Studio della qualità delle precipitazioni in due siti della provincia di Bologna: tendenza dell'ultimo decennio

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Abstract: *The purpose of this study was to evaluate the quality of atmospheric deposition (chemical composition and pH) in two periods 1997-99 and 2007-09, in the province of Bologna (Bologna, urban area and Ozzano, rural area). The results show, between the first and the second three-year period, a decrease of the acid species (sulfate, nitrate and nitrite) and an increase of the basic ones (calcium, sodium and magnesium), with consequently an increase in the pH of the rainwater, that has gone from neutral to alkaline.*
The annual atmospheric deposition decreased too: in the 1997-99 period in Bologna, the average annual deposition of SO_4^{-2} and NO_3^- were 37.9 and 27.8 kg ha^{-1} $year^{-1}$ and in Ozzano 31.7 and 34.9 kg ha^{-1} $year^{-1}$. In the 2007-09 period in Bologna, they were 24.5 and 16.5 kg ha^{-1} $year^{-1}$ and 27.8 and 31.3 kg ha^{-1} $year^{-1}$ in Ozzano.
In addition there are significant neutralization reactions: calcium, derived from calcareous soils and from Sahara desert, is the principal agent neutralizing the acid species.
Keywords: *bulk deposition, pH, acid rain, nitrates, sulphates.*

Riassunto: *Scopo di questo lavoro è valutare la qualità delle deposizioni atmosferiche (pH e composizione chimica) in due periodi 1997-99 e 2007-09, nella provincia di Bologna (Bologna, zona urbana e Ozzano dell'Emilia, zona rurale). I risultati mostrano, tra il primo ed il secondo triennio, una diminuzione delle specie acide (solfato, nitrato e nitrito) e un aumento di quelle basiche (calcio, sodio e magnesio), con conseguente aumento del pH dell'acqua di pioggia, che da valori prossimi alla neutralità è divenuta basica.*
Sono calate anche le deposizioni atmosferiche annuali: nel periodo 1997-99 a Bologna, le medie annuali delle deposizioni di SO_4^{-2} e di NO_3^- sono state di 37,9 e 27,8 kg ha^{-1} $anno^{-1}$ e ad Ozzano di 31,7 e 34,9 kg ha^{-1} $anno^{-1}$. Nel periodo 2007-09 a Bologna, sono state di 24,5 e 16,5 kg ha^{-1} $anno^{-1}$ e ad Ozzano di 27,8 e 31,3 kg ha^{-1} $anno^{-1}$.
Inoltre esistono relazioni significative di neutralizzazioni: il calcio, derivante da suoli calcarei e dall'intrusione di aerosol di origine Sahariana, è il principale agente neutralizzante delle specie acide.
Parole chiave: *bulk deposition, pH, pioggia acida, nitrati, solfati.*

INTRODUZIONE

Con il termine deposizione acida si intende generalmente il processo di ricaduta dall'atmosfera di particelle acide. Se la deposizione avviene sottoforma di precipitazioni (pioggia, neve, ecc.) si parla di deposizione umida, mentre quando le particelle giungono al suolo per impatto o gravità si parla di deposizione secca. Normalmente il pH della pioggia ha un'acidità di 5-5,6 dovuta alla dissoluzione naturale della CO_2 nell'acqua piovana e all'esistenza di fondo di SO_2 (Vong *et al.*, 1985; Rao *et al.*, 1995), ma elevate concentrazioni di composti acidi (SO_X e NO_X), tipiche delle zone con alto uso di combustibili fossili, come il centro Europa, il Nord-Est America e l'Asia dell'est, possono determinare un abbassamento del pH, con formazione di piogge acide (Alastuey *et al.*, 1999; Lee *et al.*, 2000).

Alla fine degli anni '90 anche le precipitazioni dell'Europa meridionale ed occidentale, così come del resto dell'area mediterranea, hanno raggiunto concentrazioni di specie inquinanti molto elevate, simili a quelle del Nord Europa (Kaya e Tuncel, 1997; Alastuey *et al.*, 1999), mantenendo però il loro valore di pH neutro o alcalino (Mosello, 1993; Balestrini *et al.*, 2000). In bibliografia il valore neutro o basico del pH, a fronte di elevate concentrazioni acide, viene giustificato ipotizzando possibili reazioni di neutralizzazione tra gli ioni presenti in atmosfera. Nello specifico alcuni autori ritengono che gli ioni alcalini, giunti tramite le correnti di origine Sahariana (Moulin *et al.*, 1998; Israelevich *et al.*, 2002), o presenti nei suoli calcarei (Rice e Herman, 2012, Al-Momani *et al.*, 1995), possano agire come tampone per l'acidità.

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Definire la qualità dell'acqua di pioggia attraverso il valore del pH è quindi piuttosto limitante. Il pH dell'acqua di pioggia è infatti determinato dagli ioni in essa contenuti e dalle reazioni che tra essi avvengono. Una corretta e completa caratterizzazione dell'acqua di pioggia deve quindi prevedere anche la valutazione della composizione ionica.

Gli ioni contenuti nell'acqua di pioggia hanno diverse origini. Come sopra accennato, il nitrato si origina ogni volta che avviene una reazione di combustione, pertanto le sue principali sorgenti sono il traffico veicolare, le caldaie a gas, le centrali di potenza e, in generale, gli impianti industriali. Le principali sorgenti antropiche di solfati sono la combustione di carbone, prevalentemente nelle centrali elettriche, e di gasolio. Molto rilevante è quindi il contributo del riscaldamento domestico, a cui si affianca quello dei mezzi di autotrazione, diffusamente utilizzati in Italia soprattutto per il trasporto delle merci, per le macchine agricole e la cantieristica. Altre voci non trascurabili sono i contributi emissivi di aerei e navi, in continuo sistematico aumento e prive di ogni criterio di ambientalizzazione, i vecchi treni con locomotori diesel, le aree industriali, in particolare le raffinerie, i cementifici e l'industria delle ceramica, gli inceneritori. Nonostante questi impianti abbiano subito negli anni notevoli progressi per l'abbattimento delle emissioni di SO_2 e degli altri inquinanti, queste non possono comunque essere totalmente eliminate. Altre emissioni di solfati potrebbero derivare dagli impianti di combustione della biomassa, attualmente in fase di monitoraggio. Esistono infine le sorgenti di origine naturale, quali le eruzioni vulcaniche e i fulmini.

Poi vi solo elementi che si originano dall'erosione del suolo, quali calcio, magnesio, potassio; l'ammonio deriva dall'attività agricola, mentre cloro e sodio hanno per lo più origine marina.

Un aspetto importante e da non dimenticare è il contributo transfrontaliero: poiché si tratta di aerosol, gas e particelle presenti in atmosfera, è probabile che essi derivino da aree adiacenti, trasportati con le masse d'aria.

La deposizione di questi composti atmosferici può avere effetti diversi sul terreno e sulla vegetazione sulla base delle caratteristiche del suolo: nel caso di suoli acidi e poco profondi, come quelli forestali, i composti acidi posso determinare danni irreversibili a tutto il comparto vegetazionale, a causa della precaria condizione di equilibrio in cui si trovano di per sé i suoli forestali (Sequi, 1991). Al contrario nei suoli agricoli italiani, di origine prevalentemente sedimentaria, l'acidità non provoca danni poiché viene facilmente neutralizzata dal calcare. Su questi tipi di suoli, le piogge acide si traducono, al contrario, in un apporto utile di elementi nutritivi, quali l'azoto e lo zolfo, e quindi possono essere considerate un supplemento alle comuni concimazioni. L'apporto di zolfo talora può risultare sufficiente a soddisfare i fabbisogni nutritivi di molte colture, mentre le ricadute di azoto possono avere effetti benefici sui terreni utilizzati per prati e pascoli (Francaviglia *et al.*, 1995).

Scopo principale di questo lavoro è stato quello di analizzare la qualità delle deposizioni atmosferiche (*bulk deposition*) di due siti in provincia di Bologna, uno urbano e uno rurale, nell'ultimo decennio, tramite la caratterizzazione del pH e della composizione chimica dei principali anioni e cationi.

L'elaborazione di questi dati ha permesso di comprendere le reazioni di neutralizzazione che avvengono tra gli ioni, la loro effettiva origine e l'andamento stagionale.

MATERIALI E METODI

Campioni di acqua di pioggia sono stati raccolti in due siti, uno urbano ed uno rurale entrambi nella provincia di Bologna. Il sito 1 si trova nel centro della città di Bologna (40 m s.l.m.; 11°28′ E, 44°30′ N) in zona residenziale, a 50 m da una strada ad alta intensità di traffico (~10^3 veicoli al giorno). In prossimità del punto di campionamento non si trovano importanti centri industriali e le principali sorgenti di inquinamento sono costituite dal traffico veicolare e dagli impianti di riscaldamento, in passato per la maggioranza a gasolio, recentemente convertiti in impianti a metano (Fig. 1).

Il sito 2 si trova invece nel comune di Ozzano dell'Emilia (BO) (190 m s.l.m.; 11°29′ E, 44°25′ N) in zona collinare a circa 30 km da Bologna. In prossimità del punto di campionamento si trovano campi impiegati per l'attività agricola e vegetazione spontanea. La più vicina area industriale si trova a 6 km verso N-E, mentre due strade ad elevata intensità di traffico, la Via Emilia (10^3-10^4 veicoli/giorno) e l'autostrada A14 (10^4-10^5 veicoli/giorno), si trovano nella valle sottostante a circa 5 km in linea d'aria dalla stazione di monitoraggio (Fig. 1).

Il campionamento dell'acqua di pioggia è avvenuto tramite pluviometri standard, che hanno consentito la raccolta sia delle deposizioni secche che di quelle umide (*bulk deposition*). Dopo ogni campionamento, avvenuto a cadenza settimanale, il pluviometro è stato attentamente pulito con acqua ultrapura.

Sono state raccolte ed analizzate tutte le precipitazioni avvenute nei trienni 1997-99 e 2007-09, per un totale, rispettivamente, di 163 e 112 campioni

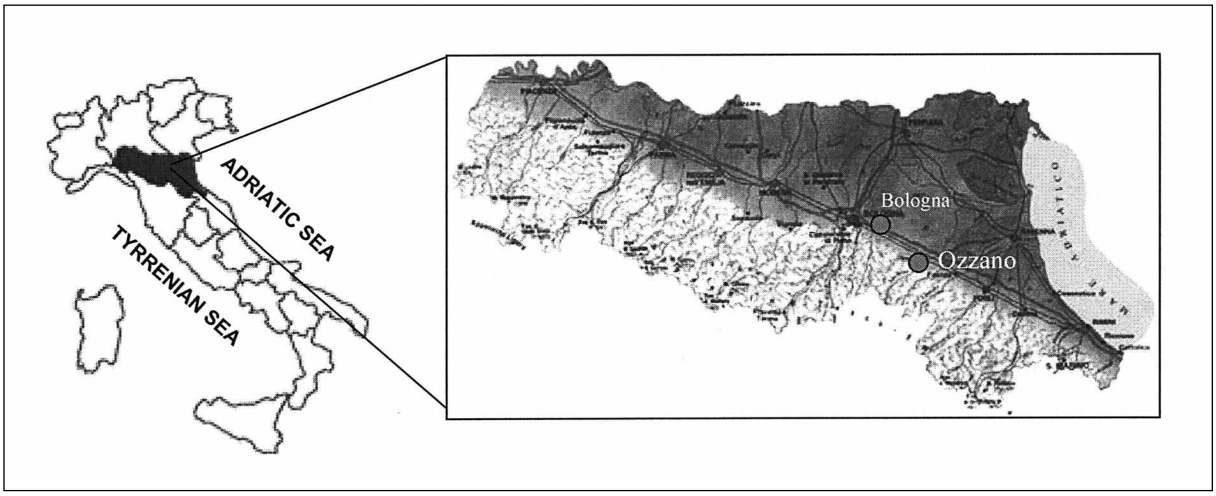

Fig. 1 - Siti di campionamento delle precipitazioni: Bologna è il sito urbano (sito 1), Ozzano dell'Emilia è il sito rurale (sito 2).
Fig. 1 - Bulk deposition sampling location: Bologna is the urban site (site 1), Ozzano is the rural site (site 2).

raccolti nel sito 1, e 123 e 96 campioni raccolti nel sito 2.
Un giorno dopo la raccolta, i campioni sono stati sottoposti alla determinazione del pH (a 20°C; pHmetro Crison) e della conducibilità elettrica (conduttimetro Crison). Un sistema di elettroforesi capillare "Beckman P/ACE 5500" è stato usato per la quantificazione dei principali anioni (SO_4^{2-}, Cl^-, NO_3^-, NO_2^-, PO_4^{3-}, HCO_3^-) e cationi (Ca^{2+}, K^+, Mg^{2+}, Na^+, NH_4^+), per mezzo di una calibrazione standard con diverse concentrazioni abbinata ad una regressione lineare per aumentarne la precisione, secondo il metodo proposto da Dinelli *et al.* (1998). Tutti i dettagli del procedimenti analitico sono descritti in Pieri *et al.* (2010).
La qualità dei dati e l'affidabilità e precisione dei risultati sono state garantite dalla ripetitività delle repliche, dal bilancio degli ioni e dal confronto tra la conducibilità elettrica misurata dal conduttimetro e quella calcolata sulla base degli ioni dissolti in soluzione (Alastuey *et al.*, 1999).

RISULTATI E DISCUSSIONE

Precipitazioni

Il regime pluviometrico dei due siti è stato caratteristico della pianura padana meridionale, con la percentuale maggiore delle precipitazioni durante l'autunno e l'inverno (circa il 60-70% del totale).
Le precipitazioni medie del periodo 1997-99 sono state 666 e 637 mm per siti 1 e 2, con valori massimi in novembre e minimi in gennaio, febbraio e luglio (Fig. 2). Nel 2007-09 le precipitazioni annuali sono state sensibilmente superiori a quelle del triennio precedente e più vicine alla media climatica del-

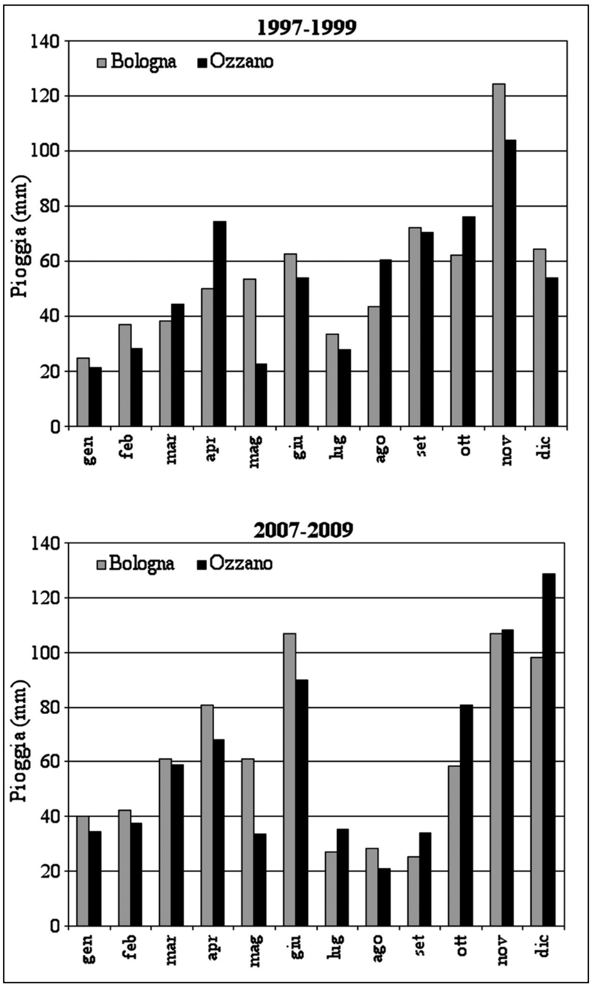

Fig. 2 - Distribuzione media mensile dell'acqua di pioggia (mm) nei due siti e nei due trienni.
Fig. 2 - Mean monthly values of rain water (mm) in the two sites and two three-year periods.

l'area. Nel sito 1 sono stati registrati 737 mm, mentre nel sito 2 730 mm, con valori più alti in giugno, novembre e dicembre e bassi in luglio, agosto e settembre (Fig. 2).
Le intensità di pioggia più frequentemente registrate sono state 2-10 mm/hr per il sito 1 e 5-10mm/hr per il sito 2.

Principali caratteristiche chimiche delle precipitazioni: pH e concentrazione ionica

Nel triennio 1997-99 la media del pH del sito 1 è stata 5,2 e 5,3 nel sito 2, mentre nel 2007-09 è stata di 6.2 nel sito 1 e 6.3 nel sito 2.
In considerazione del fatto che il pH naturale della pioggia non inquinata è compreso tra 5 e 5.6 (Vong *et al.*, 1985; Rao *et al.*, 1995), questi valori di pH descrivono una situazione di non acidità. Valori simili sono riportati in pubblicazioni riguardanti altre zone italiane (Le Belloch e Guerzoni, 1995; Balestrini *et al.*, 2000), mentre i pH di questo studio risultano essere superiori a quelli riportati in altre prove svolte in zone del mondo tipicamente caratterizzate da un'alta frequenza di piogge acide, come in Nord America (Khawaja e Husain, 1990), Singapore (Balasubramanian *et al.*, 2001), Korea del Sud (Lee *et al.*, 2000) e Cina (Tanner, 1999), dove sono stati registrati valori medi rispettivamente di 3.2, 4.5, 4.7, 4.4. (Tab. 1). Inoltre, rimanendo all'interno del bacino del Mediterraneo, si può osservare che i valori dei siti 1 e 2 sono sempre risultati essere inferiori a quello di altre città quali Morella - Italia, (Alastuey *et al.*, 1999), Ankara - Turchia, (Topcu *et al.*, 2002) e Eshidiya – Giordania (Al-Khashman, 2005) in cui sono stati registrati pH rispettivamente di 6.7, 6.3, 6.6 (Tab. 1).
In Fig. 3 sono messi a confronto le distribuzioni dei valori del pH dei due siti nei due trienni. Nel primo triennio 1997-99, la distribuzione dei valori di pH mostra, per entrambi i siti, una fluttuazione ristretta (4.5-6.0 nel sito 1 e 4.4-5.5 nel sito 2) e precipita-

Tab. 1 - Confronto di pH, concentrazione (μeq l^{-1}) e NF (rapporto di $[Ca^{2+}]/[NO_3^- + SO_4^{2-}]$) dei principali ioni delle precipitazioni nel mondo.
Tab. 1 - Comparison of pH, concentration (μeq l^{-1}) and NF $[Ca^{2+}]/[NO_3^- + SO_4^{2-}]$ *of the main ions in precipitation in world location.*

	Città del bacino del Mediterraneo					**Città caratterizzate da piogge acide**				
Sito	Longone (Italia) [a]	Sardegna (Italia) [b]	Morella (Spagna) [c]	Ankara (Turchia) [d]	Eshidiya (Giordania) [e]	Albany (USA) [f]	Singapore [g]	Korea del Sud [h]	Honk Kong (Cina) [i]	Figueira [j] (Brasile)
pH	4.8	5.2	6.7	6.3	6.6	4.2	4.5	4.7	4.4	4.9
Cl^-	12.0	332.0	36.0	20.4	121.5	5.6	22.1	37.8	-	16.0
HCO_3^-	-	-	-		151.3	-	-	-	-	-
NO_3^-	45.0	29.0	27.2	29.2	63.7	52.8	16.8	46.7	22.9	13.0
SO_4^{2-}	51.0	90.0	114.8	48.0	121.5	115.2	58.7	62.3	65.0	69.0
Ca^{2+}	46.0	70.0	176.1	71.4	192.1	6.5	21.7	26.2	17.6	32.0
H^+	-	-	0.4	24.0	0.6	3.5	45.9	30.2	35.4	14.0
K^+	2.0	17.0	26.9	9.8	51.1	1.4	4.0	3.8	2.8	10.0
Mg^{2+}	7.0	77.0.	23.0	9.3	133.6	2.8	7.4	10.9	8.9	12.0
Na^+	11.0	252.0	28.0	15.6	85.1	29.8	31.1	19.3	38.6	35.0
NH_4^+	25.0	62.0	80.0	86.4	43.0	19.3	17.3	32.6	-	30.0
NF	0.48	0.59	1.24	0.92	1.03	0.04	0.29	0.24	0.20	0.39

[a]Wet deposition, periodo 1995-1997; Balestrini et al., 2000
[b]Bulk deposition, periodo 1992-1994; Le Bolloch e Guerzoni 1995
[c]Bulk deposition, periodo 1995-1996; Alastuey et al., 1999
[d]Wet deposition, periodo 1994-1996; Topcu et al., 2002
[e]Wet deposition, periodo 2003-2004; Al-Khashman 2005
[f]Bulk deposition, periodo 1986-1988; Khawaja e Husain 1990
[g]Wet deposition, periodo 1997-1998; Balasubramanian et al., 2001
[h]Wet deposition, periodo 1996-1998; Lee et al., 2000
[i]Bulk deposition, periodo 1994-1995; Tanner 1999
[j]Bulk deposition, periodo 1999 2000; Flues et al., 2002

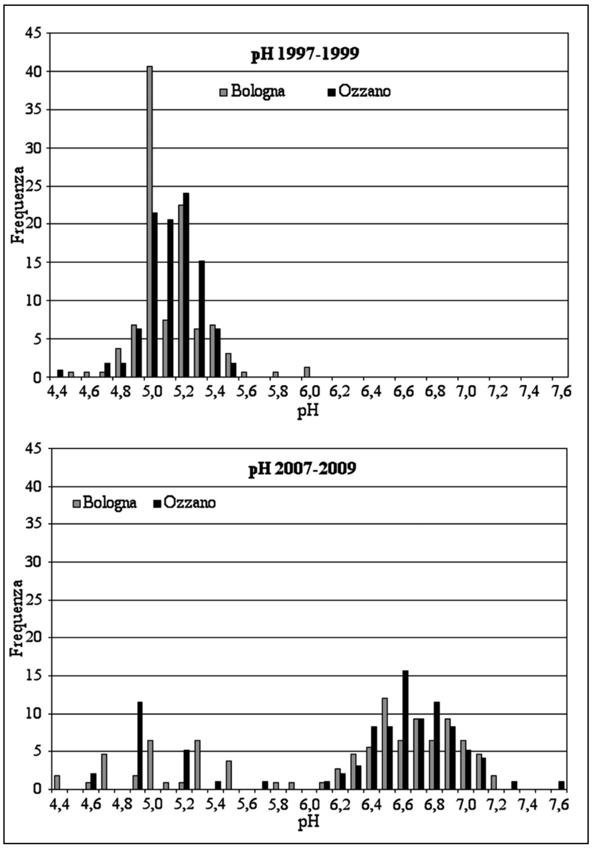

Fig. 3 - Frequenza del pH di ogni evento piovoso di Bologna e Ozzano dei periodi 1997-1999 e 2007-2009.
Fig. 3 - pH frequency distribution of bulk deposition for Bologna (site 1) and Ozzano (site 2) in the two periods 1997-1999 and 2007-2009.

zioni acide (pH<5,0) solo occasionalmente osservate (17% degli eventi del sito 1 e il 12% del sito 2). Nel secondo triennio 2007-09 la fluttuazione è risultata essere più ampia (4.4-7.2 nel sito 1; 4.6-7.6 nel sito 2), a causa di uno spostamento dei valori verso pH più basici. Le piogge acide sono diminuite nel sito 1 (9%) e sono rimaste quasi costanti nel sito 2 (14%). Da notare soprattutto l'aumento degli eventi basici, con un pH tra 5.6 e 7.6, che hanno costituito un'ampia maggioranza (72% e l'80% degli eventi in sito 1 e 2).

In altre città del mondo si trovano distribuzioni dei valori del pH molto diverse: in Brasile, la fluttuazione è molto più ampia, con valori compresi tra 3.4 e 7.3 (Pelicho *et al.*, 2006), mentre in Korea, oscillano tra 3.4 e 8.0 (Bo Kyoung *et al.*, 2000).

La distribuzione non normale e la limitata fluttuazione dei valori di pH registrata durante questo studio sono dovuti probabilmente al carbonato di calcio che agisce come tampone, mantenendo la concentrazione dello ione H^+ nella deposizione atmosferica all'interno di un definito e limitato intervallo di valori, indipendentemente dalla concentrazione delle specie acide.

Nelle Tabb. 2 e 3 viene riportata la statistica di base (media, mediana, valori max e min e concentrazione ponderata, VWM) delle principali specie ioniche di entrambi i trienni per i due siti.

I dati di concentrazione ionica indicano che il solfato è l'anione a più alta concentrazione (118.4 µeq l^{-1} nel 1997-99 e 57.7 µeq l^{-1} nel 2007-09), mentre il nitrato è presente alla concentrazione di 67.4 µeq l^{-1} nel 1997-99 e 36.8 µeq l^{-1} nel 2007-09. Tra i cationi, il calcio è l'elemento a maggiore concentrazione (121.9 µeq l^{-1} nel 1997-99 e 160.1 µeq l^{-1} nel 2007-09), seguito da Na^+ e Mg^{2+} (con una concentrazione rispettivamente di 96 e 20 µeq l^{-1} nel 1997-99, 121.9 e 53.7 µeq l^{-1} nel 2007-09).

