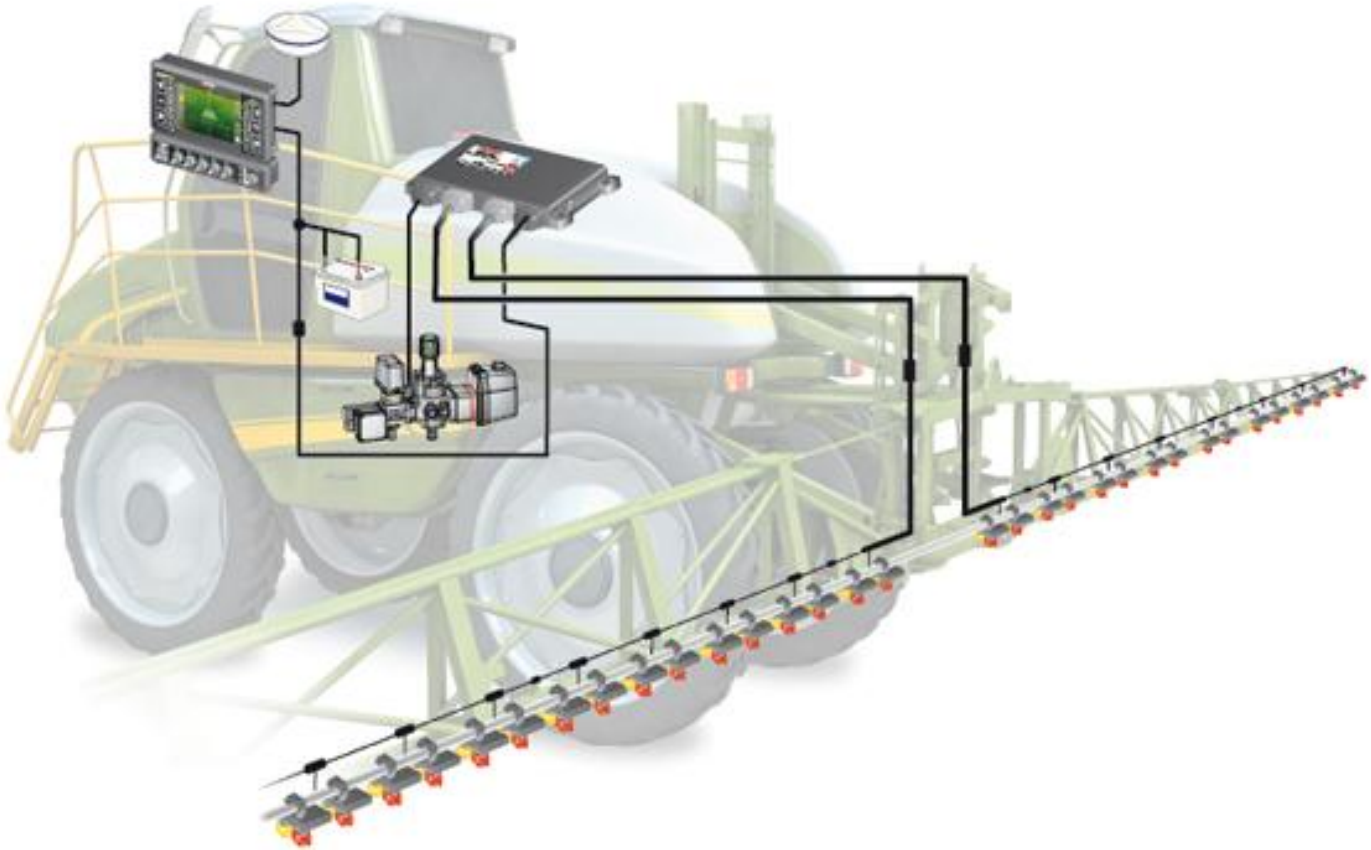
- Nozzle 02
- Nozzle 03
- Nozzle 04
- Nozzle 05
- Reference