Relativamente al primo periodo, la piccola differenza rilevata tra i due siti è stata inaspettata, consi-

Tab. 2 - Principali specie ioniche (µeq l^{-1}) dei due periodi a Bologna (sito 1). VWM: Volume Weighted Mean.
Tab. 2 - Main ionic species (µeq l^{-1}) of the two periods in Bologna (site 1). VWM: Volume Weighted Mean.

Sito 1: Bologna

1997-99	H^+	Cl^-	NO_2^-	NO_3^-	SO_4^{2-}	Na^+	Mg^{2+}	Ca^{2+}	pH
VWM±SD	8.4±0.9	105.5±9.2	6.3±0.6	67.4±4.2	118.4±9.1	96±10.6	20±1.8	121.9±7.7	5.1±0.4
Media	8.0	206.0	11.4	143.9	265.3	178.4	55.2	279.3	5.2
Mediana	6.3	111.3	4.7	88.5	134.7	97.2	23.3	160.2	5.2
Min	0.6	9.8	0	10.1	13.9	5.4	0	10.7	4.1
Max	79.4	3487.7	97	1592.7	3336.5	3161.5	639.4	3016	6.2

2007-09	H^+	Cl^-	NO_2^-	NO_3^-	SO_4^{2-}	Na^+	Mg^{2+}	Ca^{2+}	pH
VWM±SD	5.8±9.7	48.9±12.9	5.0±6.0	36.8±6.8	57.7±10.8	121.9±40.9	53.7±21.5	160.1±23.4	-
Media	3.6	133.0	26.0	91.6	143.5	175.2	93.4	274.5	6.2
Mediana	0.3	60.2	0.0	52.4	73.3	122.5	78.6	202.4	6.5
Min	0.1	11.2	0.0	2.3	14.7	11.5	0.0	21.2	4.4
Max	39.8	1206.4	1897.5	568.5	1128.6	1478.0	582.7	1327.4	7.2

Tab. 3 - Principali specie ioniche (μeq l^{-1}) dei due periodi ad Ozzano dell'Emilia (sito 2). VWM: Volume Weighted Mean.
Tab. 3 - Main ionic species (μeq l^{-1}) of the two periods in Ozzano (site 2).VWM: Volume Weighted Mean.

Sito 2: Ozzano dell'Emilia

1997-99	H^+	Cl^-	NO_2^-	NO_3^-	SO_4^{2-}	Na^+	Mg^{2+}	Ca^{2+}	pH
VWM±SD	6.2±0.7	87.6±8.9	3.7±0.4	88.7±5.9	103.8±6.8	83.2±7.8	18.7±2.7	136.8±12.5	5.3±0.5
Media	8.4	115.1	4.3	165.4	195.5	115.1	35.5	206.3	5.3
Mediana	6.3	90.8	3.0	94.3	120.3	85.6	17.7	131.2	5.2
Min	0.3	12.9	0.0	12.9	18.2	8.7	0.0	17.0	4.2
Max	63.1	811.8	25.0	1909.1	1936.7	828.1	375.8	2095.8	6.6

2007-09	H^+	Cl^-	NO_2^-	NO_3^-	SO_4^{2-}	Na^+	Mg^{2+}	Ca^{2+}	pH
VWM±SD	3.9±6.3	64.9±7.8	1.3±1.1	66.3±10.3	77.7±9.9	48.2±42.6	58.5±34.6	184.6±55.9	-
Media	2.9	129.6	3.0	177.5	180.6	130.3	95.5	351.1	6.3
Mediana	0.3	66.4	0.0	72.1	94.5	73.1	73.2	218.5	6.6
Min	0.0	0.0	0.0	0.0	0.0	13.0	6.1	54.8	4.6
Max	28.2	1071.7	57.6	1633.1	1396.4	873.0	656.2	2061.4	7.6

derando il diverso uso del suolo e la diversa localizzazione: il sito 1 si trova infatti in piena zona urbana e la qualità delle sue deposizioni è quindi molto più influenzata da impianti di riscaldamento, traffico veicolare, rispetto al sito 2, dove c'è prevalentemente attività agricola. Nel secondo periodo, i valori delle concentrazioni di nitrato e del solfato sono risultati essere addirittura maggiori nel sito rurale.
Una possibile spiegazione può essere dovuta al fatto che il sito 2 è in realtà situato in prossimità di due strade molto trafficate (A14 e la via Emilia) e di un'area industriale e lo studio della direzione dei venti nella zona indica che gli inquinanti emessi da queste sorgenti possono effettivamente raggiungere il punto di campionamento.
Così, anche se le emissioni locali dei due siti sono state presumibilmente diverse, altri fattori, soprattutto legati allo spostamento delle masse d'aria, hanno contribuito a determinare la deposizione finale.
Il confronto tra i due trienni mette in evidenza che, negli anni, sono aumentate le concentrazioni degli ioni Ca^{2+}, Na^+ e Mg^{2+}, mentre sono diminuite quelle delle principali specie acide, SO_4^{2-}, NO_3^-, NO_2^-.
Si ritiene che questa diminuzione delle specie acide rispetto al primo triennio possa essere dovuta alla promozione di politiche di salvaguardia dell'ambiente, promossa dall'Unione Europea (art.6 del trattato di Maastricht, 1991) dall'Italia e dalle singole regioni. Rispetto all'ultimo decennio sono stati mossi notevoli passi che hanno contribuito al miglioramento della qualità dell'aria attraverso la diminuzione di emissioni inquinanti tra cui, tra i più significativi, l'eliminazione della benzina con il piombo, l'utilizzo di carburanti più efficaci e meno inquinanti (Gpl, metano), la sostituzione degli impianti di riscaldamento a gasolio con quelli a metano, l'introduzione delle marmitte catalitiche.
Con i risultati ottenuti da questo studio si conferma il trend di diminuzione della concentrazione di solfati, riportato anche in bibliografia da altri autori che si sono occupati della Pianura Padana (Arisci *et al.*, 2009). Questa diminuzione, che può essere definita sistematica, è in atto già da decenni, ma la presenza ancora elevata di solfati negli aerosol e nelle deposizioni indica da un lato che le scelte tecnologiche sopradescritte sono efficaci, ma dall'altro che il problema, benché si sia affievolito negli anni, sia comunque sempre "attivo".
Per quel che riguarda i nitrati, è difficile stabilire un trend così netto come per i solfati. Come riportato anche da Logora *et al.* (2012) i nitrati stanno calando significativamente dal 2003, in risposta alla diminuzione di emissioni di NO_x riportate per la zona della Pianura Padana. Un recente report della EEA (2009) segnala però la Pianura Padana come una delle zone più problematiche per gli elevate livelli di inquinanti ed indica che la riduzione della deposizione di N calerà significativamente solo quando tutte le misure di controllo attualmente disponibili saranno totalmente applicate.

Reazioni di neutralizzazione

Come già accennato, il pH dell'acqua piovana varia in funzione della composizione ionica e delle reazioni di neutralizzazioni che avvengono tra gli ioni. Diversi studi svolti in Europa meridionale e nell'area del Mediterraneo, hanno identificato le particelle di carbonato di calcio del suolo come il principale agente neutralizzante l'acidità (Al-Momani *et al.*, 1995; Tuncer *et al.*, 2001). In bibliografia è riportato che il calcio non ha solo un'origine locale, ma può raggiungere tutte le zone del bacino del Mediterraneo, come il nord d'Italia (Moulin *et al.*, 1998; Israelevich *et al.*, 2002; Prospero *et al.*, 2002) provenendo sotto forma di polvere di calcite dal deserto del Sahara (Loye-Pilot *et al.*, 1986; Avila *et al.*, 1998).

Al fine di confermare quanto riportato in letteratura, gli eventi con elevate concentrazioni di calcio sono stati studiati attraverso l'analisi delle traiettorie dei venti, utilizzando il modello NOAA HYSPLIT (Draxel e Rolph, 2003). I risultati ottenuti a due differenti altezze (50 e 500 m) e per una durata di 96 ore dimostrano, per la nostra regione, un marcato movimento di masse d'aria provenienti dal deserto del Sahara (Fig. 4).

Per verificare il ruolo dello ione calcio nel tamponare l'acidità delle specie acide, la concentrazione degli ioni acidi [SO_4^{2-} + NO_3^- + NO_2^-] e stata correlata con la concentrazione degli ioni basici [Ca^{2+} + NH_4^+]. La Fig. 5 mostra una relazione lineare significativa ($R^2 > 0,9$) per entrambi i siti.

Utili indicazioni sulla qualità dell'acqua di pioggia posso provenire dal rapporto, NF= [Ca^{2+}]/[SO_4^{2-} +NO_3^-]. Nelle aree studiate il valore medio di NF è risultato essere per il sito 1 di 0.63 e 1.63 e, per il sito 2, 0.70 e 1.27, rispettivamente i per i trienni 1997-99 e 2007-09. Ciò conferma ulteriormente che il calcio da solo è in grado di neutralizzare la maggioranza della acidità totale, mentre il contributo degli altri ioni basici rimane limitato all'8% dell'acidità.

Nelle altre zone del Mediterraneo, quali Turchia, Spagna, Giordania, dove non esiste il problema

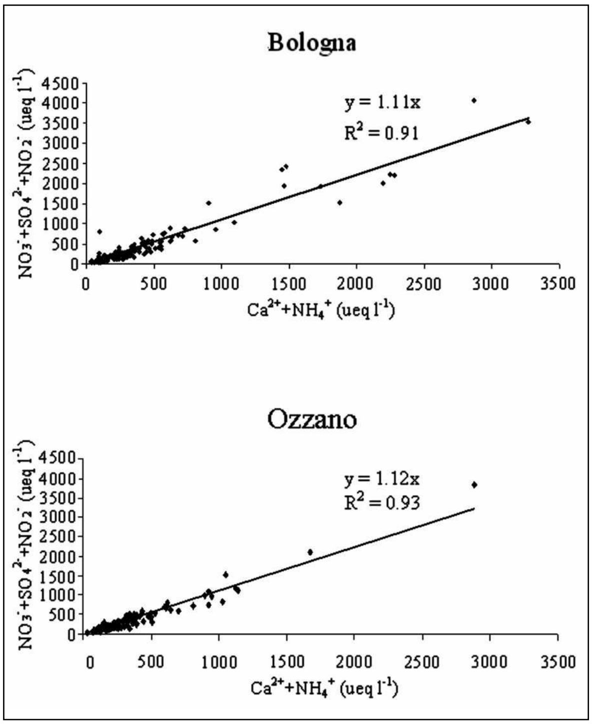

Fig. 5 - Neutralizzazioni degli ioni acidi [NO_2^- + NO_3^- + SO_4^{-2}] con gli ioni basici [Ca^{2+} + NH_4^+], espressi in □eql^{-1} nei due siti.
Fig. 5 - Neutralization between the main acidity [NO_2^- + NO_3^- + SO_4^{-2}] and the main basicity [Ca^{2+} + NH_4^+], expressed in □eql^{-1} in the two sites.

delle piogge acide, i valori di NF oscillano tra 0.48 e 1.24 (Tab. 1). In presenza di piogge acide, come nel Nord America, Singapore, Korea del Sud, Cina e Brasile, il valore del rapporto NF è notevolmente inferiore oscillando tra 0.04 e 0.39 (Tab. 1). Evi-

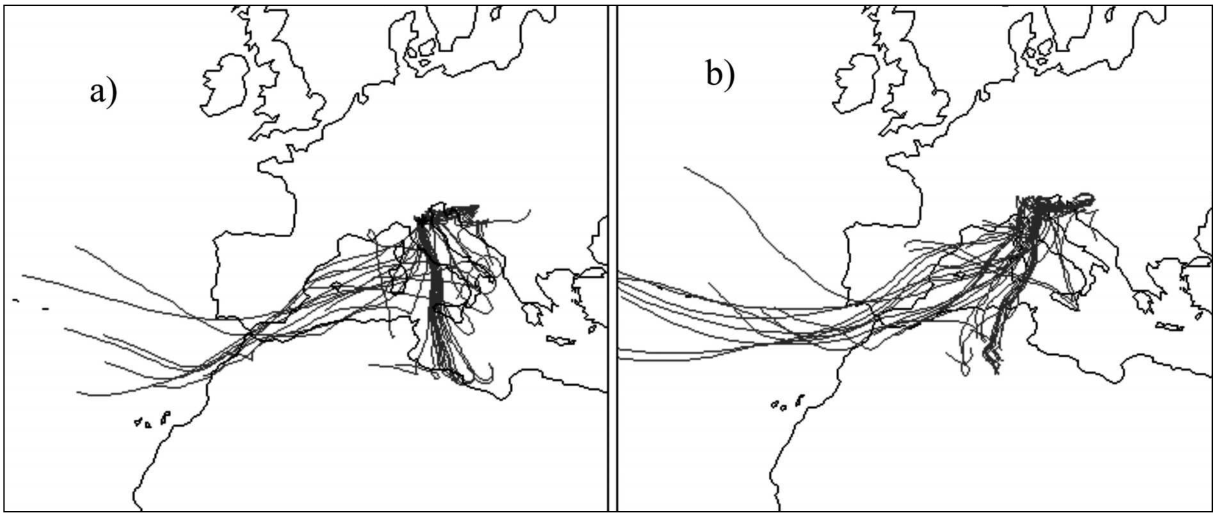

Fig. 4 - Traiettorie dei venti principali, ottenute dal modello NOAA HYSPLIT a due altezze: 50 m (a) e 500 m (b), con una durata di 96 ore.
Fig. 4 - Back trajectories obtained by means of NOAA HYSPLIT at two heights: 50 m (a) and 500 m (b), with a duration of 96 hours.

Tab. 4 - Deposizioni atmosferiche annuali di azoto e zolfo nei due trienni ed in entrambi i siti.
Tab. 4 - Annual atmospheric deposition of nitrogen and sulfur in the two three-year periods and at both sites.

SITO	TRIENNIO	N (kg/ha^{-1})	S (kg/ha^{-1})
SITO 1: BOLOGNA	1997-99	6.7	12.7
	2007-09	4.0	8.2
SITO 2: OZZANO	1997-99	8.1	10.6
	2007-09	7.2	9.3

dentemente, in queste aree distanti da importanti sorgenti di calcite come il deserto del Sahara, il calcio locale non è sufficiente per tamponare le specie acide emesse in atmosfera da sorgenti inquinanti.

Deposizioni e variazioni stagionali

In Tab. 4 sono state riportate le deposizioni medie annuali, espresse in kg ha^{-1}, di zolfo e azoto, elementi chimici di grande interesse agricolo.
Nel primo triennio (1997-99) nel sito 1, le medie annuali delle deposizioni di S e di N sono state rispettivamente di 12.7 e 6.7 kg ha^{-1} $anno^{-1}$. Nel sito 2 si sono riscontrati dei valori simili, 10.6 e 8.2 kg ha^{-1} $anno^{-1}$, rispettivamente di S e N.
Nel secondo triennio (2007-09) si è osservato un significativo calo: nel sito 1, le medie annuali delle deposizioni di S e di N sono state rispettivamente di 8.2 e 4.0 kg ha^{-1} $anno^{-1}$, mentre, nel sito 2 si sono riscontrati dei valori quasi invariati rispetto al primo periodo e cioè 9.3 e 7.2 kg ha^{-1} $anno^{-1}$.
La deposizione di azoto è costituita dalle ricadute degli ioni nitrato, nitrito ed ammonio. La deposizione annuale dell'ammonio (NH_4^+) al momento analizzato solo per il primo triennio, è risultata essere minore nel sito 1 (7 kg ha^{-1} $anno^{-1}$) rispetto al sito 2 (9,5 kg ha^{-1} $anno^{-1}$). Ciò è facilmente comprensibile se si considera che questo ione deriva prevalentemente dalle concimazioni sui suoli agricoli.
In Emilia Romagna, le deposizioni atmosferiche di azoto e zolfo sui terreni coltivati non sono considerate dannose, anzi alcuni elementi contribuiscono a soddisfare le esigenze nutrizionali delle colture (Francavaglia *et al.*, 1995 e Sequi *et al.*, 1991). Poiché il loro apporto non è trascurabile, in un agroecosistema il loro contributo deve essere tenuto in considerazione come supplemento alle concimazioni.
In Fig. 6 si riportano le deposizioni atmosferiche di entrambi i siti e dei due trienni dello ione solfato. È stato scelto di dividere l'anno in due semestri: uno autunno-invernale, che include gli eventi di precipitazione avvenuti tra ottobre e marzo, ed uno primaverile-estivo, con gli eventi avvenuti tra aprile e settembre. Questa suddivisione ha consentito di focalizzare l'attenzione sugli effetti di una specifica sorgente inquinante, gli impianti di riscaldamento a gasolio, che costituiscono la fonte principale di diossido di zolfo nelle zone urbane.
Effettivamente i risultati del primo triennio mo-

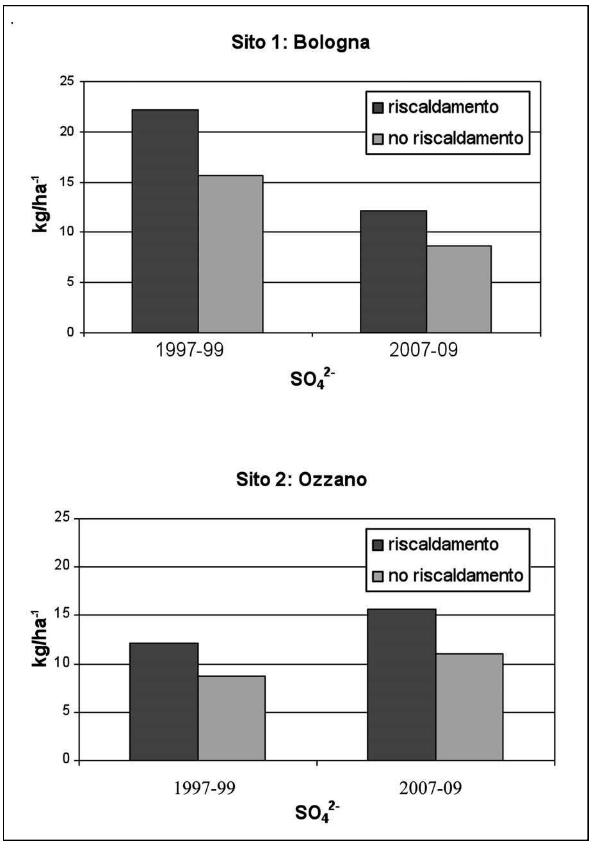

Fig. 6 - Deposizione atmosferica media annuale dello ione solfato espressa in kg ha^{-1}, suddivisa in due periodi, autunno-inverno ed estate-primavera, nei due siti.
Fig. 6 - Mean of the annual aatmospheric deposition of sulfate ion expressed in kg ha^{-1}, divided into two periods: autumn-winter and spring-summer in both the sites

strano, nel sito 1, un significativo aumento nella deposizione di solfato in autunno-inverno, periodo in cui il riscaldamento è acceso, che non è presente invece nel sito 2. La differenza risulta meno spiccata nel secondo triennio, è ciò può essere spiegato in considerazione delle politiche ambientali che nel decennio successivo hanno portato alla metanizzazione di quasi tutti i riscaldamenti degli edifici pubblici del comune di Bologna e in molte abitazioni private.

CONCLUSIONI

- Il pH delle deposizioni atmosferiche, rispetto al primo triennio, è aumentato, passando da neutro a basico.
- Rispetto al primo triennio è diminuita la concentrazione di solfati e nitrati e anche la loro deposizione.
- Le principali specie acide (solfato, nitrato, nitrito) vengono neutralizzate dalle principali specie basiche (calcio, ammonio). Il calcio svolge il ruolo principale e deriva dai suoli calcarei e dalla polvere trasportata dalle correnti atmosferiche del Sahara.
- Le deposizioni di azoto e zolfo non sono trascurabili e devono essere tenute in considerazione per un'agricoltura eco-sostenibile.
- Le maggiori deposizioni di solfato nel periodo autunno-inverno sono legate al riscaldamento domestico e sono calate probabilmente grazie alla diffusa metanizzazione.

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The CRA-CMA Archive and Library for agricultural meteorology and phenology: a heritage to know, preserve and share

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Abstract: *In the paper archive and in the library of the "Unità di Ricerca per la Climatologia e la Meteorologia applicate all'Agricoltura" (CRA-CMA) there is a significant heritage of agrometeorological and phenological data, little known in Italy and unknown by the international scientific community, which is important to organize, to share and preserve. The archive contains a valuable collection of historical meteorological datasets of climatic interest: more than 850 series in total, 260 of which are longer than thirty years and 20 that exceed one hundred years; 40 series are still in progress supplied by operating observatories. The library keeps an important collection of historical books and periodicals, both from Italy and abroad, on Atmospheric Sciences, Geophysics and Agrometeorology, dating from the second half of the XVI century. It also gathers several publications containing meteorological data from numerous Italian and foreign observatories. Historical phenological data represent a great source of information, useful to historical studies concerning phenology and climate. They illustrate development stages of crops, agricultural practices, pests and meteorological damages. They are recorded in cards, special forms, logs, referred to the period between the end of the XIX and the'70s of the XX century, and also gathered in monographs and periodicals dating from the XVIII century.*
Keywords: *historical meteorology, climatology, agrometeorology, phenology.*

Riassunto: *Nell'archivio e nella biblioteca dell'Unità di Ricerca per la climatologia e la meteorologia applicate all'agricoltura (CRA-CMA) è custodito un patrimonio di dati agrometeorologici e fenologici poco conosciuto a livello nazionale e sconosciuto alla comunità scientifica internazionale, che è necessario condividere, valorizzare e preservare. L'archivio cartaceo conserva una considerevole collezione di dati meteorologici di interesse climatico: si tratta di oltre 850 serie, di cui 260 sono più che trentennali e 20 più che centenarie; 40 vengono ancora incrementate con i dati via via rilevati dagli osservatori funzionanti. La biblioteca specializzata possiede un'importante collezione di libri e periodici storici, italiani ed esteri, sulle scienze dell'atmosfera, la geofisica e l'agrometeorologia, a partire dalla seconda metà del XVI secolo. Raccoglie, inoltre, diverse pubblicazioni seriali contenenti dati meteorologici provenienti da numerosi osservatori italiani e stranieri. I dati fenologici storici costituiscono, infine, un'immensa fonte di informazioni utili per studi fenologici e climatici di interesse storico. Essi sono principalmente di tipo descrittivo, cioè riportano lo stadio di sviluppo delle colture, le pratiche agricole, le malattie e i danni da eventi meteorologici. Sono contenuti in cartoline, schede e registri riferiti al periodo tra fine '800 e gli anni '70 del XX secolo, e in monografie e periodici autorevoli.*
Parole chiave: *meteorologia storica, climatologia, agrometeorologia, fenologia.*

INTRODUCTION

The origin of today's meteorological data collection is related to the establishment, in 1876, of the *Regio Ufficio Centrale di Meteorologia* (UCM), now CRA-CMA[3], whose headoffice is set inside the ancient "Collegio Romano" premises from 1879, in the heart of Rome, taking over the astronomic and meteorological Observatory of the Pontifical State

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[3] Office names and acronyms since 1876:
1876-1887 *Regio Ufficio Centrale di Meteorologia* - ***UCM*** (Royal Central Office for Meteorology)
1887-1923 *Regio Ufficio Centrale di Meteorologia e Geodinamica - UCMG* (Royal Central Office for Meteorology and Geodynamics)
1923-1939 *Regio Ufficio Centrale di Meteorologia e Geofisica - UCMG* (Royal Central Office for Meteorology and Geophysics)
1939-1941 *Regio Ufficio Centrale di Meteorologia e Climatologia - UCMC* (Royal Central Office for Meteorology and Climatology)
1941-1956 *Ufficio Centrale di Meteorologia ed Ecologia Agraria - UCMEA* (Central Office for Meteorology and Agroecology)
1957-2006 *Ufficio Centrale di Ecologia Agraria - UCEA* (Central Office for Agroecology)
2006-today *Unità di Ricerca per la Climatologia e la Meteorologia applicate all'Agricoltura* - ***CRA-CMA*** (Consiglio per la Ricerca e la Sperimentazione in Agricoltura - Research Unit for Climatology and Meteorology applied to Agricolture).