Study by: KUHN

II. VR spraying based on changing metering orifice size

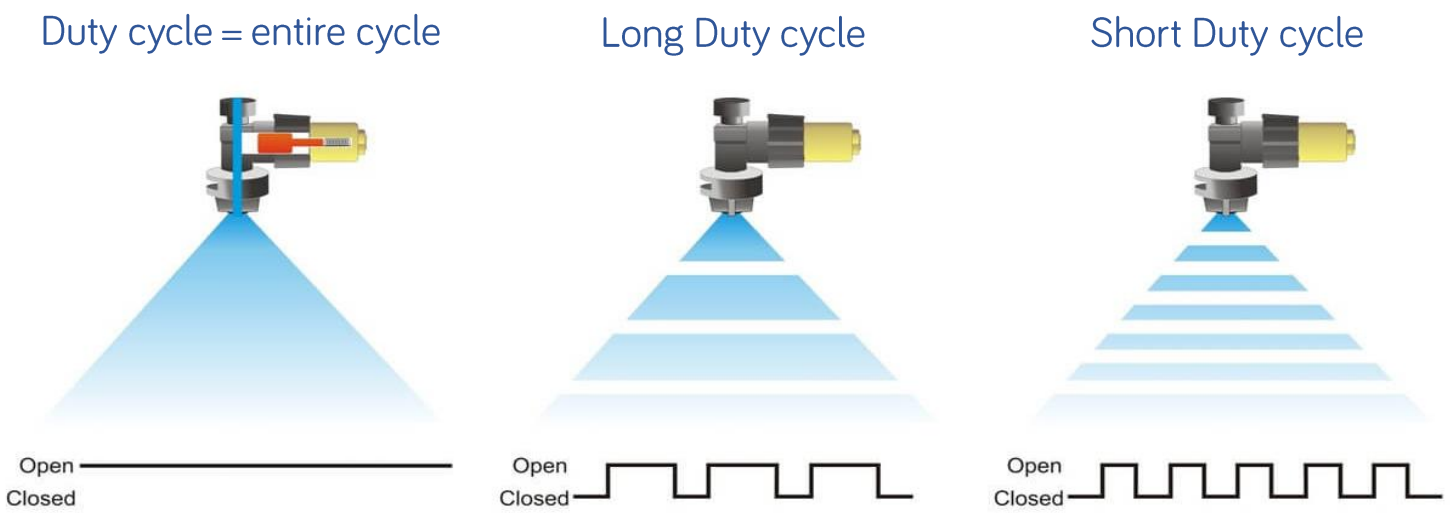
II.B. Multiple active nozzles

SELETRON by ARAG



III. VR spraying based on pulse width modulated flow control

- Conventional nozzle and pressure are selected according to the required droplet size distribution and spray pattern assuring that the maximum total flow rate during variable rate application is achievable.
- A fast-acting, electrical, solenoid-operated valve opens and closes the pass of the liquid through the metering orifice of the conventional nozzle assembly.
- The system controls the number of times the valve is open within a second (in Hz), and the amount of time that the valve is open (duty cycle). The total flow (in L) provided during a second establishes the flow rate (in L/min).



III. VR spraying based on pulse width modulated flow control

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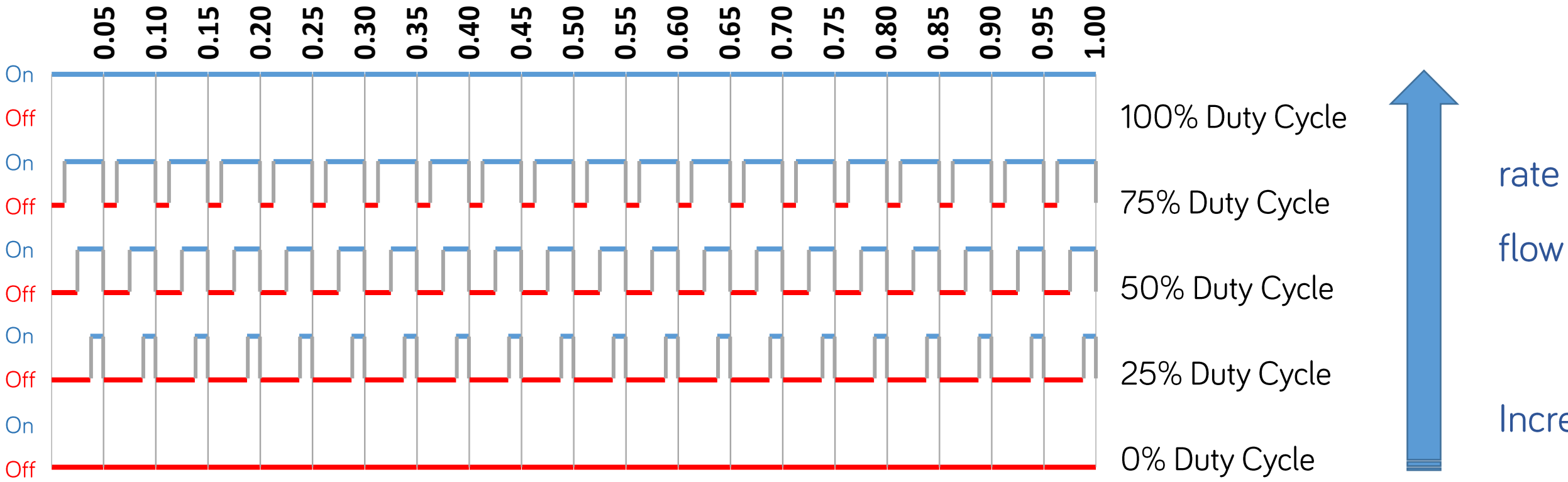
Pulse Width Modulation at 20 Hz operated at different duty cycles



III. VR spraying based on pulse width modulated flow control

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PULSE WIDTH MODULATION

Spraying speeds for various application volumes (L/ha), duty cycle, nozzle size and pressures.

NOZZLE SPACING – 50cm																
Application Volume			60 L/ha							80 L/ha						
Duty Cycle %			40	50	60	70	80	90	100	40	50	60	70	80	90	100
SIZE	BAR	L/min/nozzle	Spraying speeds (km/h) to achieve duty cycles							Spraying speeds (km/h) to achieve duty cycles						
025 LILAC	1.5	0.70	6	7	8	10	11	13	14	4	5	6	7	8	9	11
	2.0	0.81	6	8	10	11	13	15	16	5	6	7	9	10	11	12
	2.5	0.93	7	9	11	13	15	17	19	6	7	8	10	11	13	14
	3.0	1.02	8	10	12	14	16	18	20	6	8	9	11	12	14	15
	4.0	1.14	9	11	14	16	18	21	23	7	9	10	12	14	15	17
	5.0	1.27	10	13	15	18	20	23	25	8	10	11	13	15	17	19
	6.0	1.40	11	14	17	20	22	25	28	8	11	13	15	17	19	21
03 BLUE	1.5	0.84	7	8	10	12	13	15	17	5	6	8	9	10	11	13
	2.0	0.97	8	10	12	14	16	17	19	6	7	9	10	12	13	15
	2.5	1.07	9	11	13	15	17	19	21	6	8	10	11	13	14	16
	3.0	1.18	9	12	14	17	19	21	24	7	9	11	12	14	16	18
	4.0	1.37	11	14	16	19	22	25	27	8	10	12	14	16	18	21
	5.0	1.53	12	15	18	21	24	28	31	9	11	14	16	18	21	23
	6.0	1.68	13	17	20	24	27	30	34	10	13	15	18	20	23	25
04 RED	1.5	1.12	9	11	13	16	18	20	22	7	8	10	12	13	15	17
	2.0	1.29	10	13	15	18	21	23	26	8	10	12	14	15	17	19
	2.5	1.44	12	14	17	20	23	26	29	9	11	13	15	17	19	22
	3.0	1.58	13	16	19	22	25	28	32	9	12	14	17	19	21	24
	4.0	1.82	15	18	22	25	29	33	36	11	14	16	19	22	25	27
	5.0	2.04	16	20	24	29	33	37	41	12	15	18	21	24	28	31
	6.0	2.23	18	22	27	31	36	40	45	13	17	20	23	27	30	33