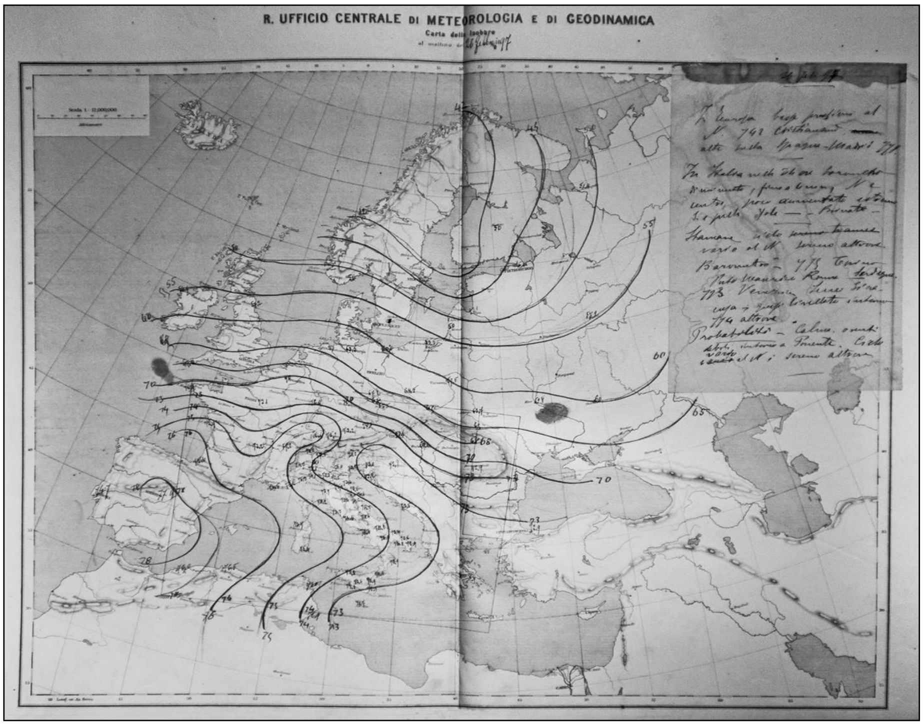


Fig. 1 - Sample of a daily isobaric chart published between 1880 and 1927. A brief note about the weather forecast for the next day was to be added to each map.
Fig. 1 - Esempio delle carte isobariche pubblicate tra il 1880 e il 1927. Una breve nota circa la previsione meteorologica per il giorno successivo era allegata ad ogni mappa.

funded by the Jesuits Community in the second half of the XVI century[4].
UCM soon established the National monitoring network raising the number of the stations from 50 up to 400 in1880, providing new tools and rules to standardize measures and observations; at the same time it began the steady and systematic collection of meteorological data, today still in progress and still feeding to the CRA-CMA Paper Archive.
Between the late XIX and the early XX century, thanks to international agreements, UCM started receiving from many European and worldwide weather stations a great deal of meteorological information, now kept by the CMA Library, gathered in yearbooks and many other scientific periodicals of historical interest (Beltrano *et al.*, 2011, 2012).
Early UCM's goal was to carry out research and studies on Italian climate using comparable and higher quality meteorological information, also to produce weather forecasts called at that time "Presagi", from Latin *praesagium,* used to depict "the forecast of oncoming events". Until the end of the 1920's, UCM used to receive data from meteorological stations to update weather charts and produce daily forecast messages to be sent throughout Italy and Europe, all by means of the telegraph system. These original maps and messages are still kept at the CRA-CMA Library (Fig. 1).

THE CRA-CMA PAPER ARCHIVE
The CMA Paper Archive consists of about 3300 folders, each containing, yearly collected, ten-days observation forms, filled by volunteer observers, keeping daily or sub-daily hand written records of air temperature, humidity, pressure, wind speed and direction, precipitation, sunshine duration, radiation, evaporation and other observations such as cover and type of cloud, snow depth, etc.
Some of these early observatories are still working. The Archive holds more than 850 series of which 260 are longer than thirty years, 20 are longer than one hundred years; 40 of such series are still in progress.
For each standard meteorological parameter we assume the Archive has more than six millions measures recorded by weather stations in Italy and in the former Italian Balkans Colonies, from former Yugoslavia, Greece and Albania. Further, meteorological data from the Italian Colonies in Africa (Ethiopia, Libya and Somalia) are also kept in the CRA-CMA Library.
One section of the observation forms, the "*Special notes on the weather*" box, is suitable for remarks in case of special weather events, written by the observer in his

[4] From the outset, the Collegio had a chair of astronomy, held in the second half of the XVI century by the German Jesuit father Christopher Clavius (1538-1612), who was the main author of the calendar reform ordered by pope Gregorius XIII. Clavius was treated with great respect by Galileo Galilei , who visited him in 1611 at the Collegio Romano and discussed the new observations being made by telescope; Clavius confirmed all observations of Galilei and had by that time accepted the new discoveries. (http://en.wikipedia.org/wiki/Christopher_Clavius)

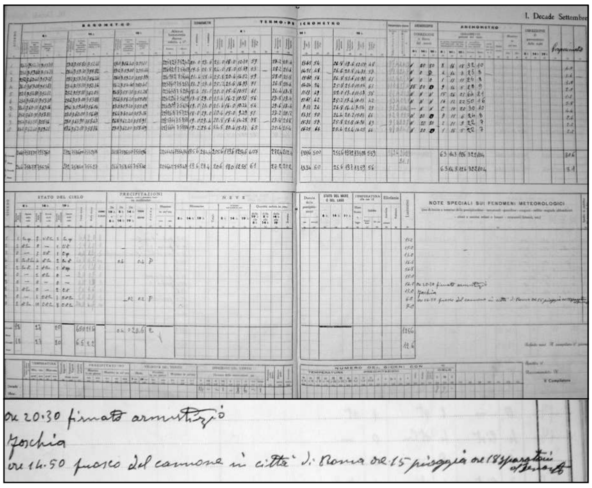
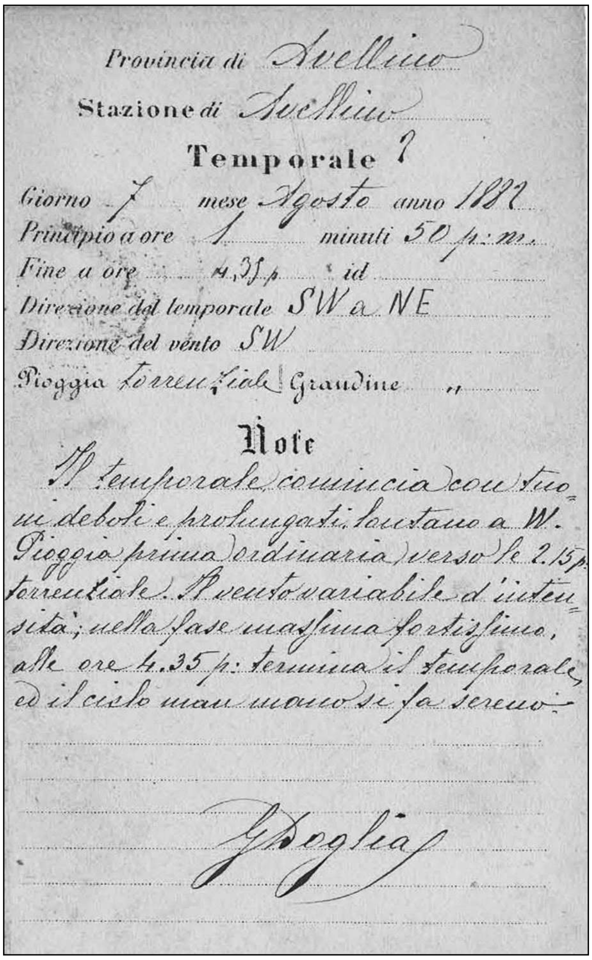


Fig. 2 - Collegio Romano Observatory: Year 1943, September month, the first ten days observation form.
Weather notes and news about the Second World War are reported in "Special notes on the weather":
September 7th, h.8:30 p.m. -"The armistice [Italy- Allied Countries] was signed;
September 8th – Haze;
September 9th, h. 2:50 p.m. "Cannon shots in Rome"; h 3:00 p.m. "Rain"; h 6:00 p.m. "Shooting in the Italian Senate".
Fig. 2 - Osservatorio del Collegio Romano: anno 1943, mese settembre, scheda delle osservazioni della prima decade. Note meteorologiche e notizie circa la seconda guerra mondiale sono riportate nella sezione "Note speciali sul tempo".

own words. These remarks do witness some colorful, significant or sometimes poetic comments about atmospheric phenomena; in some boxes we can even read remarks about local historic events. In such a way, these scientific forms are also noteworthy historical and cultural documents (Fig. 2).
Observation forms would report information about the replacement of the observers, the shift in reporting times, the exposure and site disposition change, failure and replacement of instruments and so on, namely "metadata". They allow us to trace the history of each weather station and provide a key for a critical analysis of data to improve validation and standardization processes.
As far as we have written above, the paper archive represents a valuable source of meteorological data both of the past and of the present. CRA-CMA is leading some great efforts to implement the digitization of paper data to the electronic databank constantly updated, named National Agrometeorological Data Base (BDAN)[5]; digitization is a priority program for CRA-CMA and it will continue in the future. At present, we assume that less than 30% of the whole original paper archive has been processed.

However digitization only covers the main meteorological parameters, as temperature, precipitation, pressure, sunshine duration, wind, living behind all auxiliary information like the witness remarks mentioned above, the vision observations, the type and duration of weather events and the metadata. The scanning and image capture of the paper forms are the best approach to preserve intact their full contents, so we are about to start a program to create an "Image-file Archive". The CRA-CMA Archive keeps another considerable

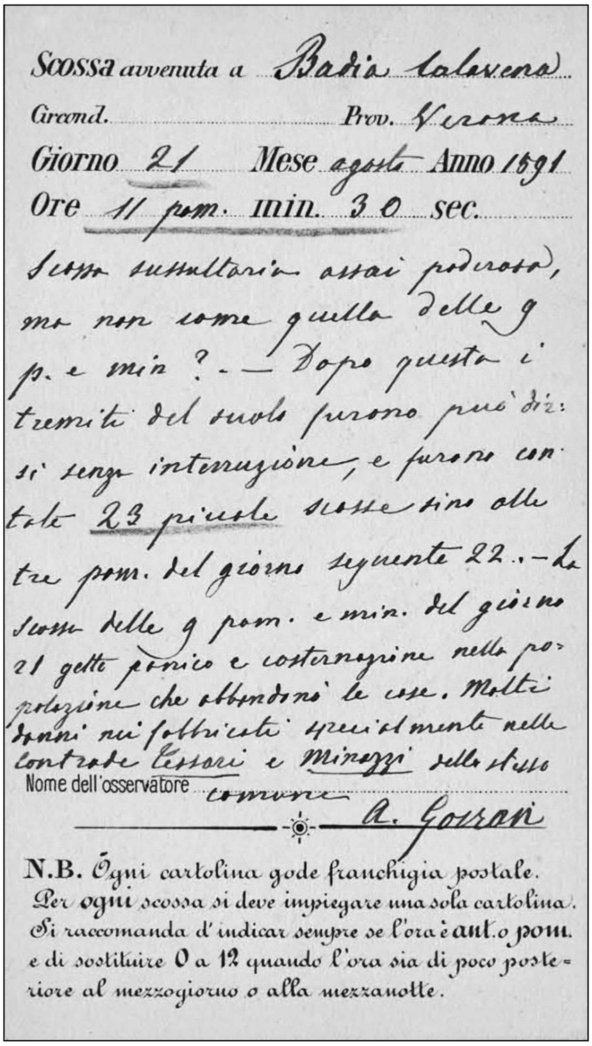


Provincia di Avellino
Stazione di Avellino
Temporale 2
Giorno 7 mese Agosto anno 1882
Principio a ore 1 minuti 50 p. m.
Fine a ore 4,35 p. id
Direzione del temporale SW a NE
Direzione del vento SW
Pioggia torrenziale Grandine "
Note
Il temporale comincia con tuoni deboli e prolungati lontano a W. Pioggia prima ordinaria verso le 2.15 p. torrenziale. Il vento variabile d'intensità; nella fase massima fortissimo, alle ore 4.35 p: termina il temporale ed il cielo man mano si fa sereno.

Fig. 3 - Sample of a Thunderstorms postcard.
Front: **Thunderstorms Service To Meteorological Observatory Rome**
Back: **Province** Avellino **Station** Avellino **Thunderstorm** 2 **Day** 7th **Month** August **Year** 1882 **Start at hours** 1 **minutes** 50p.m. **End at hours** 4,35,p. id **Thunderstorm direction** SW to NE **Rain** torrential **Hail** =
Remarks Thunderstorm starts with weak and protracted thunders far at W. Rain at first regular, about at 2,15 pm torrential. Wind of changeable intensity; in the maximum phase very strong. At 4,35 pm: thunderstorm stops and sky gradually becomes clear. Signature not understandable.
Fig. 3 - Esempio di cartolina dei temporali.

[5] Several datasets of the National Agrometeorological Data Base (BDAN) are available at the web site: www.cra-cma.it

collection: the *Thunderstorms postcards* (Fig. 3) compiled and sent by several observatories to the Office between 1880 and 1970. It does represent a source of interesting information about these severe weather phenomena. These postcards are not fully cataloged, but we do estimate that a corpus of around ten thousand thunderstorms postcards is available.



Scossa avvenuta a Badia Calavena
Grand. ... Prov. Verona
Giorno 21 Mese agosto Anno 1891
Ore 11 pom. min. 30 sec.
Scossa sussultoria assai poderosa, ma non come quella delle 9 p. e min ?.- Dopo questa i tremiti del suolo furono può dirsi senza interruzione, e furono contate 23 piccole scosse fino alle tre pom. del giorno seguente 22.- La scossa delle 9 pom. e min. del giorno 21 gettò panico e costernazione nella popolazione che abbandonò le case. Molti danni nei fabbricati specialmente nelle contrade Cessari e Minazzi dello stesso comune
Nome dell'osservatore A. Govran

N.B. Ogni cartolina gode franchigia postale.
Per ogni scossa si deve impiegare una sola cartolina.
Si raccomanda d'indicar sempre se l'ora è ant.o pom. e di sostituire 0 a 12 quando l'ora sia di poco posteriore al mezzogiorno o alla mezzanotte.

Fig. 4 - Sample of a Seismic postcard.
Front: **To Central Office for Meteorology and Geodynamics In Collegio Romano Via del Caravita, 7 Roma**
Back**: Earthquake occurred at** Badia Calavena **Disctrict Province** Verona
Day 21st **Month** August **Year** 1891 **hours** 11 p.m. **min**. 30 **sec**. Very powerful sussultatory quake, but not like those of 9 p.m. and min.?. _ After this […]. soil quaked without interruption and we counted 23 small quakes up to 10 p.m. o' clock of the following day 22nd. The quake at 9 p. o' clock of 21st brought panic and consternation among the people who abandoned houses. Many damages to buildings, especially in quarters Cessari and Minazzi of the same town. **Observer name** A. Govran.
Fig. 4 - Esempio di cartolina sismica.

Between 1887 and 1939 the UCM was given the task of managing the National Seismic Service (Beltrano *et al.*, 2001, 2002). In this role, it would receive information about all earthquakes occurred in Italy by special postcards (Fig. 4) sent from numerous geodynamic observatories and seismic stations located throughout the Country. The collection consists of about 5000 seismic postcards, cataloged by the National Institute of Geophysics and Volcanology (INGV).

THE CRA-CMA LIBRARY

The CRA-CMA Library (Fig. 5) digs its roots in the early years of the Collegio Romano Astronomical Observatory. In fact, the library comes from the Earth Sciences collection of the early Observatory (Fig. 6) integrated with later meteorological and geodynamic books. In 1879 this bibliographic collection became the core of UCM's library (Beltrano *et al.*, 2007).
Thereafter the history of the Library can be identified with the history of the Office.
In 1887 UCM took over the responsibility for the "National Geodynamic Service" holding this role until 1939. During this period, a lot of books and periodicals on seismology, volcanology and geology were acquired by the library, either from Italy and abroad (Iafrate and Esposito, 1996; Beltrano *et al.*, 2003). In 1939 the geodynamic competences of UCMG passed on to INGV and some of the geophysical and geological collections were transferred to it. Afterward the UCM focused its activity in the fields of ecology and meteorology applied to agriculture. Hence over the years, the CRA-CMA Library has been enriched with many valuable and rare collections of books and periodicals on meteorology, climatology and phenology thus becoming the leading Italian library in these fields. The library has now more than 15.000 historical texts related to meteorology (Beltrano *et al.*, 2000); most of these books are published in the XIX century and in the early twentieth century. Moreover some historical books on geophysics date back to the second half of the XVI century.
The collection contains a large variety of books on synoptic and dynamic meteorology, such as historic texts by Louis Cotte, Giuseppe Toaldo, Matthew Fontain Maury, Elias Loomis, Angelo Secchi, Robert Fitz Roy, Urbain Le Verrier, Christophorus Buys Ballot, Adolphe Quetelet, Edme Hippolyte Marié-Davy, William Ferrel, Hermann von Helmholtz, Luigi De Marchi, Adolf Sprung, Wilhelm van Bebber, Ralph Abercromby, Léon Teisserenc de Bort, Alfred Angot, Francesco Vercelli, Vilhelm and Jacob Bjerknes, Lewis Fry Richardson, Jules Charney, Ernesto Gherzi.
Several of these books are relevant for climatology and climate change. Among them are to be mentioned the

Fig. 5 - The CRA-CMA Library: "the Tacchini Gallery".
Fig. 5 - La Biblioteca del CRA-CMA: la "Galleria Tacchini".

works by Giovanni Targioni Tozzetti (1712-1783), Vincenzio Chiminello (1741-1815), Jean B.J. Fourier, John Tyndall, Svante Arrhenius, Louis Agassiz, Luigi De Marchi, Filippo Eredia, Gustav Hellmann, Ellsworth Huntington, Guy S. Callendar, Milutin Milankovic, Gordon Manley, Hubert H. Lamb, Edward N. Lorenz, Ezio Rosini, Sabino Palmieri and Vittorio Cantù.

Among Italian periodical publications available in the library, here below are the most important Italian ones, many of which were issued by the same Regio Ufficio Centrale di Meteorologia e Geodinamica (UCMG).

- *Bullettino Meteorologico dell'Osservatorio del Collegio Romano* [Weather Bulletin of Collegio Romano Observatory] (1862 - 1878).
  It was issued to give visibility and access to meteorological data and Italian studies on meteorology and terrestrial physics. This journal is the expression of the excellent work made by the Pontifical Meteorological Network founded by Jesuit Father Angelo Secchi in 1855, at the Collegio Romano Observatory, the first modern storm forecast service in the world indeed (Iafrate, 2008).
- *Bullettino Meteorologico dell'Osservatorio del Real Collegio Carlo Alberto in Moncalieri* [Meteorological Weather Bulletin of Moncalieri Observatory] (1865 - 1923).
  It was the first scientific publication of its kind in Northern Italy, similar to the Collegio Romano Bulletin. This periodical was the journal of a private meteorological network established by Father Francesco Denza, able to cover all the Italian regions (Corrispondenza Meteorologica Italiana delle Alpi e degli Appennini). This network operated in parallel with those of UCM.
- *Meteorologia Italiana* [Italian Meteorology] (1865 - 1878).
  It was the scientific journal published by the Ministry of Agriculture, Industry and Commerce's Climatological Service. This first governmental periodical on meteorology and climatology mainly contains meteorological data. From 1867 the "*Supplemento alla Meteorologia Italiana*" was added to the journal, with analysis of the meteorological measurements and original notes and memories on meteorological topic.
- *Annali del R. Ufficio Centrale di Meteorologia e Geodinamica* [Annals of the Royal Central Office for Meteorology and Geodynamics] (1879 - 1935).
  Produced by UCM, this volumes collection is the continuance of *Meteorologia Italiana*. Each volume frames one year and it is mainly divided into three parts. The first part contains memories and papers of meteorological and geodynamic interest, elaborated by the scientific staff of UCM and other Italian meteorologists and geophysicists. The most original meteorological works cover several different topics:
  - researches on thunderstorms in Italy, authored by Schiaparelli, Frisiani and Pini,

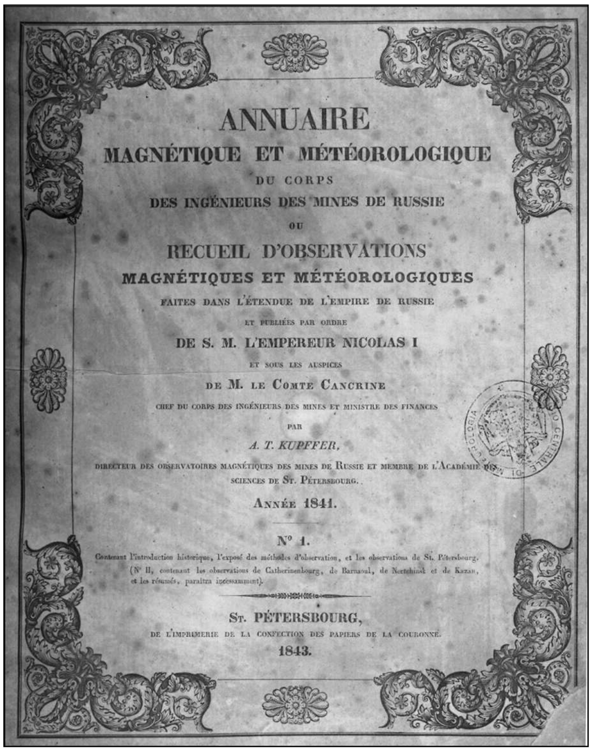

ANNUAIRE
MAGNÉTIQUE ET MÉTÉOROLOGIQUE
DU CORPS
DES INGÉNIEURS DES MINES DE RUSSIE
OU
RECUEIL D'OBSERVATIONS
MAGNÉTIQUES ET MÉTÉOROLOGIQUES
FAITES DANS L'ÉTENDUE DE L'EMPIRE DE RUSSIE
ET PUBLIÉES PAR ORDRE
DE S. M. L'EMPEREUR NICOLAS I
ET SOUS LES AUSPICES
DE M. LE COMTE CANCRINE
CHEF DU CORPS DES INGÉNIEURS DES MINES ET MINISTRE DES FINANCES
PAR
A. T. KUPFFER,
DIRECTEUR DES OBSERVATOIRES MAGNÉTIQUES DES MINES DE RUSSIE ET MEMBRE DE L'ACADÉMIE DES SCIENCES DE ST. PÉTERSBOURG.
ANNÉE 1841.
Nº 1.
Contenant l'introduction historique, l'exposé des méthodes d'observation, et les observations de St. Pétersbourg.
(Nº II, contenant les observations de Catherinenbourg, de Barnaoul, de Nertchinsk et de Kazan, et les résumés, paraîtra incessamment).
ST. PÉTERSBOURG,
DE L'IMPRIMERIE DE LA CONFECTION DES PAPIERS DE LA COURONNE.
1843.

Fig. 6 - Magnetic and Meteorological Yearbook, S. Petersburg, 1841.
Fig. 6 - Bollettino Magnetico e Meteorologico, San Pietroburgo, 1841.

- pioneering studies on theoretical and dynamic meteorology, mostly by Luigi De Marchi (Carl Gustav Rossby's researches were inspired by De Marchi's works),
- contributions to the knowledge of Italian Climate, by Filippo Eredia and Elia Millosevich,
- pioneering memories on the emerging field of Aerology (Aerological Observatory of Pavia),
- researches about terrestrial magnetism in different Italian regions by Ciro Chistoni and Luigi Palazzo.

The other parts of *Annali* are devoted to the meteorological data recorded by stations of the UCM network.

- *Bollettino Meteorico Giornaliero* [Daily Weather Bulletin] (1879 - 1927).
Published by UCM, the publication of daily weather data recorded by main Italian and foreign observatories started on November 30th 1879. On August 1st 1880 the Bulletin was increased with data from a larger number of stations, providing a summary of weather conditions in Italy and Europe, as well as a forecast dispatch then named "Presagio". Further additions and modifications gave to the journal the final form of a four sided lithographed sheet, where there are daily isobaric and isothermal charts of the Mediterranean Region and one European isobaric chart. The fourth side was mainly restricted to the daily weather dispatch, sent, by telegraph, to the main Italian observatories and harbourmasters. From 1st April 1927, this publication was continued by the Weather Office of the Air Force Ministry.
- *Rivista Meteorico-Agraria* [Ten-days Agrometeorological Journal] (1879-1931) (Ministero dell'agricoltura e foreste, 1935).
Published by the UCM, it showed, in ten days laps, the European barometric situation, the weather conditions in Italy, such as extreme temperatures, cloudiness, precipitation, etc., offering an interesting observation over agrarian news from every Italian region. Each magazine was supplemented with a map showing average isotherms and the rainfall distribution in Italy. Short agrometeorological notes were also published sometimes as an appendix.

The CRA-CMA Library has also many Italian and foreign periodicals on Aerology, Oceanography, Geography, Geology, Seismology, Volcanology, as well as many early weather charts from the second half of the 19th centuries of both historic and scientific interest.
Moreover the library contains numerous conference papers, working reports and monographs produced by UCM's researchers and employees since 1879.
It should be noted that the library also holds some original manuscripts, unpublished correspondences (19th and 20th centuries) and some interesting miscellaneous collections, e.g. more than fifty volumes containing memoirs and papers on Meteorology and Geophysics, written by the greatest Italian scientists of the 1800's and 1900's, such as Domenico Ragona, Pietro Tacchini, Luigi Palazzo, Giuseppe Mercalli, Mario Baratta, Alfonso Cavasino, Ludovico Marini, Emilio Oddone, etc.
Over the years, the library attendance and consultation did help many experts and researchers in geophysics and meteorology to produce original studies, allowing new books, articles, essays and academic works.
It has been recently learned that among the scholars who attended the library, there was the young Enrico Fermi (1901-1954). In the summer of 1918 Fermi attended his studies at this library to prepare the examinations for the admission to the Scuola Normale Superiore di Pisa. A key step in his preparation was the study of a French edition of the Treaty of Physics by Orest D. Chwolson, professor at the Imperial University of St. Petersburg. It is possible that in Rome there were only two copies of this work, one in the library of Institute of Physics in via Panisperna, yet inaccessible to the student Fermi, while the other copy was and still is held in the CRA-CMA Library. It was made available to Fermi by Eredia, his teacher and also responsible for the "Servizio Presagi" at UCM. Fermi spent most of that summer immersed in reading the treaty in the CRA-CMA library.

The CRA-CMA library is known as the "Central Library of the Italian Meteorology": today it appears as the largest Italian collection in atmospheric sciences, the main Italian memory of the historical tradition in Meteorology and one of the main bibliographic depository in Geophysics.
The library is about to join the National Library Service (SBN), in order to get more visibility and make its heritage more accessible to researchers.

PHENOLOGICAL AND AGROMETEOROLOGICAL DATA AND PUBLICATIONS

At CRA-CMA, another very interesting heritage, not yet fully inventoried and classified, is represented by raw phenological data. This kind of documentation was unknown even to us until three months ago, when, for other reasons, we went to the Institute underground room and, in several boxes (Fig. 7), we found numerous phenological documents. Here we give news about them, although we do not know their real consistence. These documents are mainly of three typologies: 1) ten days phenological cards; 2) ten days logs with information about three kind of crops (herbaceous crops; industrial crops; fruit trees) received from several correspondent phenological stations; 3) "Information forms" concerning agronomic data related to agrarian regions (plain, hill and mountain areas) of the Italian provinces.
The phenological cards are related to the period from 1934 to 1970, but it is possible that there are other ones more ancient or more recent. Some of those also contains meteorological data: extreme temperatures, number of days with rain, total of precipitation during the ten days. A cross control with information gathered from the meteorological paper archive showed that some phenological stations were meteorological too.
The ten days logs were hand written by an office operator, who took note of notices received from phenological stations by means of the cards provided for this purpose.
Information forms, at the same time sent to the Italian Central Institute for Statistics (ISTAT), to the Agricultural Ministry (to UCM, see note 1) and to the Agrarian Regional Inspectorate, recorded fortnightly news about i) meteorological events and their influence on agrarian works and development of crops and pests; ii) availability of production means in terms of mechanical equipments, manpower, animal force, fuel…; iii) livestock conditions mostly concerning the state of health; iiii) main products of agrarian markets.
Overall we estimate there are at least forty years of descriptive information basically concerning the status and phenological phases of several crops. At present we do not know if such information have already been used in phenological studies, but certainly in the last 30 years we have no notice about studies or elaborations of data extracted from the described documentation. A cataloging of the recovered documents needs to evaluate their relevance, the kind of use for these information and how it will be possible to transform the information itself into BBCH scale (Meier, 2011), nowadays the reference scale at international level.
CRA-CMA edited a journal containing systematic information on phenology: we refer to the above-mentioned "Rivista meteorico-agraria". This periodical, published every ten days, also contains agricultural information about crops, agricultural practices, phenological phases, pests and diseases, meteorological damages, for about 70 provinces. Phenological data are mostly descriptive and not quantitative.
Among old books of the library, some concern agrometeorological and phenological subjects. In particular, we quote the following publications (Dal Monte, 2009):

- Louis Cotte, *Traité de météorologie* [Treaty of meteorology, by Louis Cotte], Paris, 1774;
- Giuseppe Toaldo, *La meteorologia applicata all'agricoltura. Memoria che ha riportato il premio dalla Società reale delle scienze di Montpellier, sul problema proposto per l'anno 1774: Qual'e l'influenza delle meteore sulla vegetazione, e quali conseguenze pratiche possono ricavarsi, relativamente a quest'oggetto, dalle differenti osservazioni meteorologiche sin ora fatte …*, [Meteorology applied to Agriculture. Work which has won the prize of the Royal Society of Sciences in Montpellier, on the question proposed for the year 1774: what is the influence of meteors on the vegetation, and what practical implications can be drawn with regard to this object, from the different meteorological observations made until now? …, by Giuseppe Toaldo], Venezia, 1775;
- Vincenzio Chiminello, *Memoria che fu coronata dall'Imperiale Accademia delle scienze di Siena sul problema proposto per l'anno 1773, e aggiudicato nel 1775:* ***Non possiamo sapere per mezzo di osservazioni meteorologiche se nell'estensione di tutta Europa l'acqua che cade in pioggia ai giorni nostri sia in maggiore o minor quantità di quella che cadesse ne' secoli a noi più rimoti****; si cerca però sapere la verità del fatto per mezzo di ragioni fisiche, e quali utilità ricavar si potrebbero dalla scienza de' fatti per la coltivazione dei terreni*, [Memory which was crowned by the Imperial Academy of Sciences in Siena on the issue proposed for the year 1773, and awarded in 1775: We cannot know by meteorological observations if the water that falls today in rain throughout Europe is an amount less or greater than

the one of the past centuries; but we try to ascertain the truth of this by means of physical reasons, and what utilities could get for the cultivation of land, by abbot Vincenzio Chiminello], Padova, 1776 (Georgiadis and Mariani., 2006);

- Ministero di agricoltura, industria e commercio, *Osservazioni fenoscopiche sulle piante*, [Phenological observations on plants, by Ministry of Agriculture, Industry and Commerce], Roma, 1887;
- Istituto Centrale di Statistica del Regno d'Italia, *Periodi di semina e di raccolto per le principali coltivazioni*, [Sowing and harvesting periods for principal crops, by the Central Institute for Statistics of the Kingdom of Italy], Roma, 1937;
- Pericle Gamba, *Meteore ed agricoltura*, [Meteors and Agriculture, by Pericle Gamba], Roma, 1939.

A detailed survey of CRA-CMA's periodicals allows us to highlight the following works of our interest:

- Gaetano Cantoni, *Studj sulla temperatura del suolo arativo*, [Studies on arable soil temperature, by Gaetano Cantoni], in "Meteorologia Italiana", 1866/n. 28, p. 15-16;
- Alessandro Serpieri, *Epoca della fioritura di alcune piante in Urbino all'altezza di circa 400 metri*, di [Flowering time of some plants in Urbino at about 400 meters above sea level, by Alessandro Serpieri], in "Supplemento alla Meteorologia Italiana", 1867, p. 44;
- Giuseppe Passerini, *Temperatura del suolo ed acqua dei pozzi osservata a Guastalla (1817-69)*, [Soil temperature and water wells observed in Guastalla (1867-1869), by Giuseppe Passerini], in "Supplemento alla Meteorologia Italiana", 1869, p. 84-85;
- Giovanni Cantoni, *La meteorologia agraria*, [Agricultural Meteorology, by Giovanni Cantoni], in "Meteorologia Italiana : Memorie e notizie", 1878, fasc. II, p. 3-15;
- Domenico Ragona, *Andamento annuale della temperatura minima nello strato superficiale del suolo*, [Annual trend of minimum temperature in the surface layer of soil, by Domenico Ragona], Roma, 1885, 8 p. – Estr. da: "Annali del R. Ufficio Centrale di Meteorologia", 1884, parte I;
- Girolamo Azzi, *Per la organizzazione di un servizio di Meteorologia Agraria*, [About the organization of an Agrometeorological Service, by Girolamo Azzi], in "Rivista meteorico – agraria", 1912, p. 1247-1316;

In particular we will focus our attention on these eight publications:

Traité de météorologie was published in Paris, in 1774. Its author, Louis Cotte (1740-1815) was a French priest, corresponding member of the Académie Royal des Sciences. The fourth chapter of his treatise, named "Les Tables des Observations météorologiques & Botanico-météorologiques" presents several tables on phenological data. These data are not original observations made by the author, but he reports the observations carried out for 30 years (1741-1770) by Henri Louis Duhamel du Monceau. They concern herbaceous plants, woody crops, as well as birds and insects. Phenological data are also accompanied by meteorological data.

La meteorologia applicata all'agricoltura […] is a work by Giuseppe Toaldo (1719-1797), an Italian abbot scientist who contributed greatly to the advancement of modern meteorology. This book is a translation, by Toaldo himself, of its original version in French *Essai de météorologie appliquée a l'agriculture*, published in 1774 (Fig. 7). Its goal is the systematic study of atmospheric phenomena aimed at obtaining data for statistical weather forecasting to be applied to agriculture.

Memoria […] *sul problema proposto per l'anno 1773, e aggiudicato nel 1775: Non possiamo sapere per mezzo di osservazioni meteorologiche se nell'estensione di tutta Europa l'acqua che cade in pioggia ai giorni nostri sia in maggiore o minor quantità di quella che cadesse ne' secoli a noi più rimoti* […]: this book was written by the abbot and astronomer Vincenzio Chiminello (Toaldo's nephew and student), in response to this question. Chiminello answers this problem emphasizing an increase in rainfall and proposing the seeding lawns, in order to exploit the increased water resources available. The text was recently donated to the CRA-CMA library by professor Luigi Mariani (University of Milan).


LA METEOROLOGIA
APPLICATA
ALL' AGRICOLTURA
Memoria che ha riportato il premio dalla SOCIETA' REALE *delle Scienze di Montpellier, ſul Problema propoſto per l' Anno* 1774:
QUAL' E' L' INFLUENZA DELLE METEORE SULLA VEGETAZIONE, E QUALI CONSEGUENZE PRATICHE POSSONO RICAVARSI, RELATIVAMENTE A QUEST' OGGETTO, DALLE DIFFERENTI OSSERVAZIONI METEOROLOGICHE SIN ORA FATTE:
DEL SIG. AB. GIUSEPPE TOALDO
Prepoſito della Ss. Trinità, Profeſſore di Aſtronomia Geografia e Meteorologia nella Univerſità di Padova; membro dei Collegi di Teologia e di Filoſofia, dell' Accademia di Belle-lettere, e di quella d' Agricoltura della ſteſſa Città; della Società Economica d' Udine; dell' Accademia delle Scienze di Bologna, e corriſpondente della Società Reale delle Scienze di Montpellier:
TRADOTTA DALL' AUTORE ISTESSO DAL SUO ORIGINALE FRANCESE CON AGGIUNTE E ILLUSTRAZIONI.
IN VENEZIA CIƆIƆCCLXXV.
Preſſo GASPARE STORTI, alla Fortezza.
CON LICENZA DE' SUPERIORI.

Fig. 7 - The title page of Giuseppe Toaldo's book.
Fig. 7 - Il frontespizio del libro di Giuseppe Toaldo.

Osservazioni fenoscopiche sulle piante is a very original book, printed in Rome in 1887. Its contents are: the history of phenological observations in Europe, the rules for the observation intended to the agrophenological network founded in Italy by the Ministero di agricoltura, industria e commercio, in 1885, data from this network for the same year, the main previous Italian phenodata (already published in other publications).

Periodi di semina e di raccolto per le principali coltivazioni (1937) contains climatic values for phenological phases. For each Italian province, with respect to three altitude zones (mountain, hill and plain), we read starting and ending dates relating to the sowing and harvesting phases for 29 herbaceous crops and only to the harvesting phase for 19 woody crops. About 11 woody crops, there is also the list of most widespread varieties, with indication of the earliest and the latest one.

Meteore ed agricoltura is a small handbook containing practical instructions for farmers. It was written by a geophysicist, Pericle Gamba, and printed in 1939. At that time, its author was the director of the R. Ufficio Centrale di Meteorologia e Climatologia (see note number 1). The book is divided into chapters dealing with the various meteorological phenomena and their influence on different crops. The classification of climates on pages 26-28 is very innovative, since elaborated, for each agricultural region, according to the crops that have the greatest growth and higher yield, so we have the climate of olive, the climate of vine, the climate of cereal, the climate of forest, etc..

Epoca della fioritura di alcune piante in Urbino all'altezza di circa 400 metri: this is a table where, for nearly fifty plants, Alessandro Serpieri, seismologist and meteorologist at Urbino, notes the starting day of the flowering stage for the year 1867 and its average date deduced from a decade of phenological observations (Fig. 8). Serpieri organized phenological surveys on about 280 species, mostly wild, in the territory of Urbino. The observed phenophase was the beginning of flowering. He also compared the data collected in Urbino with those of Bruxelles and calculated the phenological gradients, (Puppi G. and Zanotti A.L, 2009).

About the importance of phenological observations will insist later Girolamo Azzi – eminent agricultural ecologist who headed the Ufficio Centrale di Climatologia e Ecologia Agraria (see note 1) from 1940 to 1946- in his work *Per la organizzazione di un servizio di Meteorologia Agraria* (1912). This writing emphasizes how the organization of an efficient agrometeorological Service is essential for Italy. Azzi's reference model is the Russian Service of Agricultural Meteorology.

Epoche della fioritura di alcune piante in Urbino all'altezza di circa 400 metri.

Nomi delle piante osservate fino al 30 Aprile 1867	Fioritura nel 1867	Epoca media della fioritura	N.° anni	Epoca media della fioritura a Bruxelles meno 13 giorni
Acer campestre . . .	9 Aprile	28 Aprile	5	
Acer Pseudo-Platanus .	22 Aprile			18 Aprile
Aesculus hypocastanum .	18 Aprile	7 Mag.	3	23 Aprile
Amygdalus communis . .	20 Gennaio	15 Marzo	6	
Antirrhinum majus . .	20 Aprile	20 Mag.	5	26 Mag.
Broussonetia papyrifera	22 Aprile			
Buxus sempervivens . .	18 Febbraio	9 Marzo	3	19 Marzo
Carpinus Betulus . . .	28 Marzo			
Centaurea Cyanus . . .	4 Aprile	10 Mag.	3	3 Giug.
Cheiranthus Cheiri . .	12 Marzo	25 Marzo	4	21 Marzo
Collutea arborescens .	18 Aprile			14 Mag.
Corchorus japonicus . .	23 Marzo	3 Aprile	2	5 Aprile
Cornus mas	3 Marzo	22 Marzo	3	23 Marzo
Cornus sanguinea . . .	22 Aprile	16 Mag.	3	
Coronilla Emerus . , .	9 Febbraio			1 Mag.
Corylus avellana . . .	29 Dic. 1866	14 Gen.	5	24 Gen.
Crataegus Oxyiacantha .	4 Aprile	28 Aprile	5	24 Aprile
Cytisus Laburnum . . .	18 Aprile	11 Mag.	3	25 Aprile
Evonimus europaeus . .	23 Aprile	8 Mag.	2	6 Mag.
Fragaria vesca	17 Marzo	7 Aprile	6	1 Aprile
Fraxinus Ornus	30 Aprile	7 Mag.	3	
Juglans regia	7 Aprile	28 Aprile	5	
Leontodon Taraxacum .	21 Febbraio	21 Marzo	3	30 Marzo
Lonicera Caprifolium .	13 Aprile	14 Mag.	3	18 Mag.

Fig. 8 - Alessandro Serpieri: Table with phenological data of Urbino, in "Supplemento alla Meteorologia Italiana", 1867, p. 44.

Fig. 8 - Alessandro Serpieri: Tabella con i dati fenologici di Urbino, in "Supplemento alla Meteorologia Italiana", 1867, p. 44.

CONCLUSIONS

CRA-CMA library and archive represent a rich repository of meteorological, climatological and phenological historical information.

In Italy CRA-CMA is acknowledged as the main institution which provides reference and consulting services concerning meteorological and climatic data to universities and agencies or other institutions of national interest, while in spite of its potential and its rich heritage very little known, it appears to be rather unknown to the scientific and academic international community.

Several projects are carried out to achieve full exploitation of our data. The ongoing digitizing program represents a first step to draw up climatic studies at European scale on:

– climate dynamics in a comparative-historical perspective, with special regard to the Mediterranean region;
– identification of main atmospheric circulation patterns as they daily evolve at sub-synoptic scale and at mesoscale;
– reconstruction of temperature and pressure fields at mesoscale, spatially interpolating historical data;
– climatic and phenological mesoscale models verification based on historical weather and phenological observations –in order to evaluate the impact of climate change on growing crops.

At present the accessing and using the archival documents and books is limited owing to the incompleteness of inventories and catalogues and for the lack of specialized staff operating in full-time. Therefore one of CMA's main goals is to ease access to the large variety of historical weather data held in the paper archive and library, in order to raise credit abroad and to take part in international researches on historical climatology.

We hope this presentation will encourage the exchange of information and will open new relationships and collaborations.

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Field-scale ammonia emissions from surface spreading of dairy slurry in Po Valley

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Abstract: *Po Valley (Northern Italy) is one of the major ammonia (NH_3) emitting regions of Europe, where the slurry spreading causes high NH_3 volatilisation, reducing its agronomic value and becoming a potential cause of environmental concerns. In autumn 2011 a field trial was conducted to estimate the NH_3 losses from the application of dairy slurry at rate of 57 m^3 ha^{-1} on bare soil. The emissions were estimated from surface application of dairy slurry by using an inverse dispersion modelling technique associated with long term exposure passive samplers and the measure of the atmospheric turbulence. NH_3 emissions levels resulted high within the first 24 hours from the spreading, reaching the 73% of the entire losses, with a maximum value of 163 µg m^{-2} s^{-1} after 3 hours and 20 minutes, whereas the 50% of the emissions was achieved after 10 hours. The phenomenon stopped after 168 hours with a total NH_3 losses equal to 44% of the total ammoniacal nitrogen (TAN) applied. Results showed and confirmed that surface application involves high NH_3 emissions and then alternative low-emission techniques have to be adopted.*
Keywords: *ammonia emissions, inverse dispersion modeling, surface slurry application, passive samplers.*

Riassunto: *In pianura Padana la distribuzione superficiale dei reflui zootecnici determina elevate emissioni di ammoniaca (NH_3), riducendo il loro valore agronomico e causando problemi ambientali. L'obiettivo di questo studio è la stima dell'emissione di NH_3 a seguito di una distribuzione superficiale di 57 m^3 ha^{-1} di reflui zootecnici su suolo nudo nell'autunno 2011. La stima è stata effettuata mediante l'applicazione di un modello per la dispersione degli inquinanti, associato alla misura della concentrazione dell'NH_3 mediante esposizione in pieno campo di campionatori a diffusione passiva e all'utilizzo di un anemometro sonico per la misura della turbolenza atmosferica. L'emissione di ammoniaca è stata elevata nelle prime 24 h dalla distribuzione, evidenziando un picco massimo dopo 3 ore e 20 minuti (163 µg m^{-2} s^{-1}), laddove il 50% dell'intera emissione è stato raggiunto già a 10 ore dalla distribuzione. L'emissione di NH_3 è stata pari al 44% del totale di azoto ammoniacale applicato. I risultati mostrano e confermano come la distribuzione superficiale sia un metodo che determina alte perdite di ammoniaca e che quindi deve essere incentivato l'uso di tecniche alternative.*
Parole chiave: *emissioni di ammoniaca, modelli a dispersione, distribuzione superficiale dei reflui, campionatori passivi.*

INTRODUCTION

Agriculture is the primary source of gaseous ammonia (NH_3) in atmosphere and its emissions are mainly originated from the field application of animal manure and fertilisers (Gènermont *et al.*, 1998; Sommer *et al.*, 2001; Asman *et al.*, 2004), animal waste and grazing (Jarvis and Pain, 1990).

Ambient NH_3 assumes an important role and growing interest among different atmospheric nitrogen reactive species as a key to mitigate the impact of nitrogen (N) on terrestrial ecosystems (Sutton, 2006). The environmental issues due to NH_3 emissions include mainly acidification of soils, eutrophication of water with loss of biodiversity, respiratory diseases and the long-range transport of sulphur (S) and N (Sutton *et al.*, 1993; Asman *et al.*, 1998; Erisman *et al.*, 2001; Harper, 2005). Moreover, by 2020 NH_3 is expected to be the largest single contributor to acidification, eutrophication and formation of secondary particulate matter (Ammann *et al.*, 2005).

The need of reliable NH_3 measurements at field-scale becomes decisive (i) to promote abatement strategies, (ii) to derive emission factors to be used in national and international emission inventories, (iii) to validate models, (iv) to evaluate the ammonia exchange over natural surfaces in the continuum soil-plants-atmosphere domain, (v) to quantify the value of agronomic N-fertilisers.

The ammoniacal losses from agriculture contributes to over 90% in Europe (EEA, 2011), where Po Valley (Northern Italy) is one of the most emitting region of the whole area (Skjøth *et al.*, 2011). Nevertheless, the lack of measured data at

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field scale in such region (Valli *et al.*, 2001), was only recently filled (Carozzi, 2011).

NH_3 losses from field-applied manure, particularly slurry, were measured in many European experiments (Søgaard *et al.*, 2002; Sintermann *et al.*, 2011a). Due to the sticky characteristics given by its polar configuration, NH_3 is capable to bind and to be released from solid surfaces, resulting in biased measurement of the emission. However, despite many techniques have been developed (Brodeur *et al.*, 2009), a standardized method is not yet available. The different techniques vary with regard to sensitivity, selectivity and speed; furthermore measuring NH_3 is often expensive, extensive and time consuming (Aneja 1997; Harper and Sharpe, 1998). Nowadays among all the available techniques for measuring or estimating NH_3, the most popular are (i) fluxes measurement approaches, as enclosure methods (Mosier, 1989) and micrometeorological methods (Kaimal and Finnigan, 1994), (ii) concentration-based dispersion modelling, Lagrangian (Flesch *et al.*, 2004), Eulerian (Loubet *et al.*, 2010) or Gaussian (Gash, 1985) types, and (iii) ammonia emission models (Gènermont and Cellier, 1997).

The emission of NH_3 at field-scale depends on the interaction of various factors which contribute to decrease or increase the losses: fertiliser type (nitrogen content, pH, dry matter), soil type (water content, soil reaction), cultivation techniques (amount and application methods of fertilisers) and climatic conditions (temperature, wind speed, rainfall) (Sommer *et al.*, 1991; Moal *et al.*, 1995; Génermont and Cellier, 1997; Sommer *et al.*, 2001; Sommer and Hutchings 2001; Søgaard *et al.*, 2002; Misselbrook *et al.*, 2005).

The aim of this study was to estimate the NH_3 emissions caused by surface spreading of dairy slurry by using a concentration-based dispersion model. The quantification of the NH_3 fluxes was obtained by applying the backward Lagrangian Stochastic model (bLS) WindTrax (Flesch *et al.* 1995; 2004), since it has been increasingly employed in the last years (Sintermann *et al.* 2011b; Ni *et al.* 2012). The model was implemented by the use of passive diffusion samplers (Tang *et al.*, 2001) and the measure of atmospheric turbulence.

MATERIALS AND METHODS

The experimental site

The trial was performed from the 9th to 17th of October 2011 in Bigarello (MN), (Lat. 45°11' N, Long. 10°54' E, Alt. 23 m a.s.l.) in a field of 4.3 ha characterized by silty-clay soil (Hypercalcic Calcisol). Maize crop was previously harvested in September and stubbles were chopped and left on the surface. A uniform dairy slurry application rate of 57 m^3 ha^{-1} was applied on 10th of October using a 20 m^3 tank equipped with a splash plate. The spreading started from the longitudinal row passing to the centre of the field, close to measuring devices, towards the upwind edge, and then from the centre to the downwind side of the field. The slurry application (started at 8.15 a.m. and lasted 4 hours) supplied 68 kg N ha^{-1} of total ammoniacal nitrogen (TAN = NH_4^+ + NH_3). The TAN content was the 63% of the total slurry N content, while the values of the dry matter and the pH were 30 g kg^{-1} and 7.5, respectively.

Meteorological data were collected by a standard weather station, located close to the field. During the trial air temperature ranged from 0 to 25°C (mean value: 12.3°C), relative humidity was 29 to 98% (mean value: 65.5%). The mean of wind speed was 1.2 m s^{-1} with a maximum value of 4.7 m s^{-1}, whereas the main wind direction was SW. No rain events occurred in the sampling period.

During the experiment ammoniacal (NH_4–N) and nitrate (NO_3–N) nitrogen, pH and water content were daily measured at 0-5 cm and 5-15 cm soil depth. Particularly, concentrations of soil NH_4–N and NO_3–N were performed with a KCl extraction and determined by spectrometric detection (FIAstar 5000 Analyzer, Foss Tecator, Denmark). These analysis were in agreement with the ISO 11732 (1997) and ISO 13395 (1996) procedures. The values of soil pH were obtained in water solution with a soil-to-solution ratio of 1:2.5 (weight/volume), whereas the soil water content (SWC) was determined gravimetrically for each soil sample by the oven-drying method.

Air ammonia measurements

The air NH_3 concentration was quantified through the exposure of the passive samplers ALPHA (Adapted Low-cost Passive High Absorption) developed by Tang *et al.* (2001) and Sutton *et al.* (2001a). The operating principle of ALPHA samplers is the capture of gaseous NH_3 on acid support coated with citric acid. These tools are designed to measure NH_3 air concentration less than 1 μg m^{-3} (Leith *et al.*, 2004) to over 4 mg m^{-3} (Carozzi, 2011).

Samplers were placed both in the centre of the field to measure the NH_3 concentration from the slurry application (*C*) and 1 km away from the field and from any other known source of NH_3.

The latter sampling point was used to measure the background level of NH_3 concentration (C_{bgd}). Samplers were exposed in three replicates at the height (z) of 1.25 m from the displacement height $d = 0$, corresponding to the ground. The positions of the ALPHA samplers and the shape of the fields were mapped using a GPS device.

ALPHA were replaced a minimum of twice per day, after dawn and just before sunset, in order to monitor the change of atmospheric turbulence, which affects the dispersion of pollutants. During the daylight hours of the spreading day and the day after, the samplers replacement was done every three hours to have a more detailed time step. On the third day the replacement was done each 6 hours and subsequently every 12 hours.

The exposed filters were leached with deionised water (3 mL) and then analysed by spectrometric detection (FIAstar 5000 system, FOSS, Denmark) through a gas semi permeable membrane (ISO 11732, 1997), in order to measure the concentration of NH_4-N (mg L^{-1}). The air NH_3 concentration (µg m^{-3}) was then calculated by multiplying the NH_4-N concentration, the volume of air sampled in one hour (V_a = 0.003241315 m^3 h^{-1}), the time of exposure (hours) (Sutton *et al.*, 2001b; Tang *et al.*, 2008), and the stoichiometric ratio between NH_4-N and NH_3. The mean concentration and the standard deviation of the three replicates were calculated both for background (σ_{bgd}) and field measurements (σ_C).