Australian Government
Grains Research and Development Corporation

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

GRDC_PWM_Nozzle_Selection_Guide_2019

III. VR spraying based on pulse width modulated flow control

Application rate modulation map

Selection of the drop size

III. VR spraying based on pulse width modulated flow control

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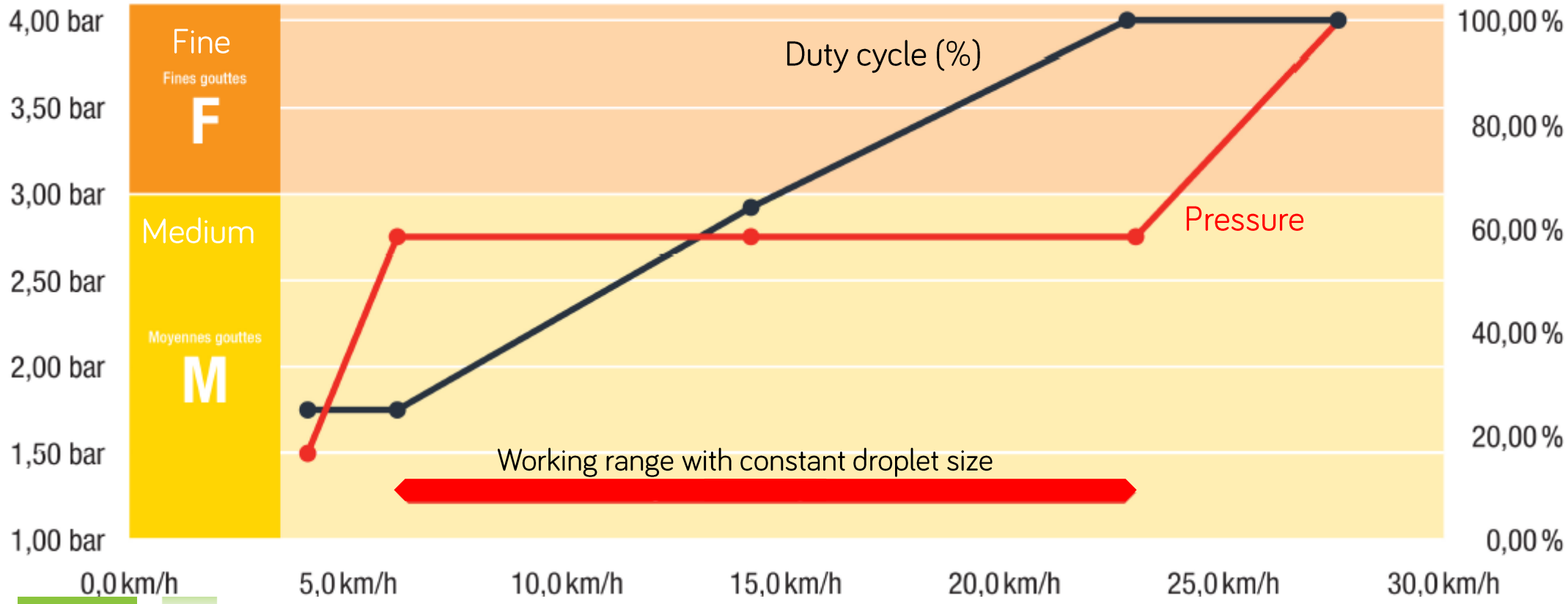
PRESSURE AND DUTY CYCLE (%) ACCORDING TO FORWARD SPEED



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III. VR spraying based on pulse width modulated flow control

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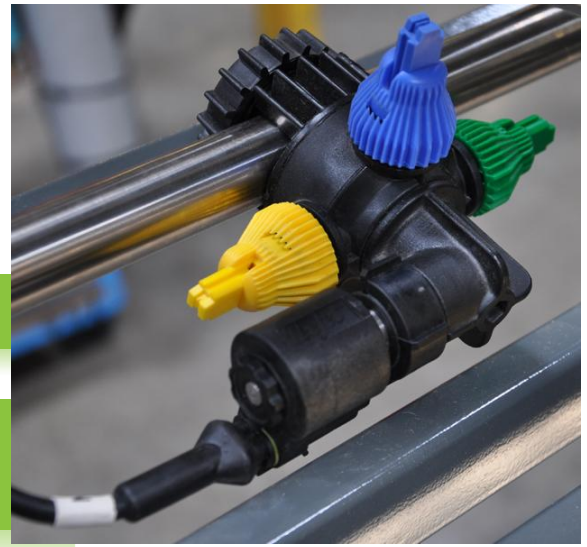
SPRAYTRONIC by BERTHOUD

Pulse Width Modulation at 20 Hz



BERTHOUD Forward together

AUTOSPRAY by KUHN

Pulse Width Modulation at 20 Hz

KUHN

ExactApply™ by JOHNN DEERE

Pulse Width Modulation at 30 Hz

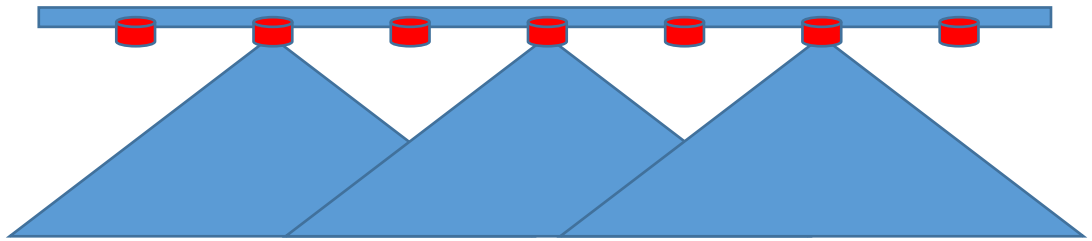
JOHN DEERE

III. VR spraying based on pulse width modulated flow control

TO AVOID UNTREATED FIELD AREAS DUE TO PULSED FLOW

Adjacent nozzles with 1/2-cycle "phase shift"