Micrometeorological measurements

Micrometeorological measurements were performed to supply the parameters of atmospheric turbulence to the bLS model WindTrax (see section 2.4). The friction velocity (u^*), the Monin-Obukhov length (L) and the surface roughness length (z_0), together with wind speed (U) and wind direction (WD), were derived from a three-dimensional ultrasonic anemometer (USA-1, METEK GmbH, Elmshorn, Germany). The sampling frequency was 10 Hz and the device was set in the centre of the field at the same height of the ALPHA samplers. Friction velocity (m s^{-1}) is derived from the Weber's formula (1999):

$$u_* = \sqrt{-\overline{u'w'}} \qquad \text{[eq. 1]}$$

where u' and w' indicate the fluctuations of the wind components u and w along the three directions of the wind. The Monin-Obukhov length L [m] was derived from the Monin and Obukhov similarity theory (MOST, Stull, 1988) under horizontally homogeneous and steady state conditions:

$$L = -\frac{u_*^3\, T}{k\; g\; \overline{w'T'}} \qquad \text{[eq. 2]}$$

where T [K] is the mean air temperature within the surface boundary layer, k is the von Kàrmàn's constant (0.41), g is the acceleration of gravity (9.81 m s^{-2}) and w' T' is the covariance between w and T.

The roughness length was derived from the wind speed profile relationship, as:

$$z_0 = \frac{z}{\exp\left(\frac{k \cdot U(z)}{u_*} - \Psi_m(z/L)\right)} \qquad \text{[eq. 3]}$$

where U is the magnitude of the horizontal component of wind speed (m s^{-1}) and Ψ_m is a Monin–Obuhkhov universal function for momentum, estimated from the approach described by Flesch *et al.* (2004). The u_* and L were further filtered ($u^* > 0.2$ m s^{-1} and $|L| > 5$ m) to guarantee the condition for the MOST application (Flesch *et al.*, 2004; Hensen *et al.*, 2009; Loubet *et al.*, 2009). Moreover, to parameterise the bLS model, a constant value of z_0 (0.028 m) was calculated as the median value of eq. 3 over the experimental period.

The backward Lagrangian Stochastic model WindTrax

The WindTrax model (Thunder Beach Scientific, Halifax, Canada) is based on the backward Lagrangian stochastic dispersion theory described by Flesch *et al.*, (1995; 2004) and it has been employed to estimate the transfer coefficient D (s m^{-1}). The transfer coefficient is used to derive the flux of NH_3, S (µg m^{-2} s^{-1}), emitted from the fertilised surface, on the basis of the NH_3 measured concentrations (C and C_{bgd}, in µg m^{-3}), from the relationship:

$$S = \left(C - C_{bgd}\right) \times D^{-1} \qquad \text{[eq. 4]}$$

where D is retrieved by the model as the number of the interactions (N_{source}) between the source area and the thousands of trajectories (N)

generated by the model and located upwind from the position of the two NH_3 samplers in the space (see eq. 5).

$$D = \frac{1}{N} \sum_{N_{source}} \left| \frac{2}{w_0} \right| \qquad \text{[eq. 5]}$$

where (w_0) is the vertical wind speed of those trajectories that intersect the source area. The dispersion model used with the long term exposure samplers can be applied only with short time intervals (typically 30 min or 1 hour), because of the strong change of the atmospheric stability over a timescale of few hours. In the same way, the estimation of *S* is possible considering only the periods of atmospheric stationarity reached by short integration time of the turbulence parameters (u^*, *L* and z_0), as the MOST theory states. For the determination procedure of *S* three hypotheses have to be assumed: (i) non-reactivity of the emitted NH_3 in the atmosphere, (ii) spatial homogeneity of the flux from the surface and (iii) steadiness of z_0 (Loubet and Cellier, 2001; Loubet *et al.*, 2009; Nemitz *et al.*, 2009).

RESULTS

Micrometeorological conditions

The trends of u_* and the atmospheric stability parameter (*z/L*) measured together with their statistics, are shown in Fig. 1 and Tab. 1, respectively. Friction velocity marked the typical high peak values during the daylight hours and the minimum values over the night time, where the amplitude and the magnitude of the peaks are directly related to the presence of horizontal wind. The negative peaks of *z/L* indicated the daily instability whereas positive peaks showed the nocturnal stability. Night and early mornings were characterized by phases of stability conditions, excepted for 14th and 15th of October where cloud cover and a strong and persistent wind occurred.

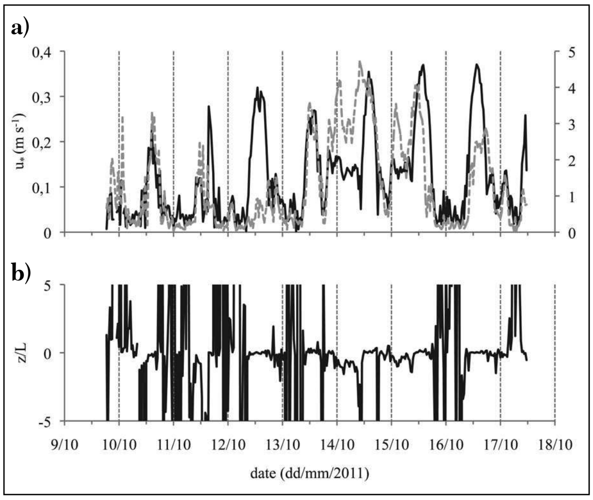

Fig. 1 - a) friction velocity (u^*) and wind speed (grey dotted line) over the experiment; b) atmospheric stability parameter (*z/L*).
Fig. 1 - a) velocità di frizione (u^*) e velocità del vento (linea grigia tratteggiata) per la durata dell'esperimento; b) parametro di stabilità atmosferica (z/L).

		min	*max*	*mean*	*median*	*σ*
u_*	m s^{-1}	0.00	0.37	0.12	0.09	0.09
z/L		-43403	1492	-143	0	2331
Wind speed	m s^{-1}	0.0	4.7	1.3	0.8	1.2
C	µg m^{-3}	9	820	96	29	173
C_{bgd}	µg m^{-3}	8	35	15	14	8
S (flux)	µg m^{-2} s^{-1}	0	163	6	1	17

Tab. 1 - Main statistics of atmospheric turbulence parameters (u^* and *L*), NH_3 concentration measured in the fertilised field (*C*) and its background level (C_{bgd}), *Wind speed* and the estimates NH_3 flux (*S*).
Tab. 1 - Principali statistiche dei parametri della turbolenza atmosferica (u^* e L), concentrazione di NH_3 misurata al centro del campo (C) e di background (C_{bgd}), velocità del vento (*Wind speed*) *e del flusso di NH_3 stimato (S).*

Ammonia concentrations

Fig. 2 shows the concentrations of NH_3 (µg m^{-3}) measured over the experimental period in the centre of the field and present as background. Before the application of the fertiliser, the concentration was 1.7 µg m^{-3} higher than the background value. In the first three hours after the spreading, the field NH_3 concentration rose up to 505 µg m^{-3}, followed by a fast increase to 820 µg m^{-3} in the subsequent three hours. In the following measurement period (6 to 15 h), the concentration decreased down to 300 µg m^{-3} and then increased during the night time hours to 539 µg m^{-3}. After the first 24 hours the concentration gradually decreased, reaching the background concentration after further 60 hours. In the last measurement period (84 to 168 h) the magnitude measured in the centre of the field and as background was coincident. Tab. 1 shows the statistics relative to such NH_3 concentrations.
The variability (σ) of the three ammonia samplers ranged from 0.2 to 31.8 µg m^{-3}. In Fig. 3 the

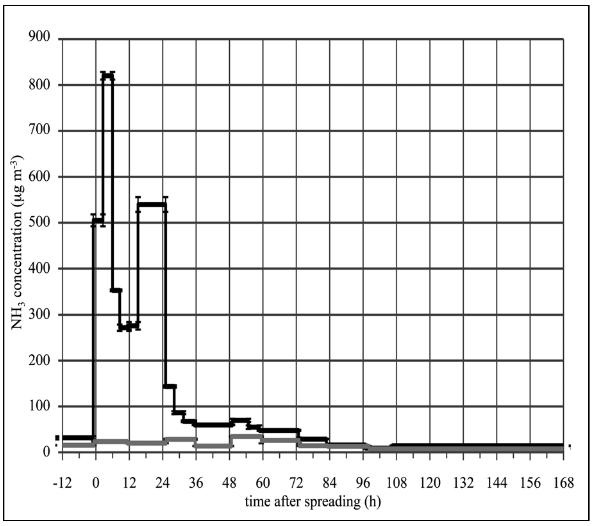

Fig. 2 - NH_3 concentrations measured in the centre of the fertilised field (dark line) and in its background values (gray line). The error bars show standard deviations.
Fig. 2 - Concentrazioni di NH_3 misurate nel centro del campo fertilizzato (linea nera) e come background (linea grigia). Le barre di errore mostrano le deviazioni standard.

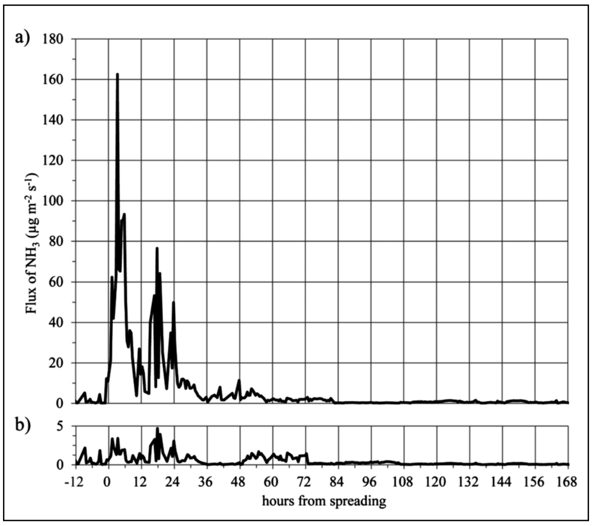

Fig. 4 - a) NH_3 flux simulated by the inverse dispersion model WindTrax. b) uncertainty in the modelling approaches employed due to the uncertainty in the concentrations measurements.
Fig. 4 - a) flussi di NH_3 stimati attraverso l'impiego del modella a dispersione WindTrax. b) incertezza nella stima dei flussi attraverso il modello, dovuti alla incertezza nella misura delle concentrazioni.

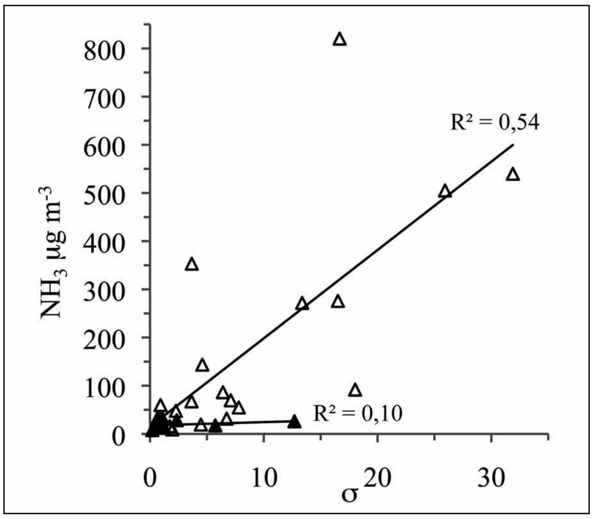

Fig. 3 - Scatter plots reporting the average of NH_3 concentration and relative standard deviation (σ) for measurements in the field (Δ) and at the background (▲).
Fig. 3 - Grafico a dispersione riportante la media delle concentrazioni di NH_3 e la deviazione standard (σ) misurate nel centro del campo (Δ) e come background (▲).

relation between σ and the mean values of concentration measured in the field and as background is displayed for each measurement period. The relation between C_{bkg} and σ_{bgd} was not significant ($R^2 = 0.10$, $P>0.05$), while a significant relationship was detected between C and its σ_C ($R^2 = 0.54$, $P<0.01$).

Ammonia emissions from slurry spreading

The flux estimated by the bLS model WindTrax and the error due to the dispersion of the NH_3 concentration mean value are displayed in Fig. 4. The emission trend showed high peaks immediately after the spreading, with a maximum value (163 µg m^{-2} s^{-1}) reached after 3 hours and 20 minutes (see Tab. 1). Subsequently, the emission decreased quickly to rise again during the night time hours (15 to 21 h). The last high peak occurred after 24 hours because of the increase of the solar radiation. In the last measurement period (24 to 168 h) a gradual reduction to low values (2 µg m^{-2} s^{-1}) was detected. Errors ranged from 0 to 4.7 µg m^{-2} s^{-1}, with a mean value of 0.4 µg m^{-2} s^{-1}.

Dynamics of soil NH_4-N, NO_3-N and pH

The dynamics of N into the soil as ammonium and nitrate form, together with the trends of SWC and pH at 0-5 and 5-15 cm depth, are displayed in Fig. 5a and 5b, respectively. The measurement period ranged from -72 to 96 hours with a time step of 24 hours, where time 0 represented the time immediately before the manure spreading. Samplings at -48 and -24 hours were not carried out because of the high soil moisture. The content of NH_4-N in the soil profile (0-15 cm) was constant before the slurry application (around 1 mg L^{-1}, from 0 to -72 hours) and rose up after the fertilisation, particularly in the first layer (0-5 cm).

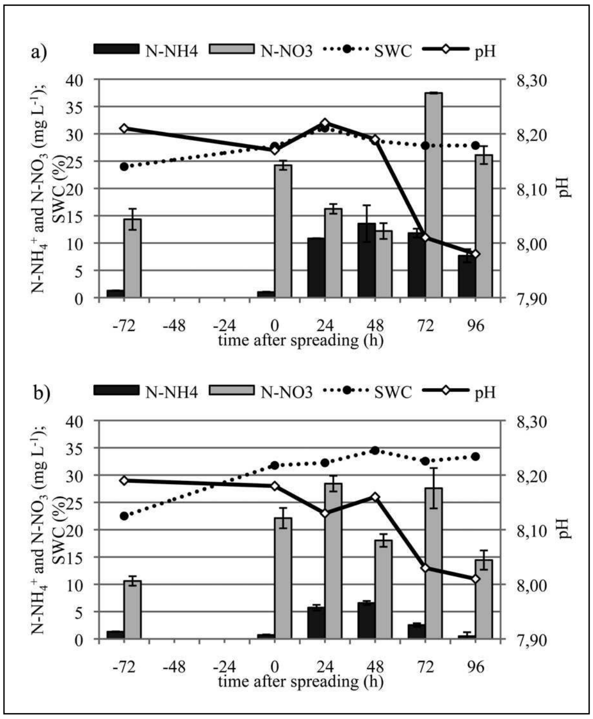

Fig. 5 - Trend of soil N-NH_4^+, N-NO_3^-, pH and water content (SWC) during the time after slurry spreading in the field trial: a) 0 – 5 cm depth; b) 5 – 15 cm depth.

Fig. 5 - Andamento del valore di pH e del contenuto di N-NH_4^+ e N-NO_3^- e acqua (SWC) nel suolo durante le ore dello spandimento del liquame in campo: a) profilo 0 – 5 cm di profondità; b) profilo 5-15 cm di profondità.

The highest values in the two soil layers were observed 48 hours after the spreading.

The values of NO_3-N concentration did not seem to have a specific trend over time. In both layers the maximum values were reached at 72 h, showing the highest values in the lower layer (5-15 cm). At 72 and 96 hours the NO_3-N concentration appeared to be higher in the 0-5 cm depth (+26% and +44%, respectively).

The values of pH were reduced by 0.23 and 0.19 units in the 0-5 and 5-15 cm, respectively. The pH fast decrease started after 48 hours. The SWC showed values ranging from 24 to 31% in the 0-5 cm profile, with the maximum value observed 24 hours after the spreading. In the deeper layer a wider variation of SWC occurred (from 22% at -72 hours to 35% at 48 hours).

DISCUSSION

The NH_3 volatilisation estimated over the field trial followed the typical trend reported elsewhere (i.e. Sommer and Hutchings 2001; Powell *et al.*, 2011). The highest emission rate was recorded immediately after the slurry application. Subsequently, it quickly fell down because the concentration of TAN in soil surface decreased as consequence of emission itself, infiltration, absorption in the soil matrix, or nitrification (van der Molen *et al.*, 1990; Sommer *et al.*, 2004). Cumulative NH_3 loss observed at the end of the trial was visibly exhausted and equal to 30.2 kg N ha^{-1}, corresponding to an emission factor (EF) of 44.4% of the TAN applied. The emission ranged from 40% to 53% between 6 to 12 hours from the spreading. Similar findings were obtained by other authors, measuring a range of total loss between 30 and 70% of the TAN (Sommer and Hutchings, 1995; Meisinger and Jokela, 2000). After 24 and 48 hours the total loss reached 73% and 88%, respectively, getting to the 100% of the emission at the end of the trial at 168 hours. The trend of the cumulate emission can be represented by the Michaelis-Menten equation (eq. 6) already used in this context by Søgaard *et al.* (2002):

$$N(t) = N_{\max} \frac{t}{t + K_m} \quad \text{[eq. 6]}$$

where N_{max} is the total loss of NH_3 (fraction of TAN applied) and K_m [h] is the time t satisfying $N(t) = ½ N_{max}$. A low value of K_m indicates that a high proportion of the total NH_3 loss occurs soon after application, whereas a high K_m value indicates that losses occur over a longer period. In our case after 10 hours the 50% of the total NH_3 was emitted (K_m = 10 hours). The EF obtained in this field trial is coherent with what has been reported in the recent literature for similar conditions (see the review by Sintermann *et al.*, 2011b). Furthermore, applying the regressive model ALFAM (Søgaard *et al.*, 2002), based on the data deriving from 800 experiments and on the Michelis-Menten equation type described above, the EF obtained resulted 40% of the TAN.

The fluxes estimated by the bLS model WindTrax showed high levels of emission when *z/L* parameter assumed negative values, or else when the atmosphere is in unstable condition. That was evident during the hours immediately close to the application of the slurry, characterized by high levels of concentration. The high fluxes observed during the night time hours of the spreading day (15 to 24 h) were due both by high levels of ammonia concentration (see Fig. 2) and the alternation of the atmosphere conditions. In fact, over the night, atmospheric condition can range from high stability, where the vertical gradients of ambient concentration are enhanced to very small

diffusivity, to unstable conditions, in which concentration gradients are small due to the intense turbulent activity of the surface layer (Erisman *et al.*, 1988; Famulari *et al.*, 2009). Another factor affecting ammonia emissions was the vertical wind speed (w), whereas the horizontal wind speed is not involved. In fact, as occurred from 14th to 15th October, the strong horizontal wind speed recorded did not affect the emissions that remained at low level. On the opposite, during the night time hours of the spreading day, when the value of vertical wind speed was high, an increase of emission occurred. The pattern of NH_3 emissions followed the trend of the measured concentrations and the high emission peaks took place in correspondence with the high values of concentration. Over the spreading daylight hours and the subsequent two days, the frequency of the ALPHA samplers change (3 hours in the first two days and 6 in the third, instead of 12 hours) allowed to obtain a more detailed ammonia concentrations and fluxes. In fact, integrating these concentrations over a time of 12 hours, the peaks of emission resulted lower and the final EF decreased by 5% (from 44 to 39% TAN). Therefore the temporal detail in the acquisition of the NH_3 concentration is a crucial point for a correct determination of the emission (Carozzi *et al.*, 2012). Loubet *et al.* (2010) found that for an exposure time between 2 and 12 hours, the underestimation of NH_3 emission was not expected to be larger than 5 to 10% (± 5%) in a 100 m^2 surface area. Moreover, the use of inverse dispersion models, coupled with long term exposure concentration samplers, produced similar results if compared to the fastest and error-prone Eddy Covariance approach, when measuring NH_3 fluxes at field scale (Ferrara *et al.*, 2012; Carozzi, 2011).
Despite the low sampling frequency, an increase of the NH_4-N concentration into the soil after the application of the slurry was recorded. As emissions ended also the NH_4-N concentration decreased, whereas the NO_3-N concentration started to increase due to the nitrification process (which was most evident at 0-5 cm depth soil profile). As reported by Gènermont and Cellier (1997) and Misselbrook *et al.*, (2005) NH_3 emission and soil pH are directly related. In our case they started to decrease at the same time (after 24 h). Such behaviour was probably due to the release of protons (H^+) caused by the transition from NH_4^+ to NH_3 in the nitrification process (van Breemen *et al.*, 1982; Freney *et al.*, 1983). Lastly the increase of the SWC due to the slurry application was observed in the first 24 hours in the 0-5 cm layer, whereas in the 5-15 cm layer the effect was extended till 48 hours.

CONCLUSIONS

Surface application of dairy slurry determined high ammonia emission levels within the first 24 hours, followed by a first rapid and then gradual decrease to low emission levels in the subsequent days. Ammonia losses were the 44% of the total TAN applied. The results obtained highlighted the need of low-emission techniques, such as surface spreading with incorporation and injection, which are supported by scientific data showing the reduction of ammonia emission under experimental conditions. However, the incorporation of slurry should be done as soon as possible because the 50% of the total ammonia emission occurred within 10 hours. Reliable NH_3 quantification has to be considered a central aspect for decision makers, to promote abatement strategies and to derive emission factors used in national and international emission inventories.

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Agroclimatic potential for cultivation of two sorghum cultivars in mixtures with okra and maize in a forest-savanna transition zone of Nigeria

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Abstract: *Agroclimatic potential for cultivation of two sorghum cultivars grown in mixtures with okra and maize was investigated in a forest-savanna transition zone of Nigeria at the Experimental Research Farmland of the National Horticultural Research Institutes (NIHORT) - Ibadan during. During the main five phenological stages of sorghum (*Sorghum bicolor (L.)* Moench) the agrometeorological variables were daily recorded and averaged on ten days,likewise the crops growth and productive variables were fortnightly measured . Two sorghum cultivars (Janare and Farin Dawa), okra (*Hibiscus esculentus *L. – cultivar NHAe 47-4) and maize (*Zea mais *L. – cultivar Suwan-1) were intercropped in simple randomized complete block design (RCBD) fitted into split plot arrangements with three replicates in two field trials during 2009 and 2010 cropping seasons. In 2010 the crops showed a longer growing season and received more rainfall compared to 2009 season (692 mm vs 487.2 mm). Instead in 2009 warmer temperatures were recorded compared to 2010 during the establishment, early vegetative stage (33.2 °C vs 32 °C), and the reproductive one (28.5 °C vs 27 °C). The mean grain yields of sorghum cultivars were significantly ($p<0.05$) higher in 2009, especially in the okra combinations with cultivars Farin dawa and Janare (0.84* and *0.72 t ha^{-1} respectively), than in 2010 (0.80* and *0.67 t ha^{-1} respectively). These results may be due to the higher mean soil temperatures occurred in 2009 at 5 and 20 cm, respectively of 28 °C and 26 °C, compared to the 2010 season, when the mean soil temperatures were of 27°C and 25 °C at 5 and 20 cm respectively. Generally, Farin Dawa accumulated more heat than Janare in both 2009 and 2010 from planting to maturity regardless of the cropping system.*
Keywords: *sorghum, okra, maize, forest-savanna, transition zone.*

Riassunto: *Il lavoro mira ad analizzare le potenzialità agroclimatiche della zona di transizione foresta-savana per la coltivazione di due cultivar di sorgo in coltura pura ed in consociazione con okra e/o mais. L'analisi è stata condotta durante le stagioni 2009 e 2010 in un campo sperimentale sito presso la Stazione Sperimentale dei National Horticultural Research Institutes (NIHORT) di Ibadan (Nigeria).*
*Cinque periodi fenologici di sorgo (*Sorghum bicolor (L.)* Moench) hanno costituito l'unità di tempo per le indagini. Durante tali periodi, le principali variabili agrometeorologiche sono state misurate con passo giornaliero e trasformate successivamente in valori medi o totalizzati con passo decadale. A ciò si sono aggiunte misure biologiche sulla coltura e relative a diverse variabili di crescita e di produzione. Le due cultivar di sorgo (Janare e Farin Dawa), okra (*Hibiscus esculentus *L. – cultivar NHAe 47-4) e mais (*Zea mais *L. – cultivar Suwan-1) sono state inserite in un disegno sperimentale a blocchi randomizzati completi (RCBD) realizzato con tecnica split – splot e che prevedeva tre repliche. I risultati conseguiti hanno mostrato che la stagione di crescita 2010 è stata relativamente più piovosa (692 millimetri contro 487 millimetri), meno calda e prolungata rispetto al stagione 2009, la quale è risultata dal canto suo più ricca di risorse termiche durante la fase iniziale di sviluppo (33.2 °C contro 32 °C), e la fase riproduttiva (28,5 °C vs 27 °C). I rendimenti medi del sorgo sono risultati significativamente più elevati (p <0,05) nella stagione 2009 specie se in combinazione con le cultivar di okra Farin Dawa e Janare (0,84 e 0,72 t ha^{-1}) rispetto alla stagione 2010 (0,80 e 0,67 t ha^{-1} rispettivamente). È ipotizzabile che ciò sia stato determinato dalla più elevata temperatura media del terreno del 2009 rispetto al 2010 a 5 cm (28 vs 26 °C) e a 20 cm (27 vs 25 °C). In generale per il periodo semina-maturazione e per gli anni 2009 e 2010 la cultivar Farin Dawa ha accumulato più calore rispetto a Janare.*
Parole chiave: *sorgo, okra, mais, zona di transizione foresta-savana.*

INTRODUCTION

Although Nigeria is among the largest producers of sorghum, this crop is not as popular in Nigeria as either rice or maize (Agboola, 1979). Nevertheless the sorghum shows some advantages: (i) it is a multipurpose crop, useful to feed humans or livestock, (ii) it presents a relatively high protein content (15%) compared with rice (Oryza sativa) (13%) and maize (11%) and (iii) it is a drought tolerant crop.

Sorghum is well-known for its capacity to tolerate conditions of limited moisture and to grow during periods of extended drought that would impede production for most other grain crops. It is one of the most drought-tolerant grain crops and by this point of view it is both an excellent ideotype to

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address genetic improvement of other cereals and an interesting reference crop to evaluate mechanisms of drought tolerance of other species (Tuinstra *et al.*, 1997).
Sorghum is able to endure quite arid conditions through both drought resistance and drought escape mechanisms as a result of its extensive root system, waxy leaves and ability to temporarily stop growth when the drought becomes excessive. A drought escape mechanism is exhibited when sorghum becomes dormant under adverse water conditions but resumes growth when water relations improve even after relatively severe drought. Early drought stops growth before floral initiation and the plant remains vegetative but it will resume leaf and flower production when conditions become favorable again for growth. Late drought stops leaf development but not floral initiation.
For high yields, cultivars with cycle from 110 to 130 days require 450 – 650 mm of water (Doorenbos and Kassam, 1979). Furthermore, in order to maximize sorghum yields, soil moisture should be maintained above 55% of the available water capacity in the rooting zone of the soil profile throughout the growing season. When the growing period is long, stalking cultivars can recover by producing additional stalks with bearers, even if critical water deficits occur during vegetative growth. Extreme water deficits during the flowering period reduce pollination or cause spikes to dry out. Nevertheless the decrease of the resultant yield can be partially compensated by additional stalks with spikes (Doorenbos and Kassam, 1979).
Studies have equally shown that greatest reduction in okra yield occur when stress is imposed at the flowering stage. Similarly moisture stress during the pod filling stage resulted in more than 70% reduction in fruit yield of okra, while the lowest reduction in fruit yield was observed when moisture stress occurred during the vegetative stage (Mbagwa and Adesipe, 1987). Some later studies have suggested that flowering stage is the most sensitive to stressful conditions (Bänziger *et al.*, 1999). The selection of crop genotypes for tolerance to midseason drought stress has been found to improve the broad adaptation and the specific adaptation to drought environments. (Chapman *et al.*, 1997).
Research into rice and maize cultivation has been extensive in nearly all the eco-climatic zones of Nigeria, but in contrast the research endeavor in sorghum is not only small but restricted to the savanna region. Notable examples are those by Curtis (1968), Kassam and Andrews (1975), Leng (1982), Obilana (1983), Doggett (1988) and Craufurd and Aiming (2001).
Therefore it is not surprising that sorghum cultivation is restricted to the northern part of Nigeria where it is usually intercropped with maize, millet and cowpea (Agboola, 1979). However, Bello (1997) has investigated and highlighted the agro-climatic potential of the forest-savanna transition zone of Nigeria for the cultivation of sorghum. Based on his finding, it would appear that with changes in ecological boundaries resulting from changing in land use and climate pattern, the exploitation of the transitional humid zone may offer options for increase of sorghum production in the country. Currently the scientific literature is scarce of these studies for this zone . Moreover in forest-savanna transition zone of southwestern Nigeria, the traditional farmers are more satisfactory grow different species of crops than one. Indeed it is cheaper for farmers to grow many of their own requirements than to buy them (Kurt, 1984, Gomez and Gomez 1986). Therefore, the common cropping system in the zone is intercropping and the common crop combinations include maize-cassava, maize-mellon, maize-okra intercrop. At the same time there is a lack of information on maize-sorghum and sorghum-okra intercrop.
Therefore the basic aim of this research is to promote a wider adoption of Soghum to improve cropping systems and overall to enhance the results of the traditional intercrops.

MATERIALS AND METHODS

Experimental site

The experiment was carried out at Experimental, Teaching and Research Farmland of the National Horticultural Research Institutes (NIHORT), Ibadan (7° 22'N, 3° 50'E) during the 2009 and 2010 cropping seasons (Fig. 1). The study area is characterized by a tropical climate with distinct wet and dry seasons. The wet season is the effect of the moist southerly monsoon blowing from the Atlantic Ocean, whilst the dry season is the effect of the continental North Easterly harmattan winds blowing from the Sahara desert.
The resulting rainfall pattern is bimodal with the main rainy season in April-July period, while the secondary one is in August-October period. The annual rainfall ranges between 1400 and 1500 mm in Ibadan and its environs. Isolated and scanty rains usually start in mid-March and steadily increase to reach the peak values in July followed by a short break in August and another peak in September.

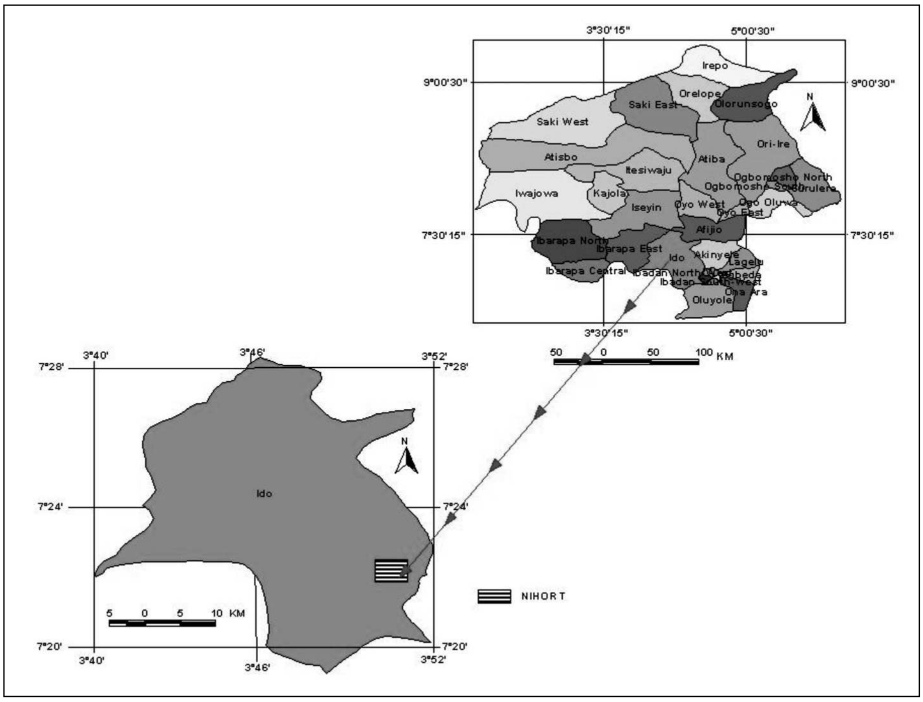


Fig. 1 - Location of NIHORT within Ido local government area in Oyo State, Nigeria.
Fig. 1 - Localizzazione del NIHORT all'interno dell'area governativa Ido dello Stato di Oyo.

The dry season is normally from October to March and it is often characterized by hot days.
The region is relatively hot with mean annual air temperature of about 30°C. The greatest variation in temperature is experienced between July (25.7°C) and February (30.2°C). Extreme values of relative humidity are respectively reached at the peak of dry season (February: 37-54%) and during the rainy season (from June to September: 78-85%) (Adejuwon 1971).

Crop management
Two cultivars of Sorghum (Farin Dawa and Janare), one of maize (Suwan 1) and one of okra (NHAe 47-4) have been used in two field trails during both seasons adopting the species e combinations described in Tab. 1. Two - four seeds of sorghum, maize and okra were planted at 2.5 cm depth. Sorghum was planted three weeks after okra and maize to allow the establishment of these two latter. Spacing was 90 x 60 cm for Sorghum (2 seedlings/stand), 90 x 30 cm for maize (1 seedling/stand) and 90 x 30 cm for okra (1seedling/stand).
Each plot size was 6 x 3 m for a total plot size of 100 x 20 m. In both seasons, land preparation was carried out by disc-ploughing and ridging. Plots were hoe weeded at third and sixth h weeks after planting along with other cultural practices. Fertilizer was applied into furrows at mid-interrow two weeks after the okra and maize emergence and was covered with soil.

Combination	Acronyms
white sorghum	S1
red sorghum	S2
maize/white sorghum	MS1
maize/red sorghum	MS2
okra/white sorghum	OS1
okra/red sorghum	OS2
maize/okra/white sorghum	MOS1
maize/okra/red sorghum	MOS2

Tab. 1 - Sorghum monocultures and different crops combinations of sorghum-maize-okra considered for the experimental plots and adopted acronyms.
Tab. 1 - Monocolture e consociazioni di sorgo, mais e okra oggetto di sperimentazione e relativi acronimi.

The experimental plots were arranged in a randomized complete block design (RCBD) fitted into split-plot design with three replicates. Three data-sets, concerning the growth and productive variables and the agro-climatic indices, were collected during the main critical phenological stages.
Meteorological data, representative of the fields microclimatic conditions, were daily recorded by a ground weather station located at 200 m near to the experimental site and then processed into decadal values. The following meteorological variables were daily monitored: rainfall (Rr, mm), mean relative humidity (Rh, %), open water evaporation (Ev, mm), maximum and minimum temperature (Tx and Tn, °C), sunshine hours, wind speed at a height of 2m (Ws, ms^{-1}).

Growth and productive variables

Per each plot the following growth variables were measured on a sample of plants: plant height (cm), leaf area (cm^2), number of leaves per plant, stem diameter (mm).Leaf Area LA (cm^2) was determined by a no-destructive method, carrying out measurements on 10 leaves per plot and then computing the respectively averages. Specifically, the okra LA was estimated following the equation 1 (Asif, 1977) and the LA of each single leaf blade was assessed for sorghum and maize following the equation 2 (Stewart and Dwyer, 1999).
(1) LA=115X- 1050
where L is the length of mid rib (cm).
(2) LA= (L x W) * L_{af}
where L is the length (cm), W is the maximum width (cm) and L_{af} is the leaf area factor. For this latter, a value of 0.75 has been adopted, facing to reported values of 0.75 (Montgomery, 1911), 0.73 (Mckee, 1964), 0.72 (Keating and Wafula, 1992), 0.79 (Birch *et al.*, 1998) and 0.74 (Stewart and Dwyer, 1999).
Per each plot the following productive variables, concerning the indicated species, were measured: grain yield (sorghum and maize), panicle length (sorghum), cob weight (maize), weight of 100 grains (maize), pods number per plant and pods weight, length and diameter (okra).

Statistical analysis

Analysis of variance was carried out by set methods (Steel *et al*. 1997) using the PROC GLM procedure of the SAS Statistics package (SAS Institute Inc., 2000). The cropping pattern and cultivars were considered as random effects, while the planting seasons were considered as fixed effects. Cultivars and cropping patterns mean differences within each planting season were separated using Fisher's Least Significant Difference (LSD) test at $P \leq 0.05$.

RESULTS AND DISCUSSION

The results were discusseded considering the data recorded for white and red sorghum grown alone as referencedata-set that therefore was matched with the data obtained for the other combinations of species (the intercropping with maize and/or okra).

Agrometeorological variables

The 10-days mean values measured for Tx, Tn, Rr Rh and Ws during both seasons and the main phenological stages of sorghum are shown in Figg. 2 and 3.

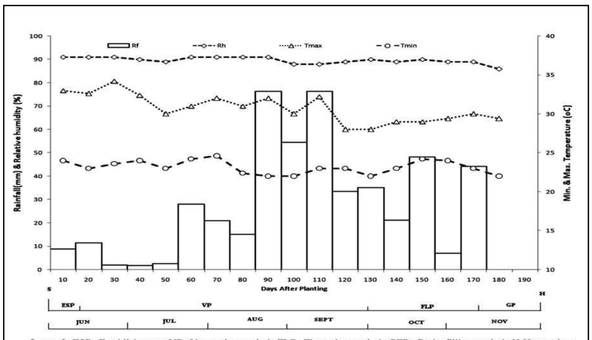


Fig. 2 - Time series of main agrometeorological variables during different phenological stages of experimental crops in 2009 season (June-November).
Fig. 2 - Serie storiche delle principali variabili agrometeorologiche durante le differenti fasi fenologiche per la stagione 2009 (Giugno-Novembre).

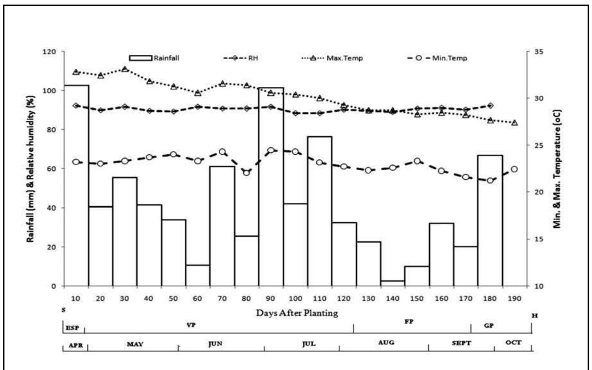


Fig. 3 - Time series of main agrometeorological variables during different phenological stages of experimental crops in 2010 season (June-November).
Fig. 3 - Serie storiche delle principali variabili agrometeorologiche durante le differenti fasi fenologiche per la stagione 2010 (Giugno-Novembre).

The total rainfall occurred in 2010 season was higher than 2009 (692 mm in 2010 vs. 487.2 in 2009) as result of the higher precipitation during the vegetative (537.5 mm vs 366.6 mm) and reproductive (154.5 mm vs 120.6 mm) phase.
As the figures 2 and 3 show, the temperature trends during both seasons follow the typical one of the Nigeria savanna area (Olaniran and Babatolu, 1987). Minimum temperature ranged between 22 and 24 °C in 2009 and between 21.2 and 23.4 °C in 2010. Maximum temperature ranged between 28 and 33 °C in 2009 and between 27 and 32 °C in 2010. During the planting, establishment and early vegetative stages warmer temperatures were recorded compared to the reproductive stages in both years2009 (24 vs 22 and 33 vs 28 °C) and 2010 (23 vs 22 and 31vs 27 °C).
During the 2009 season the mean minimum temperature was 24 °C during the establishment stage (ESP) but dropped to 23°C during the flowering period (FLP) while the least minimum temperature of 22°C was observed during the grain filling period (GFP). The 2010 growing season experienced a much lower minimum temperature with recorded values of 23.2, 22.57 and 21.6°C for ESP, FLP and GFP respectively. Maximum

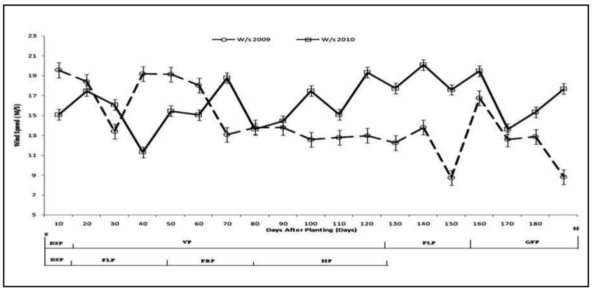


Fig. 4 - Wind speed (m s^{-1}) during 2009 and 2010 seasons.
Fig. 4 - Velocità del vento (m s^{-1}) nelle stagioni produttive 2009 e 2010.

temperature in 2009 season dropped from 33°C at ESP, to 29.3°C at FLP, while 30°C was recorded at GFP. In 2010, maximum temperature values were 32.7, 28.71 and 28.24°C at ESP, FLP and GFP, respectively.
Fig. 4 shows Ws (m s-1) in 2009 and 2010. Ws at 10 and 60 days after planting (DAP) was higher during 2009 (19.6 and 13.4 m s-1) compared to 2010 (11.3 and 15.1 m s-1). However, Ws at 70 and 180 DAP was higher during 2010 (13.6 and 20.1 m s-1) than 2009 (8.7 and 16.7 m s-1). In any case the maximum wind speed reached during windy days was not enough to cause physical damage for the crop

Treatments	2009			2010		
	GDDPI	GDDFL	GDDGM	GDDPI	GDDFL	GDDGM
White sorghum						
S1	1909	2212	2916	1779	2289	2975
OS1	1946	2259	2972	1779	2317	3030
MS1	2067	2381	3087	1835	2435	3149
MOS1	2116	2412	3099	2077	2499	3198
Red sorghum						
S2	1691	2200	2904	1757	2265	2881
OS2	1696	2260	2881	1785	2284	3030
MS2	1981	2380	3048	1841	2410	3077
MOS2	2025	2399	3086	2077	2481	3099
LSD(0.05)	110.3	76.07	35.07	74.43	36.73	62.52
White sorghum (mean)	2009	2316	3018	1868	2385	3088
Red sorghum (mean)	1848	2310	2980	1865	2360	3022
LSD (0.05)	81.61	55.04	45.82	72.84	34.89	21.57
Alone sorghum (mean)	1800	2206	2910	1768	2277	1569
Sorghum/okra (means)	1821	2260	2927	1782	2301	1598
Sorghum/ maize (means)	3058	3571	4612	2756	3639	3236
Sorghum/maize/ okra (mean)	3128	3612	4641	3116	3739	3286
LSD (0.05)	52.91	34.00	56.56	71.24	33.05	41.61

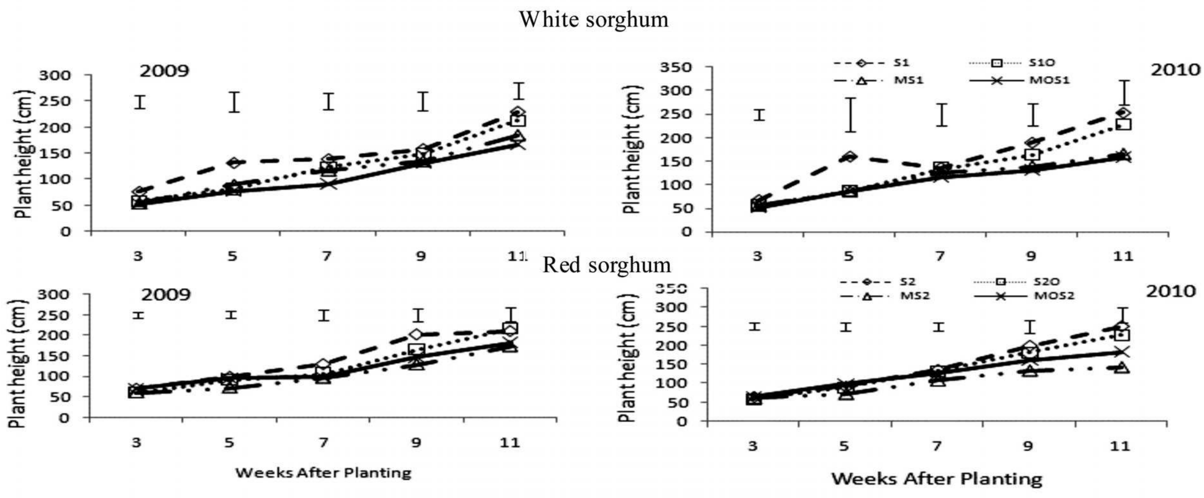
GDDPI: GDD from sowing to panicle initiation; GDDFL: GDD from sowing to flowering; GDDGM: GDD from sowing to maturity.

Tab. 2 - Growing degree days or heat units accumulation of two Sorghum cultivars as influenced by intercropping with Okra and Maize in 2009 and 2010.
Tab. 2 - Cumuli di unità di caldo (gradi giorno) per le due cultivar di sorgo in coltura pura o consociate con mais e/o Okra.

because the windy events occurred when the plants were fully established and approaching the ripening. On the other hand, during the days with lower wind speed, the proper conditions to receive sunlight for maximum photosynthesis were occurred for the plants.
Thermal resources expressed as growing degree days (GDD) from sowing to maturity are shown in Tab. 2. From planting to maturity more heat was cumulated by the white sorghum genotype (S1) than the red one (S2) in both seasons.
During **2009 the cumulative** GDD, from sowing to panicle initiation, reached the threshold of 1909 °C for S1, preceded respectively by OS1 (1946°C), MS1 mixtures (2067°C) and MOS1 (2116 °C). Likewise the values for red sorghum combination reached 1691°C for S2, preceded respectively by OS2 (1696 °C), MS2 (1981°C) and MOS2 (2025°C).
During **2010 the cumulative** GDD, from sowing to panicle initiation, for white sorghum was 1779°C for both S1 and OS1, preceded by MS1 (1835°C) and MOS1 (2077 °C). The values for red sorghum combination ranged from 1757°C for S2, followed by OS2 (1785 °C), MS2 (1841 °C) and MOS2 (2077 °C). For both years similar relations were observed for the periods from sowing to flowering and from sowing to maturity.
Values of soil temperature during crop season (not shown in figures) were higher in 2009 (28 and 26 °C at 5 and 20 cm respectively) than in 2010 (27 and 25 °C at 5 and 20 cm respectively).

Growth characteristics
The main biometric characteristics of the two sorghum cultivars in monoculture and in mixtures (MS1, MS2, OS1, OS2, MOS1, MOS2) at 3, 5, 7, 9 and 11 weeks after planting (WAP) are briefly commented hereafter.

Plant height of sorghum (Fig. 5)
In **2009**, the plant height of white sorghum (S1) in both monoculture and mixtures was statistically different at 5, 7 and 11 WAP, while red sorghum (S2) showed no significant differences ($p<0.05$) in all sampling time, except at 5 WAP for the treatments with red sorghum (S2). More specifically S1 increased from 76.3 to 229.4 cm whereas S2 increased from 71.0 to 210.7 cm at 3 and 11 WAP respectively. OS1 increased from 59.0 cm 212.8 cm while OS2 increased from 59.9 to 215.8 cm at 3 and 11 WAP respectively. MS1 increased from 53.7 to 184.8 cm whereas MS2 increased from 60.6 to 174.2 cm at 3 and 11 WAP respectively. Finally MOS1 increased from 52.6 to 166.6 cm while MOS2 increased from 69.4 to 182.9 cm at 3 and 11 WAP respectively.
In **2010**, plant height of sorghum was significantly different at 5, 9 and 11 WAP for treatments with white sorghum (S1) and red sorghum (S2). More specifically S1 increased from 76.3 to 229.4 cm, whereas S2 increased from 71.0 to 210.7 cm. OS1 increased from 56.9 cm to 227.8 cm whereas OS2 increased from 58.4 to 227.7 cm. MS1 increase from



MS1: Maize/ White Sorghum Intercrop; MS2: Maize/Red Sorghum Intercrop; MOS1: Maize/Okra/White Sorghum Intercrop; MOS2: Maize/Okra/Red Sorghum Intercrop; S1: White Sorghum (Farin Dawa);S2: Red Sorghum (Janare); SO1: White

Fig. 5 - Effects of intercropping with maize and okra on the Plant height (cm) of two sorghum cultivars in 2009 and 2010 seasons.
Fig. 5 - Effetti della consociazione con mais e okra sull'altezza (cm) delle piante di sorgo delle due cultivar in esame per le stagioni produttive 2009 e 2010.

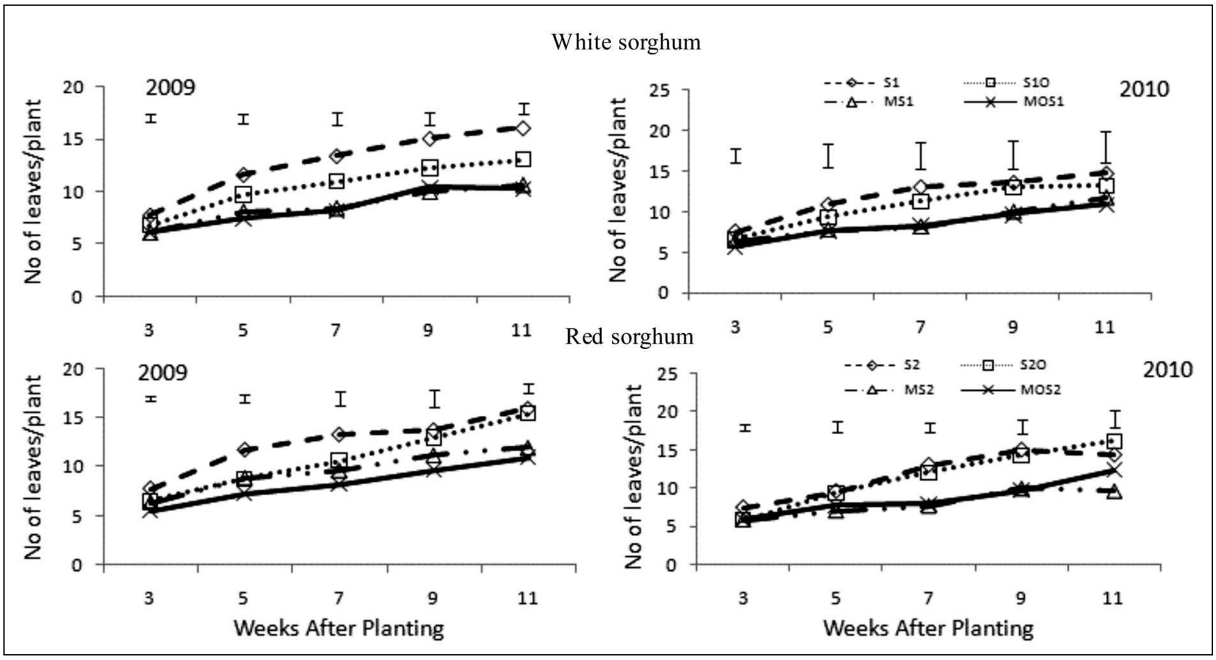


Fig. 6 - Effects of Intercropping with okra and maize on the number of leaves of the two sorghum cultivars in 2009 and 2010 seasons.
Fig. 6 - Effetti della consociazione con mais e okra sul numero di foglie delle piante di sorgo delle due cultivar in esame per le stagioni produttive 2009 e 2010.