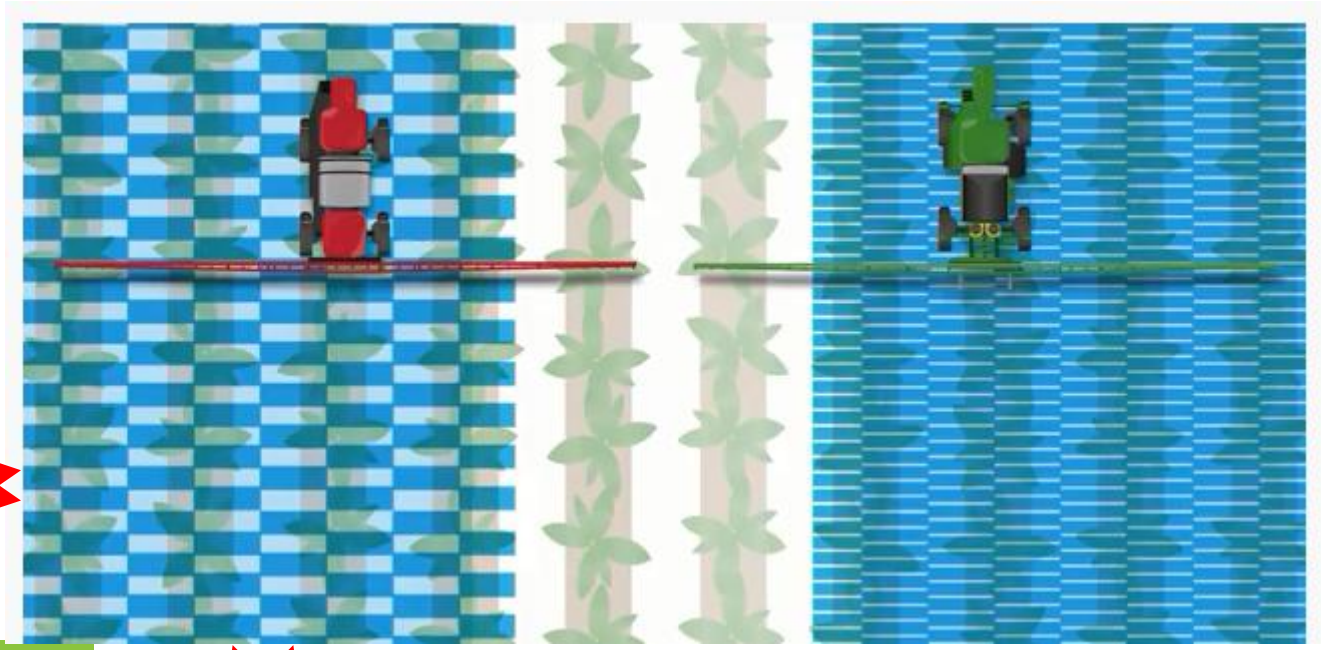
Wide spray-angle nozzles (110-degree) to assure uniform distribution



III. VR spraying based on pulse width modulated flow control

LOWER MODULATION FREQUENCY

HIGHER MODULATION FREQUENCY



pulsed flow

"phase shift"

JOHN DEERE

HIGHER MODULATION FREQUENCY (Hz)

Shorter travelled length between cycles

Higher spatial resolution for site-specific application

III. VR spraying based on pulse width modulated flow control

ADVANTAGES

- Wider flow rate and forward speed ranges with a single nozzle
- Consistent droplet size and spray pattern as pressure is constant
- Pressure can be set lower to obtain larger droplets (to reduce drift or to increase spray coverage). Increasing duty cycle assures application rate.
- Individual nozzle control allows to reduce overlapping and allows turn compensation

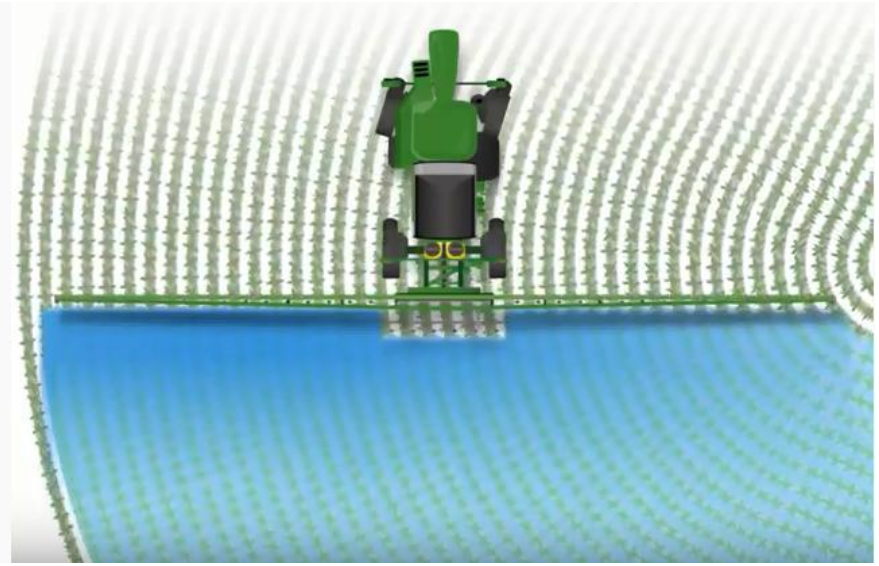
Advantages of individual nozzle control (1/2)