55.7 to 165. 7 cm, whereas MS2 increased from 62.8 to 143.0 cm at 3 and 11 WAP respectively. Finally MOS1 increased from 51.7 to 158.2 cm from 3 and 11 WAP while MOS2 increased from 65.3 to 182.8 cm at 3 and 11 WAP respectively.

Number of leaves per plant of sorghum (Fig. 6)
In **2009 season**, the number of leaves per sorghum plant of S1 in both monoculture and mixtures was statistically different for all the sampled plots. Similarly S2 cultivar showed significant differences ($p<0.05$) in all plots with treatments containing S2. Number of leaves per plant in monoculture S1 ranged from 7.8 to 16.1 whereas in S2 increased from 7.8 to 16.0 at 3 and 11 WAP respectively. OS1 increased from 6.8 to 13.0 leaves while in OS2 it increased from 6.6 to 15.4 at 3 and 11 WAP respectively. MS1 increased from 6.1 to 10.7 whereas MS2 increased from 6.33 to 12.00 at 3 and 11 WAP respectively. Finally MOS1 increased from 6.1 to 10.3 while MOS2 increased from 5.56 to 10.99 at 3 and 11 WAP respectively.
In **2010 season**, sorghum showed a number of leaves per plant significantly different in treatments containing S1 at all sampling times. Similarly, the difference was significant in treatments containing S2 at all sampling times. Number of leaves per plant for S1 increased from 7.6 to 14.8 whereas values for S2 ranged from 7.5 to 15.0 at 3 and 9 WAP respectively. OS1 increased from 6.67 to 13.2 whereas OS2 increased from 5.8 to 16.1 at 3 and 11 WAP respectively. MS1 increased from 6.4 to 11.8 whereas MS2 increased from 5.8 to 10.0 at 3 to 9 WAP respectively. Finally MOS1 increased from 5.8 to 10.9 at 3 and 11 WAP whereas MOS2 increased from 5.9 to 12.3 at 3 and 11 WAP respectively.
In terms of number of leaves per plant, both sorghum cultivars perform better in sorghum/okra intercrop than in sorghum/maize intercrop.

Leaf area of sorghum (Fig. 7)
In **2009 season**, leaf area of S1 in both monoculture and mixtures was statistically different at all sampling times. Similarly S2 cultivar showed significant difference ($p<0.05$) at all sampling times except at 3WAP in mixtures containing S2. S1 increased from 293.1 to 850.7 cm^2 at 3 and 11 WAP respectively, whereas leaf area of S2 alone increased from 199.1 to 775.8 cm^2 at 3 and 9 WAP respectively. Leaf area of S1 in SO1 increased from 164.8 cm^2 at 3 WAP to 923.3 cm^2 at 11 WAP while leaf area of S2 in SO2 increased from 159.8 to 819.1 cm^2 at 3 and 9 WAP respectively. MS1 increased from 173.1 to 596.3 cm^2 whereas MS2 that increased from 136.2 to 587.1 cm^2 at 3 and 9 WAP respectively. Finally MOS1 increased from 132.1 to 558.7 cm^2 at 3 and 11 WAP whereas

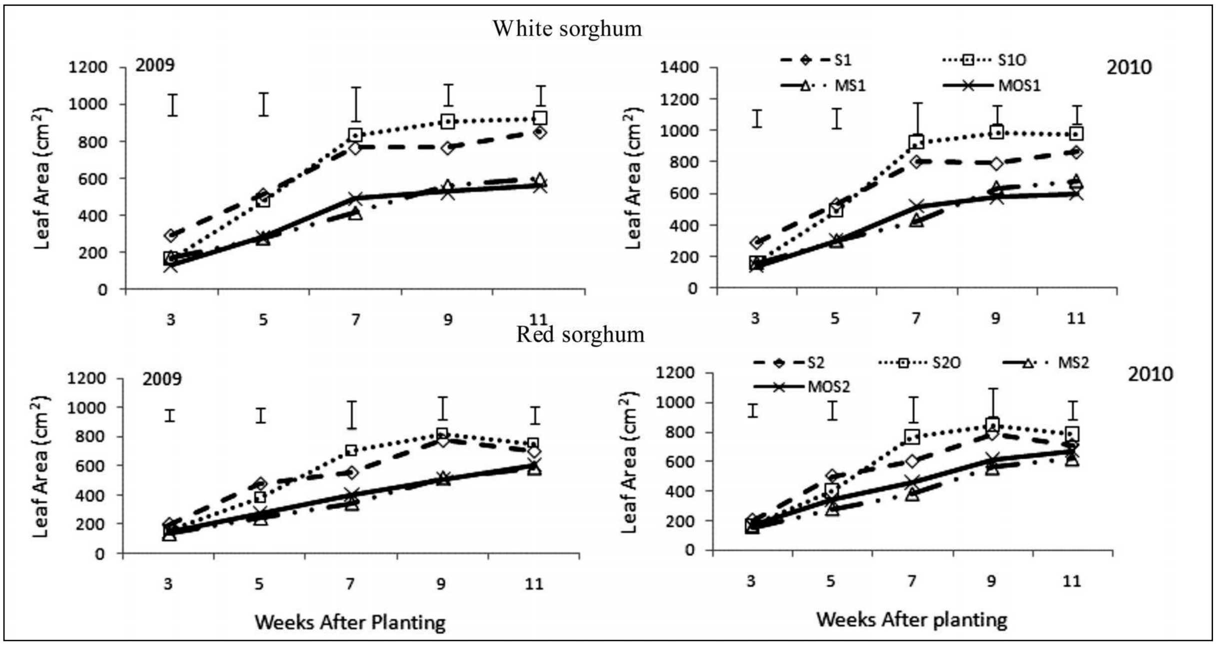


Fig. 7 - Effects of intercropping with okra and maize on the leaf area (cm²) of the two sorghum cultivars in 2009 and 2010 seasons.
Fig. 7 – Effetti della consociazione con mais e okra sull'area fogliare (cm²) delle piante di sorgo delle due cultivar in esame per le stagioni produttive 2009 e 2010.

MOS2 increased from 148.1 to 605.2 cm² at 3 and 9 WAP respectively.

In **2010 season**, leaf area of S1 was significantly different at all sampling times for treatments containing S1 cultivar. Similarly, the difference in leaf area of red sorghum was significantly different for treatments containing S2 at all sampled occasions except at 3 WAP. S1 increased from 289.5 to 865.8 cm² whereas S2 increased from 203.7 to 789.1 at 3 and 9 WAP respectively. SO1 increased from 162.5 cm² to 976.0 cm² whereas SO2 increased from 167.4 to 848.5 cm² at 3 and 9 WAP respectively. MS1 increased from 158.4 to 677.4 cm² whereas MS2 increased from 154.0 to 620.2 cm² at 3 and 11 WAP respectively. Finally MOS1 increased from 142.0 to 600.1 cm² whereas MOS2 increased from 166.3 to 668.8 cm² at 3 and 11 WAP respectively.

In terms of leaf area both sorghum cultivars perform better in sorghum/okra intercrop than in sorghum/maize intercrop.

Stem Diameter of sorghum (Fig. 8)

During the **2009 season**, stem diameter of S1 in both monoculture and mixtures was statistically different at all sampling times. Similarly the stem diameter of S2 cultivar showed significant difference ($p<0.05$) at all sampling times in treatment containing S2 while no significant different between sorghum cultivars.

Stem diameter of S1 ranged from 24.9 to 34.8 mm whereas S2 ranged from 25.2 to 35.4 mm between 5 and 11 WAP . SO1 increased from 23.5 to 30.3 mm while SO2 increased from 23.9 to 30.7 mm. MS1 increased from 19.1 to 24.2 mm whereas MS2 increased from 15.6 to 19.1 mm. Finally MOS1 increased from 14.0 to 19.7 mm while MOS2 increased from 13.5 to 17.3 mm.

During the **2010 season** the difference in stem diameter of white sorghum was significant for both treatments S1 and S2 at all sampled occasions. S1 increased from 28.3 to 34.5 mm whereas the values in S2 alone increased from 28.4 to 36.5 mm between 3 and 11 WAP. Stem diameter of S1 in SO1 increased from 24.38 to 32.94 mm whereas SO2 increased from 24.6 to 34.4 mm. MS1 increased from 14.3 to 20.0 mm whereas MS2 increased from 13.0 to 18.9 mm between 3 and 11 WAP. Finally MOS1 increased from 14.05 to 17.37 mm whereas MOS2 increased from 13.28 to 20.28 mm.

Similarly to the results for the leaf area Bboth sorghum cultivars perform better in sorghum/okra intercrop than sorghum/maize intercrop in terms of stem diameter. . These results can be explained as consequences of the prevalent antagonistic character of the symbiosis sorghum-maize.

Days to panicle initiation (heading), flowering and grain maturity of sorghum (Tab. 3)

Intercropping with okra affected only days from planting to flowering during 2009 and both days to

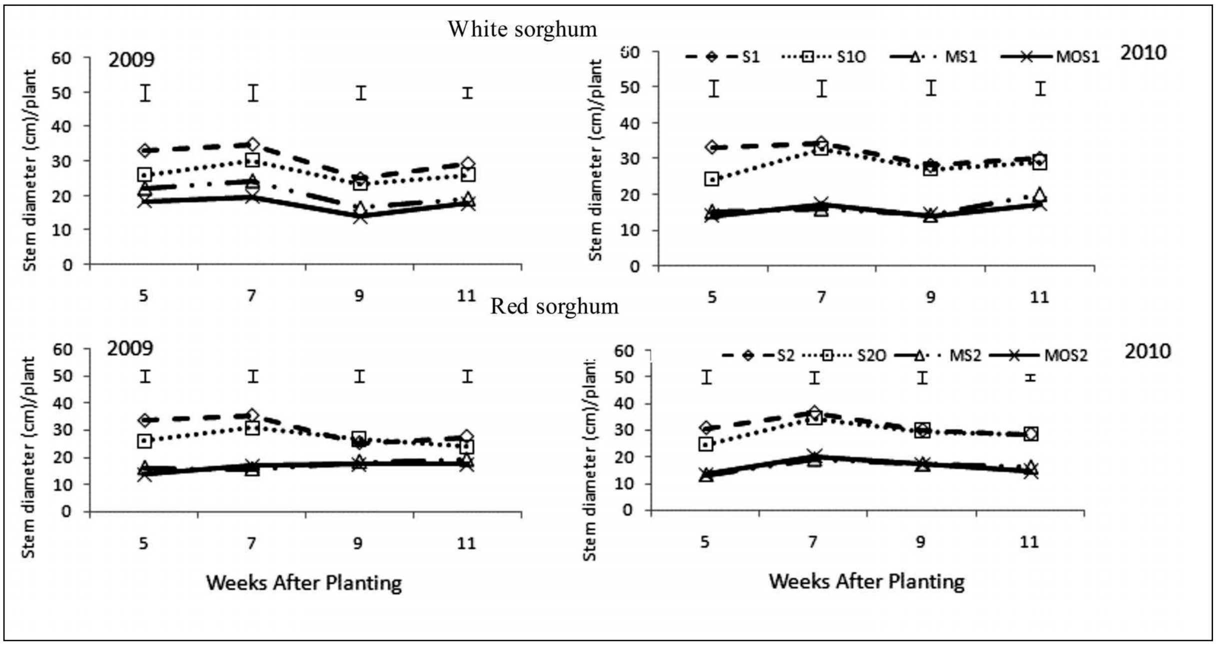


Fig. 8 - Effects of intercropping with okra and maize on Stem Diameter (cm) of the two sorghum cultivars in 2009 and 2010 seasons.
Fig. 8 - Effetti della consociazione con mais e okra sull'area fogliare (cm²) delle piante di sorgo delle due cultivar in esame per le stagioni produttive 2009 e 2010.

Treatments	2009			2010		
	Days from planting to Panicle Initiation	Days from planting to Flowering	Days from planting to Grain Maturity	Days from planting to Panicle Initiation	Days from planting to Flowering	Days from planting to Grain Maturity
White sorghum						
S1	96	127	166	110	125	164
OS1	96	129	169	112	127	167
MS1	99	136	176	119	133	174
MOS1	113	138	177	121	137	176
Red sorghum						
S2	95	126	165	98	124	164
OS2	96	129	164	99	125	167
MS2	100	136	173	114	132	175
MOS2	113	137	176	116	136	178
LSD(0.05)	4.20	4.20	2.09	5.99	2.06	1.53
White sorghum (mean)	101	132	172	116	131	170
Red Sorghum (mean)	101	132	169	107	129	171
LSD (0.05)	4.11	3.04	2.97	4.43	2.01	1.74
Sorghum alone (mean)	95	126	165	104	124	164
Sorghum/okra (mean)	96	129	166	105	126	167
Sorghum/maize(mean)	100	204	262	176	199	261
Sorghum/maize/okra (mean)	113	206	265	179	205	265
LSD (0.05)	4.01	1.87	3.84	2.86	1.95	1.95

Tab. 3 - Effects of intercropping okra and maize on the phenology of two sorghum cultivars in 2009 and 2010 seasons.
Tab. 3 - Effetto della consociazione con mais e okra sulla fenologia delle due cultivar di sorgo nelle anate 2009 e 2010.

flowering and to grain maturity during 2010. On the other hand the intercropping with maize affected significantly all the three selected phenological ranges both for 2009 and 2010.
Furthermore heading, flowering and grain maturity have been always attained earlier by mixtures sorghum-okra than mixtures sorghum-maize.
During **2009 season**, days to heading for white sorghum combinations have been 96 for S1 and OS1, followed by 99 for MS1 and 113 for MOS1 where for mixtures with red sorghum these days were respectively 95, 96, 100 and 113.
The days to flowering for white sorghum combinations have been 127 for S1, 129 for OS1, 136 for MS1 and 138 for MOS1 where for mixtures with red sorghum these days were respectively 126, 129, 136 and 137.
Days to grain maturity in treatments containing white sorghum (S1) have been 166 days for S1, 169 for OS1, 176 for MS1 and 177 for MOS1 whereas in mixtures with red sorghum these days were respectively 165, 164, 173 and 176.
For **2010 season** days to heading for white sorghum combinations ranged from 110 days of S1 to 112 days of SO1 to 119 of MS1 to 121 days of MOS1. Days to flowering in red sorghum combinations ranged from 98 days of S2 to 99 days of OS2 to 114 days of MS2 to 116 days of MOS2.
Days to flowering for mixtures with white sorghum ranged from 125 days of S1 followed by 127 of OS1, 133 of MS1 and 137 of MOS1 where for mixtures with red sorghum these days were respectively 124, 125, 132 and 136.
Days to grain maturity for mixtures with white sorghum ranged from 166 days of S1 to 169 days of OS1 to 176 days of MS1 to 177 days of MOS1 where for mixtures with red sorghum these days were respectively 164, 167, 174 and 176.

Treatments	2009			2010		
	Panicle Length (cm)	Grain weight/ head (g)	Grain Yield (t/ha)	Panicle Length (cm)	Grain weight/ head (g)	Grain Yield (t/ha)
White sorghum						
S1	46.0	69.5	1.05	71.0	65.8	0.88
OS1	48.7	60.5	0.84	57.8	58.8	0.80
MS1	50.0	51.0	0.65	60.3	43.8	0.61
MOS1	51.0	40.2	0.45	57.2	37.2	0.42
Red sorghum						
S2	49.7	66.1	0.94	70.7	41.2	0.91
OS2	50.0	55.8	0.72	56.4	51.5	0.67
MS2	51.5	39.8	0.64	52.5	37.6	0.53
MOS2	52.3	37.2	0.53	55.3	23.7	0.48
LSD (0.05)	1.08	9.04	0.07	13.05	28.69	0.25
White sorghum (mean)	48.9	55.3	0.75	61.6	51.4	0.68
Red sorghum (mean)	50.9	49.7	0.71	58.8	38.5	0.65
LSD (0.05)	1.15	9.73	0.13	13.14	17.74	0.17
Sorghum alone (mean)	47.8	67.8	1.0	70.9	53.5	0.90
Sorghum/okra (means)	49.3	58.2	0.78	57.1	55.2	0.74
Sorghum/maize (means)	50.8	45.4	0.65	56.4	40.7	0.57
Sorghum/ maize /okra (mean)	51.7	38.7	0.49	56.5	30.4	0.45
LSD (0.05)	1.21	10.42	0.19	13.25	6.79	0.09

Tab. 4 - Panicle Length, Grain weight/head (g) and Grain yield (t/ ha) of two sorghum cultivars as influenced by intercropping with Maize and Okra in 2009 and 2010 seasons.
Tab. 4 - Lunghezza del pannicolo, resa in granella per infiorescenza (g) e produzione totale (t / ha) delle due cultivar di sorgo in coltura pura o consociata con mais e/o okra per le stagioni 2009 e 2010.

Treatment	2009		2010	
	No of pods/plant	Pod yield (t/ha)	No of pods/plant	Pod yield (t/ha)
White Sorghum				
O	9	2.8	10	5.5
MO	6	2.0	12	4.3
OS1	10	3.1	22	9.9
MOS1	7	1.9	11	4.4
Red Sorghum				
O	12	4.2	23	9.5
MO	5	1.8	5	2.1
OS2	9	3.4	16	7.1
MOS2	6	2.1	10	3.6
LSD (0.05)	5.63	0.82	9.26	4.67
White sorghum (mean)	9	2.5	14	6.0
Red sorghum (mean)	8	2.9	14	5.6
LSD (0.05)	2.05	0.75	3.80	0.51
Okra alone (mean)	11	3.5	17	7.5
Okra/sorghum (mean)	10	3.3	19	8.5
Okra/maize (mean)	5	1.9	8	3.2
Okra/maize/sorghum (mean)	6	2.0	10	4.0
LSD (0.05)	3.24	1.32	10.35	3.6

Tab. 5 - Effects of intercropping sorghum cultivars and maize on the yield characters of okra in 2009 and 2010 seasons.
Tab. 5 - Effetti della consociazione con sorgo e/o mais e/o sulle caratteristiche produttive dell'okra nelle due annate 2009 e 2010.

Yield data evaluation

Yield is function of the integrated effect of all the yield components which are usually affected by the growing meteorological and environmental conditions, farmer activities and cropping pattern. Yields of single crops are hereafter discussed.

Sorghum yield

Tab. 4 shows panicle length, grain weight per head and grain yield of the two sorghum cultivars.

Statistical analysis shows that for 2009 (i) grain weight per head of sorghum alone and sorghum/okra are significantly higher than sorghum/maize and sorghum/maize/okra and (i) final yield of sorghum alone is significantly higher than sorghum/okra which in turn is significantly higher than sorghum/maize and sorghum/maize/okra. A similar behavior is present in 2010 with the only difference given by the non significance of the difference in the grain weight per head of sorghum alone and sorghum/okra.

During **2009 season**, panicle length for white sorghum mixtures ranged from 46.0 cm of S1 to 48.7 cm of OS1 to 50.0 of MS1 to 51 of MOS1 whereas for mixtures with red sorghum the values were respectively 49.7, 50, 51.5 and 52.3.

Grain weight per head of white sorghum ranged from 69.5 g of S1 to 60.5g of OS1 to 51 g of MS1 to 40.2 g of MOS1 whereas for mixtures with red sorghum the values were respectively 66.1, 55.8, 39.8 and 37.2.

Grain yield of white sorghum ranged from 1.05 tha^{-1} of S1 to 0.84 tha^{-1} of OS1 to 0.65 tha^{-1} of MS1 to 0.45 tha^{-1} of MOS1 whereas for mixtures with red sorghum the values were respectively 0.94, 0.72, 0.64 and 0.53.

During **2010 season** (Tab. 3) panicle length for white sorghum mixtures ranged from 71.0 cm of S1 to 60.3 cm of MS1 to 57.8 cm of OS1 to 57.2 cm of MOS1 whereas for mixtures with red sorghum the values were respectively 70.7, 56.4, 55.3 and 52.5 cm.

Grain weight per head for white sorghum mixtures ranged from 65.8 g for S1 to 58.8 of OS1 to 43.8 of

MS1 to 37.2 of MOS1 whereas for mixtures with red sorghum the values were respectively 51.5, 41.2, 37.6 and 23.7 g.
Grain yield per plot for white sorghum mixtures ranged from 0.88 t ha^{-1} of S1 to 0.80 of OS1 to 0.61 of MS1 to 0.42 of MOS1 whereas for mixtures with red sorghum the values were respectively 0.91, 0.67, 0.53 and 0.48 t ha^{-1}.

Okra yield

In **2009 season** (Tab. 5) white sorghum mixtures show the highest pod yield in OS1 (3.1 tha^{-1}) followed by O alone (2.8 tha^{-1}), MO (2.0 tha^{-1}) and MOS1 (1.9 tha^{-1}). On the other hand red sorghum mixtures show the highest pod yield for O (4.2 tha^{-1}), followed by OS2 (3.4 tha^{-1}), MOS2 (2.1 tha^{-1}) and MO (1.8 tha^{-1}). Furthermore the mean yields were statistically different.
Similarly during **2010 season**, white sorghum mixtures show the highest pod yield in in OS1 (9.9 tha^{-1}), followed by O (5.5 tha^{-1}), MOS1 (4.4 tha^{-1}) and MO (4.3 tha^{-1}) whereas in red sorghum combinations, the yield were decreasing from O (9.5 tha^{-1}) to OS2 (7.1 tha^{-1}), MOS2 (3.6 tha^{-1}) and MO (2.1tha^{-1}).

Maize yield (t ha^{-1})

Tab. 6 shows the maize yield and weight of 100 maize grains.
For **2009 season**, yields of different maize mixtures were not statistically different for treatments containing white sorghum (S1) while the difference was statistically significant for treatments containing red sorghum (S2).
Furthermore in treatments containing white sorghum, highest yield (1.86 t ha^{-1}) is obtained from maize alone (M), followed by 1.65 of MO 1.23 of MS1 and 1.14 of MOS1 whereas in red sorghum combinations, the yield were decreasing from M (1.41 t ha^{-1}), MO (1.24), MOS2 (0.97) and MS2 (0.82).
Weight of 100 grains of maize in the treatment containing white sorghum was highest in maize alone (18.40g), followed by maize/okra mixture (15.83) and MOS1 mixture (16.33). In red sorghum treatments, M also shows the highest weight (19.17 g) followed by MO (16.17), MS2 (15.1) and MOS2 (13.50).
For **2010 season** the highest yield has been obtained from M (1.95 t ha^{-1}) followed by MO (1.51), MS1 (1.36) and MOS1 (1.18). In red sorghum treatments, M also shows the highest yield (1.51 t ha^{-1}) followed by MO (1.4), MOS2 (0.96) and MS2 (0.93).
Weight of 100 grains of maize in the treatment containing white sorghum was highest in maize alone (18.27g), followed by MO (15.8), MOS1 (14.57) and MS1 (13.30). In red sorghum treatment

	2009		2010	
Treatments	Maize grain yield (tha^{-1})	Weight of 100 grains (g)	Maize grain yield (tha^{-1})	Weight of 100 grains (g)
White sorghum				
M	1.86	18.40	1.95	18.27
MO	1.65	15.83	1.51	15.77
MS1	1.23	14.83	1.36	13.30
MOS1	1.14	16.33	1.18	14.57
Red sorghum				
M	1.41	19.17	1.51	20.57
MO	1.24	16.17	1.42	17.80
MS2	0.82	15.10	0.93	15.67
MOS2	0.97	13.50	0.96	13.70
LSD (0.05)	0.86	3.23	0.92	3.79
White sorghum (mean)	1.47	16.35	1.50	15.48
Red sorghum (mean)	1.11	15.99	1.21	16.94
LSD (0.05)	0.42	2.27	0.42	4.66
Maize alone (mean)	1.64	18.79	1.73	19.42
Maize/okra (mean)	1.45	16	1.47	16.79
Maize/sorghum (mean)	1.03	14.97	1.15	14.49
Maize/okra/sorghum (mean)	1.06	14.92	1.07	14.14
LSD (0.05)	0.76	3.22	0.37	4.25

Tab. 6 - Effects on maize production of intercropping with sorghum and/or okra in 2009 and 2010 seasons.
Tab. 6 - Effetti della consociazione con sorgo e/o okra sulle caratteristiche produttive del mais nelle due annate 2009 e 2010.

M had also the highest weight (20.57 g), followed by MO (17.8), MS2 (15.7) and MOS2 (13.7).
The better performance of maize in 2010 can be attributed to a relatively steady and higher amount of rainfall across all the phenological stages compared with 2009 season which had a lower amount of rainfall. The same observation was made by Makinde *et al.*, (2009) working on maize-cucumber intercrop. These observations confirm the high sensitivity of maize to water shortage especially during the range of 40-60 days centered on the male flowering.