SPARKLE

- Reduced overlapping

KUHN

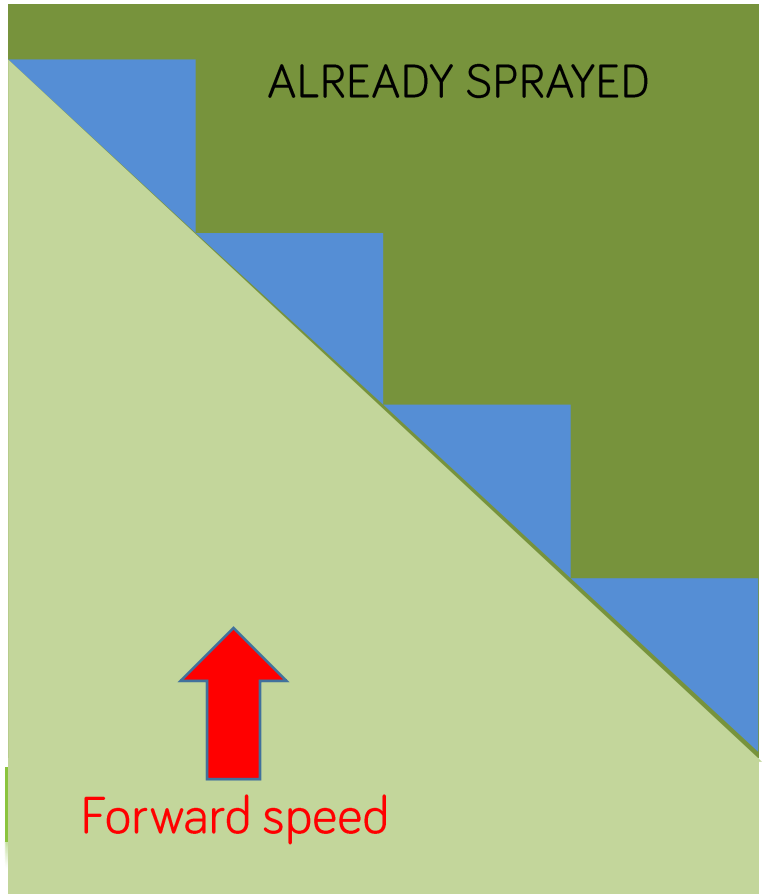
- Turn compensation



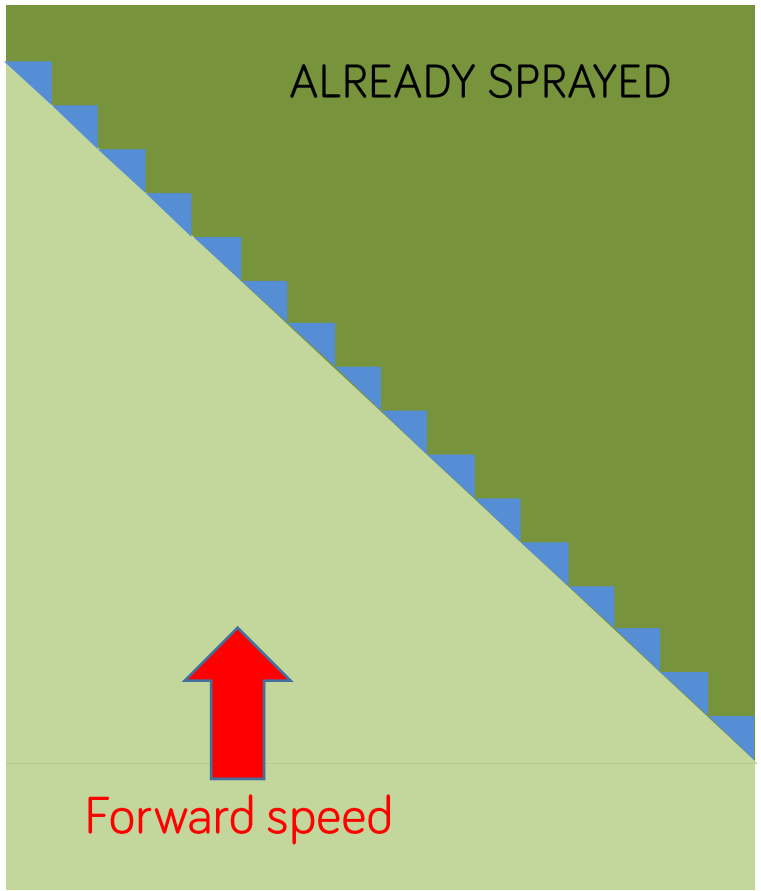
JOHN DEERE

Advantages of individual nozzle control (2/2)

16 Nozzles grouped into four sections controlled by GPS



16 Nozzles individually controlled by GPS



Alternative Variable Rate Spraying Strategies (1/3)

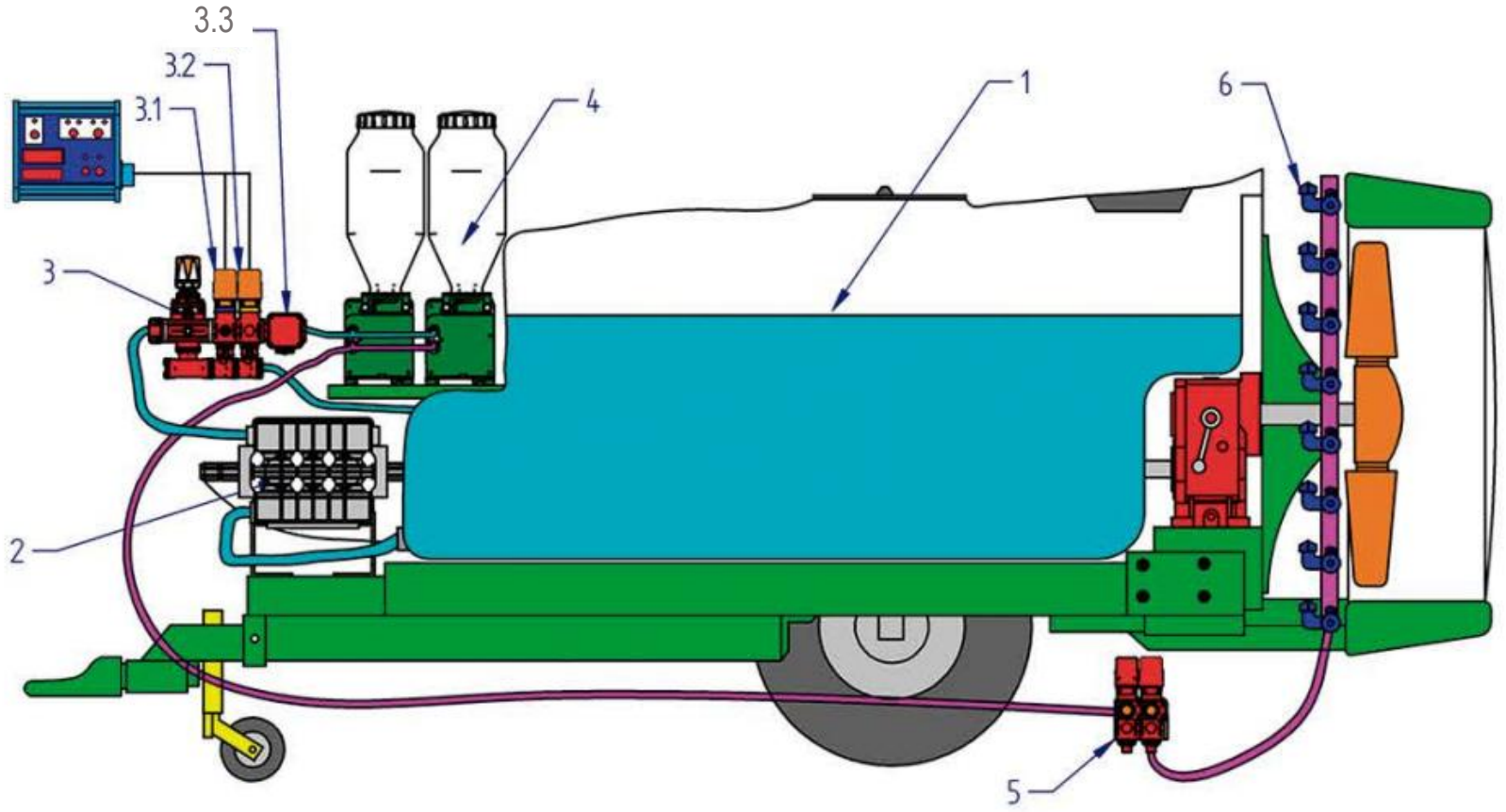
Chemical direct-injection systems with carrier control

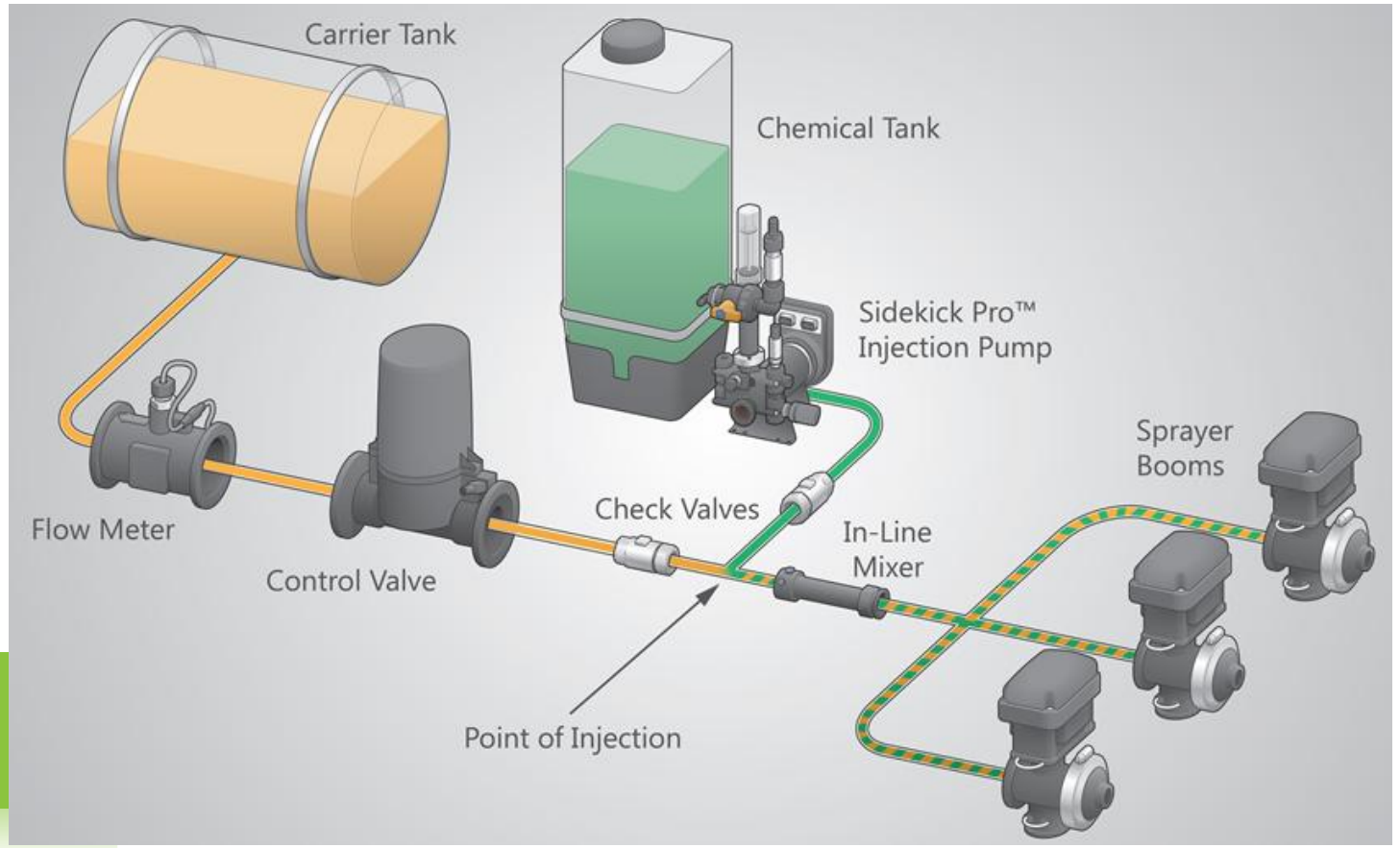
- Allows variable chemical dosage with no variation in application rate
- Two different hydraulic circuits: one for the carrier (water) and one for the chemical
- One control system operates a servo valve to adjust the carrier rate according to prescribed application rate and to forward speed
- Second control system operates the injection pump to adjust the chemical-injection rate according to prescribed dosage and to forward speed
- Different chemicals at different dosages can be managed although becomes prone to changes in droplet and spray characteristics.
- Eliminates chemical exposition during pre-mixing and cross-contamination
- Eliminates leftovers and thus tank rinsing

Alternative Variable Rate Spraying Strategies (2/3)

Chemical direct-injection systems with carrier control

1. Carrier tank
2. Carrier pump
3. Valves body
3.1 Main on/off valve
3.2 Pressure control valve
3.3 Flow meter
4. Chemical tanks and injection pumps
5. Section valves
6. Nozzles



Alternative Variable Rate Spraying Strategies (2/3)

Chemical direct-injection systems with carrier control