CONCLUSION AND RECOMMENDATIONS

This study confirms the agro climatic potential of the forest-savanna transition zone of Nigeria for intercropping between sorghum cultivars, Janare and Farin Dawa and okra (NHAe 47-4) and maize (Suwan-1). Results show that the relevant differences in mean daily air and soil temperatures and in rainfall during the two seasons, 2009 and 2010, significantly affected the crops growth and yield.
In both growing season the weather conditions were cooler during the vegetative and reproductive growth stages, than during the establishment and early vegetative periods. 2010 was more rainy and colder season compared to 2009. The results shows that the study area has a higher agroclimatic potential for the cultivation of okra with sorghum cultivars, Janare and Farin Dawa, than with maize (Suwan-1).
The combination of the two sorghum cultivars (Janare and Farin Dawa) with okra (NHAe 47-4) did not affect significantly the okra phenological development (i.e. vegetative growth, flowering and fruiting stages) and the sorghum growth and production in both seasons. The mean pod yields of okra in 2009 and 2010 seasons were significantly ($p \leq 0.05$) higher in sorghum intercrop than in maize intercrop. This may be probably due to the wide differences in the stages of growth and development in relation to resources requirement and utilization of sorghum and okra. Okra had largely reached physiological maturity before the phase of maximum growth of sorghum.
The mean grain yields of sorghum cultivars were significantly ($p<0.05$) higher in the 2009 season especially in okra combination with cultivars Farin dawa and Janare (0.84 *and* 0.72 t ha^{-1} respectively) than in the 2010 season. Perhaps this was due to higher mean soil temperature of 28°C and 26°C at 5 and 20 cm in 2009 season compared with 2010 season when mean soil temperature was 27°C and 25°C at 5 and 20 cm respectively. Generally, Farin Dawa accumulated more heat than Janare in both 2009 and 2010 seasons from planting to maturity regardless of cropping system.
Finally, in order to reduce the risk of crop failure for the farmers due to unpredictable weather conditions, okra/sorghum combination is highly recommended since it is able to maximize the crops performance in both meteorological conditions characterizing the two years of experiment and therefore it is able to reduce the impact of climate variability on the crops growth and production.

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Indici vegetazionali da satellite per il monitoraggio in continuo del territorio

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Abstract: *This technical paper tries to describe the available satellite vegetation indices, in particular NDVI, for the continuous monitoring of the earth surface. The available time series, the web link for download and some examples of their applications are briefly described.*
In the Region Emilia-Romagna, in forestry applications, the 16 days composite MODIS NDVI time series (AQUA and TERRA) are used for the analysis of anomalies.
The 2008 land use map of Emilia-Romagna is fundamental, as it is used to define the areas of monitoring and validation. At present, the 250/500 m geometric resolution of MODIS, as the future 375 m of VIIRS (SUOMI-NPP), seems to be fine-tuned to identify changes in the vegetation state. Further studies are needed for a better understanding of the accuracy of the system.
Keywords: *NDVI, EVI, NDWI, LAI, fPAR, remote sensing, MODIS, AVHRR, SPOT-VEGETATION, SUOMI-NPP, drought, desertification, climate change.*

Riassunto: *La presente nota tecnica riporta una descrizione degli indici di vegetazione da satellite, in particolare NDVI, per il monitoraggio in continuo della superficie terrestre. Sono sinteticamente descritte le serie storiche disponibili, i link per il loro download ed alcuni esempi di utilizzo.*
In Emilia-Romagna, in ambito forestale, si utilizzano le serie storiche NDVI a 16 giorni di MODIS (AQUA e TERRA) per l'analisi delle anomalie dell'indice. Di fondamentale importanza è la carta di uso del suolo della Regione Emilia-Romagna, che viene usata per la definizione delle aree di monitoraggio e di validazione. Allo stato attuale, la risoluzione geometrica di 250/500 m di MODIS, come la futura di 375 m di VIIRS (SUOMI-NPP), sembrano individuare variazioni nello stato vegetazionale. Ulteriori studi sono in fase di esecuzione per una migliore comprensione della precisione del sistema.
Parole chiave: *NDVI, EVI, NDWI, LAI, fPAR, telerilevamento, MODIS, AVHRR, SPOT-VEGETATION, SUOMI NPP, siccità, desertificazione, cambiamenti climatici.*

INTRODUZIONE

Gli indici di vegetazione calcolati da sensori satellitari a media e bassa risoluzione rappresentano un ottimo strumento di monitoraggio del pianeta Terra poiché permettono di cogliere le variazioni di determinate grandezze vegetazionali in modo sinottico.
Tipicamente questa categoria di piattaforme è di particolare interesse per applicazioni meteorologiche e per il monitoraggio globale della biosfera.
Gli standard adottati nella configurazione dei sensori e la loro capacità di rivisitare giornalmente tutta la superficie terrestre contribuiscono a mantenere un monitoraggio costante nel tempo.

SATELLITI E SENSORI

I principali satelliti attualmente dedicati al monitoraggio della vegetazione sono riportati in Tab. 1.
I sensori misurano lo spettro elettromagnetico terrestre acquisendo in più bande comprese nel visibile (VIS), vicino infrarosso (NIR), medio infrarosso (SWIR) e termico (TIR). Le risoluzioni geometriche più alte si hanno generalmente sulle bande del VIS e NIR, mentre nel SWIR e TIR sono più basse. L'energia emessa in queste ultime due bande è minore per cui servirebbero sensori più complessi per ottenere risoluzioni similari alle prime.
Dei sensori riportati quello di maggiore interesse è MODIS poiché fornisce risoluzioni fino ai 250 m particolarmente utili per descrivere un territorio assai eterogeneo dal punto di vista della morfologia ed uso del suolo come quello italiano. Il sensore VIIRS (SUOMI NPP), che rappresenta l'evoluzione di MODIS, è da poco in orbita e sta ultimando la calibrazione.
Per ulteriori dettagli si faccia riferimento a Townshend e Justice (2002) dove si descrive lo sviluppo delle piattaforme satellitari gestite dagli Stati Uniti e destinate all'osservazione in continuo delle Terra. Partendo dalla costellazione NOAA (National Oceanic and Atmospheric Administration), vengono descritti i passaggi alla futura costellazione NPOESS (National Polar Operational Environmental Satel-

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SATELLITE	SENSORI	RIS. GEOM. (M)	ENTE	ANNO LANCIO	SPETTRO
Meteosat Second Generation (MSG)	HRV-SEVIRI	1000-3000	EUMETSAT	2002	VIS-NIR-SWIR-TIR
AQUA	MODIS	250-500-1000	NASA	2002	VIS-NIR-SWIR-TIR
TERRA	MODIS	250-500-1000	NAAA	2000	VIS-NIR-SWIR-TIR
NOAA Series	AVHRR	1000	NOAA	1978*-2009**	VIS-NIR-SWIR-TIR
METOP Series	AVHRR/3	1000	EUMETSAT	2006*-2011**	VIS-NIR-SWIR-TIR
SUOMI NPP	VIIRS	375-750	NASA	2011	VIS-NIR-SWIR-TIR
ENVISAT†	MERIS	300	ESA	2002	VIS-NIR
SPOT 5	VEGETATION††	1000	CNES	2002	VIS-NIR-SWIR

* Primo della serie lanciato in orbita, ** Ultimo della serie lanciato in orbita, † Non operativo da inizio aprile 2012
†† Non operativo da fine aprile 2012

Tab. 1 - Satelliti e sensori a media e bassa risoluzione a confronto.
Tab. 1 - List of satellite and sensor of low and medium resolution.

lite System), passando attraverso i satelliti precursori AQUA, TERRA e SUOMI NPP.

COSA SI MISURA

La vegetazione è caratterizzata da una firma spettrale univoca che facilmente la distingue da altri oggetti presenti sulla superficie.

$$NDVI = \frac{NIR - R}{NIR + R}$$

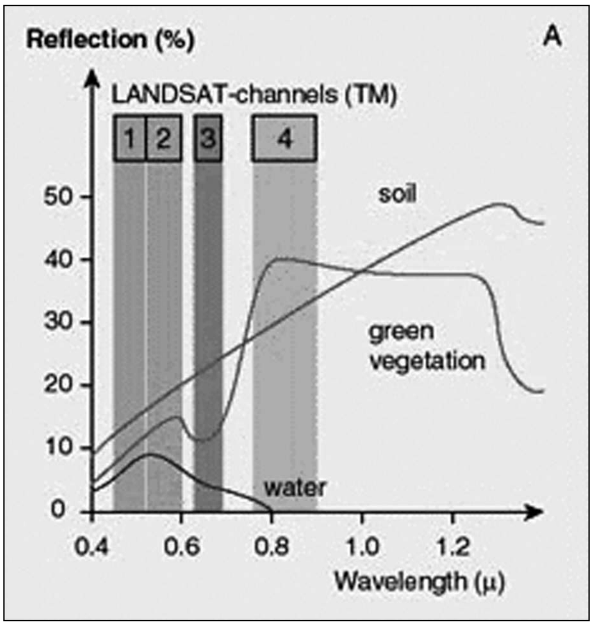

Fig. 1 - Immagine ESA su firme spettrali.
Fig. 1 - ESA image on spectral signatures.

In Fig. 1 [fonte ESA] si mostra l'andamento spettrale di vegetazione, acqua e suolo nudo nello spettro del visibile ed infrarosso. Le piante assorbono luce nel blu e rosso ed emettono nel verde, ma soprattutto nel vicino infrarosso creando un marcato gradino con il rosso (R), chiamato in letteratura "red edge". Questo gradino è la base principale per calcolare l'indice più studiato che si chiama NDVI (normalized difference vegetation index).

Questo indice valuta la presenza di attività fotosintetica in quanto mette in relazione lo spettro del rosso, in cui c'è assorbimento da parte della clorofilla, e quello del vicino infrarosso in cui le foglie riflettono la luce per evitare il surriscaldamento. I valori sono necessariamente compresi tra -1 e +1. La presenza di vegetazione assume valori maggiori di 0.2.

L'indice NDVI è stato utilizzato a partire dagli anni Settanta del secolo scorso per monitorare le caratteristiche biofisiche della vegetazione delle grandi pianure americane. Successivamente l'indice è divenuto il principale indicatore da satellite della presenza di vegetazione sulla superficie terrestre e dell'evolversi della stessa nel tempo.

Le banche dati disponibili e l'ampia bibliografia presente permettono di poter confrontare questo indice in più contesti. Allo stesso tempo, il continuo sviluppo di nuovi sensori che tengono conto dell'interoperabilità dei dati acquisiti garantisce, seppur con le dovute calibrazioni, lunghe serie temporali.

Alcune varianti dell'NDVI sono rappresentate da: EVI (enhanced vegetation index) [I] e NDWI (normalized difference water index) (Gao, 1996).

Il calcolo dell'EVI utilizza anche il dato spettrome-

trico riferito alla banda del blu e necessita di specifici coefficienti di calibrazione. L'indice EVI nasce con lo scopo di limitare i problemi dovuti alla eventuale presenza di nubi/foschia/fumo e di evitare la saturazione dei valori che caratterizza NDVI nelle aree equatoriali. Queste circostanze però sono poco comuni alle nostre latitudini.
L'indice NDWI invece sostituisce la banda del rosso con il medio infrarosso. Si misura così una grandezza differente rispetto all'NDVI, in quanto la risposta nel medio infrarosso è molto diversa rispetto al rosso. Per questo, il significato intrinseco dell'NDVI è più facilmente associabile allo stato della vegetazione.
Anche grandezze come il LAI (indice di area fogliare) che rappresenta l'area totale delle foglie per unità di superficie del terreno o fPAR (frazione della radiazione solare assorbita dalle piante) possono essere stimate da satellite attraverso equazioni basate sull'NDVI.
Uno studio sul Nord America (Fang et al., 2008) mostra che l'applicazione di filtri spazio temporali permette di migliorare la precisione nella descrizione del LAI ottenuto da MODIS.
Rossi *et. al.*, (2008) hanno invece comparato differenti indici di siccità, come SPI (da dati meteo), NDVI e fPAR (da MERIS) sull'area di studio della penisola iberica. I risultati mostrano come fPAR può potenzialmente integrare la valutazione del livello di siccità di un territorio. La sua applicazione però rimane a livello sperimentale.

PRODOTTI E ARCHIVI DISPONIBILI SUL WEB

Di seguito vengono descritti alcuni archivi disponibili on line. In Tab. 2 si riportano i collegamenti diretti agli stessi.

VITO

Le serie storiche NDVI del sensore SPOT-VEGETATION dell'agenzia spaziale francese CNES (Centre national d'études spatiales) sono gestite dal gruppo di lavoro VITO [II]. I dati diventano gratuiti tre mesi dopo l'acquisizione.
Sono elaborati i valori giornalieri, definiti come S1 o la composizione a 10 giorni S10, creata tramite la scelta del pixel con il valore più alto (maximum value composite – MVC).
Sono disponibili anche i dati D10, corretti attraverso la calibrazione BRDF (bi-directional reflectance distribution function). Mentre nel prodotto S10 sono riportati tutti i pixel, nel D10 viene applicato un controllo maggiore sulla qualità dell'immagine e solo i pixel con i valori migliori sono mantenuti. In questo caso si genera una immagine che presenta buchi in caso di pixel contaminati o nuvolosi in tutta la composizione a 10 giorni.
La serie copre il periodo dal 1998 a marzo 2012. Tutti i formati sono a 1 km di risoluzione spaziale in coordinate geografiche. Le immagini sono distribuite in formato hdf.

WCD-DLR

Il sito gestito dall'Agenzia Spaziale Tedesca (DLR) [III] elabora e distribuisce immagini giornaliere, composizioni settimanali e mensili di NDVI a partire dalla costellazione NOAA.
Le immagini coprono tutta Europa. Le mappe giornaliere sono composte tramite MVC, mentre le mappe settimanali e mensili subiscono varie fasi di elaborazione per garantire una migliore discriminazione delle aree coperte da nubi. Le immagini sono a 1.1 km di risoluzione geometrica, La finestra temporale copre quasi interamente il periodo dal 1994 all'attuale [IV].

GIMMS

Il gruppo del Global Land Cover Facility (GLCF) [V] gestisce l'archivio GIMMS (Global Inventory Modeling and Mapping Studies) in cui è disponibile la banca dati NDVI ricavata dalla costellazione NOAA (satelliti 7-9-11-14-16, sensore AVHRR). La finestra temporale coperta va dal 1981 al 2006 con copertura globale.
La risoluzione geometrica è di 8 km. Le immagini sono in formato tif in coordinate geografiche.

LP DAAC

Il sito LP DAAC [VI] gestito da NASA e USGS distribuisce i prodotti a media risoluzione elaborati a

ARCHIVIO	WEB LINK
VITO	http://www.vgt.vito.be/pages/catalogue.html
WCD-DLR	http://wdc.dlr.de/data_products/SURFACE/NDVI/index.html
GIMMS	http://glcf.umiacs.umd.edu/data/gimms/
LP DAAC	https://lpdaac.usgs.gov/get_data/

Tab. 2 - Link diretti alle banche dati descritte (accesso al 20/08/2012).
Tab. 2 - Link to images website archives.

partire dalla riflettanza delle immagini MODIS. Le grandezze calcolate sono indici come LAI, fPAR, NDVI e EVI, classificazione e dinamiche della copertura del suolo, anomalie termiche ed incendi. Una descrizione dei prodotti MODIS è disponibile al link [VII]. Nelle Tab. 3 e 4 si riporta una descrizione sintetica delle grandezze. La lettera dopo la "M" o tra parentesi si riferisce al satellite: O per TERRA, Y per AQUA e C per combinazione AQUA e TERRA.
I dati di input per il calcolo delle variabili ambientali sono le immagini elaborate MO(Y)D09. Esse sono espresse in riflettanza alla superficie e derivano dai prodotti calibrati radiometricamente e geometricamente (livello L1B). Gli elaborati finali possono essere frutto della combinazione di più prodotti. Ad esempio nel calcolo del LAI viene usata anche la classificazione dei biomi terrestri disponibile in MOD12. Quest'ultimo è particolarmente interessante poiché riporta la classificazione al 2009 della copertura del suolo derivata dalla serie storica delle immagini MODIS in cui è per ben visibile l'individuazione dell'urbano su tutta la pianura emiliano-romagnola. La principale legenda disponibile è quella suggerita da IGBP (International Geosphere-Biosphere Programme) [VIII].
La serie di prodotti MO(Y)D17 stima la produttività primaria lorda e netta, espressa in kg di Carbonio per m^2, a livello annuale o a livello settimanale. Attualmente la serie storica sta subendo una fase di rielaborazione per migliorare i risultati sulle aree contaminate da nubi. Questi prodotti sono validati allo stadio 3, che indica che l'accuratezza è stata verificata su misure indipendenti con un rigoroso approccio statistico.
Le immagini possono essere cercate sul sito NASA [IX] o scaricate direttamente via ftp [X]. Le immagini sono in formato hdf, proiettate su griglia sinusoidale (Fig. 2). La finestra temporale va dal 2000 all'attuale.
Si riportano i link ai documenti tecnici che descrivono la base teorica degli algoritmi di calcolo di alcuni prodotti MODIS trattati:

- NDVI e EVI (MOD13) [XI]
- LAI e fPAR (MOD15) [XII]
- Anomalie termiche ed incendi (MOD14) [XIII]
- Copertura del suolo (MOD12) [XIV]

Sono disponibili molti studi in cui vengono messe a confronto le varie banche dati. Ad esempio Fensholt *et. al.*, (2009) confronta i dati GIMMS, MODIS e SPOT VEGETATION sulle aree del Sahel, verificando che in zone secche la bassa risoluzione del sensore AVHRR riesce a monitorare le variazioni, mentre nelle zone più umide, i prodotti MODIS a maggiore risoluzione risultano migliori. Anche Brown *et. al.*, (2006) confrontano più data set so-

CODICE	PRODOTTO	PIATTAFORMA	RIS. GEOM. (M)	PERIODO
MO(Y)D13	Indici di vegetazione (NDVI e EVI)	TERRA e AQUA	250-500-1000	Composizione a 16 giorni o mensile
MO(Y o C)D15	LAI e fPAR	TERRA, AQUA e combinazione TERRA+AQUA	1000	Composizione a 4 o 8 giorni
MO(Y)D17	Produttività primaria lorda e netta	TERRA	250	Annuale o composizione a 8 giorni

Tab. 3 - Prodotti sull'ecosistema.
Tab. 3 - Ecosystem Products.

CODICE	PRODOTTO	PIATTAFORMA	RIS. GEOM. (M)	PERIODO
MO(Y)D13	Indici di vegetazione (NDVI e EVI)	TERRA e AQUA	250-500-1000	Composizione a 16 giorni o mensile
MO(Y o C)D15	LAI e fPAR	TERRA, AQUA e combinazione TERRA+AQUA	1000	Composizione a 4 o 8 giorni
MO(Y)D17	Produttività primaria lorda e netta	TERRA	250	Annuale o composizione a 8 giorni

Tab. 4 - Prodotti sulla copertura terrestre.
Tab. 4 - Land Products.

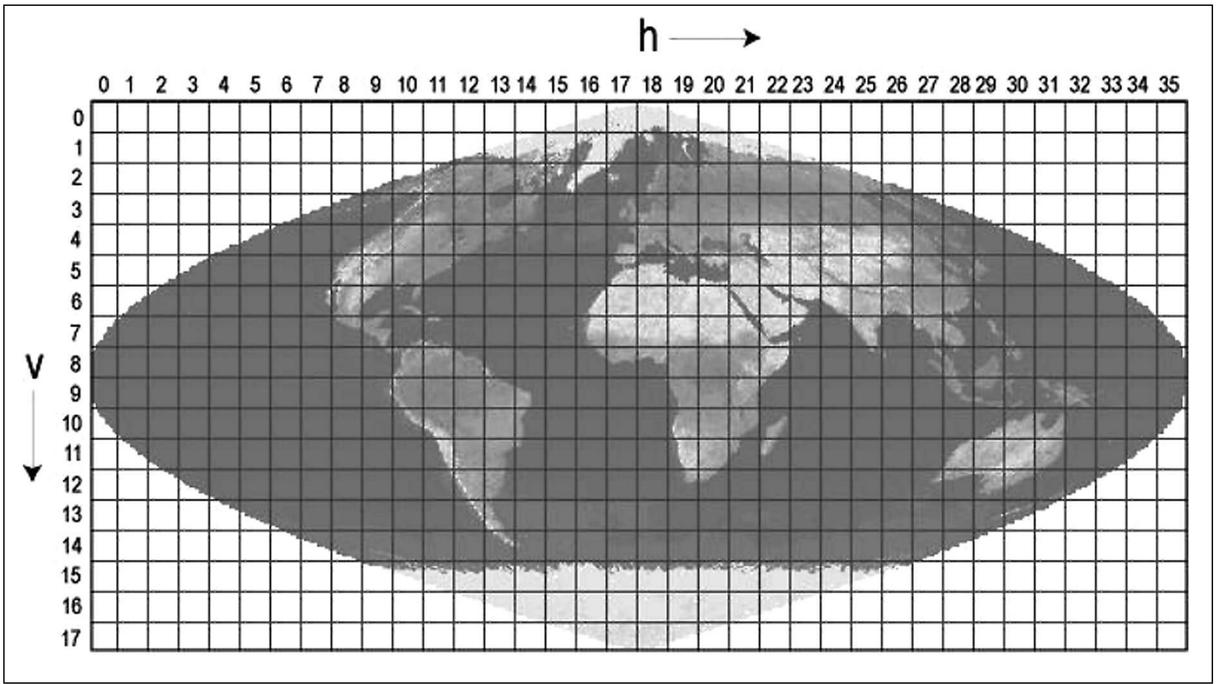

Fig. 2 - Griglia sinusoidale dei dati MODIS.
Fig. 2 - Sinusoides grid of MODIS.

stenendo che i dati raccolti dalla serie NOAA forniscono informazione fondamentali per il monitoraggio in continuo dell'indice NDVI.
Gallo *et. al.*, (2005) hanno verificato che il riprocessamento delle vecchie serie storiche NDVI da AVHRR può permettere il loro confronto con sensori tipo MODIS e VIIRS.

APPLICAZIONI NEL MONDO

A livello italiano non risulta disponibile un portale unico del monitoraggio basato su indici da satellite. Ogni regione può predisporre i suoi strumenti, ad esempio la Toscana usa NDVI e sue anomalie per studi sullo stato della vegetazione [XV].
A livello europeo, l'osservatorio della siccità (JRC-EDO) pubblica elaborazioni su NDWI (da MODIS) e fPAR (da MERIS). Questi prodotti sono consultabili tramite un webgis [XVI]. Agli indici da satellite si affiancano altri indicatori di tipo meteorologico. Questo servizio attualmente ha sospeso la produzione delle mappe fPAR a causa del guasto permanente avvenuto a ENVISAT.
In Spagna sono stati compiuti studi su differenti banche dati di NDVI da AVHRR per valutare la consistenza della variazione del bilancio del carbonio (Alcaraz-Segura *et. al.*, 2010). Lo studio suggerisce di valutare i trend considerando banche date di più sensori per sopperire a eventuali mancanze di coerenza spaziale tra le immagini.

Negli Stati Uniti i servizi di monitoraggio della siccità gestiti dalla NASA usano le serie storiche NDVI per il controllo in continuo della siccità, integrando dati storici derivati dalla serie NOAA AVHRR e MODIS. Alla pagina web [XVII] si riportano alcuni riferimenti bibliografici di interesse, mentre alla pagina web [XVIII] si possono consultare le analisi eseguite durante la grave siccità di luglio 2012. Uno dei primi studi su NDVI e siccità è stato compiuto da Kogan (1995) sulla siccità degli anni Ottanta del secolo scorso negli Stati Uniti.
In Messico gli indici EVI e NDVI sono stati utilizzati per caratterizzare lo sviluppo fenologico di campi di mais. I confronti hanno riguardato sia il sensore MODIS che SPOT-VEGETATION, mostrando che i prodotti D10 meglio identificano le variazioni di crescita delle colture agricole. Nella realtà messicana non è stato notato un miglioramento dei risultati passando dai 1000 ai 250 m di risoluzione geometrica (Chen *et. al.*, 2006).
Esempi di utilizzo dell'NDVI sono disponibili anche per la Cina sulle aree Nord occidentali (Wang *et. al.*, 2007) o in Tibet (Weishou *et. al.*, 2011).
Il servizio meteorologico australiano elabora mappe di NDVI dai sensori della costellazione NOAA a livello mensile [XIX].
Nell'ambito del programma di osservazione globale del clima (GCOS), l'organizzazione meteorologica mondiale (OMM), in collaborazione con UNESCO

e UNEP, propone l'indice fPAR come indicatore per il clima globale e ne fissa le raccomandazioni per integrare dati esistenti e futuri.

APPLICAZIONI IN EMILIA-ROMAGNA

Tra gli indicatori di siccità, Arpa ha scelto di post elaborare i prodotti NDVI a 16 giorni di AQUA e TERRA (MOD13Q1) a risoluzione di 250 m, creando una banca dati su tale riferimento. Le immagini distribuite a libero accesso dalla NASA sono validate, ampiamente utilizzate, facilmente gestibili e con diffusa bibliografia di supporto. Disponendo poi di dati geografici di dettaglio è possibile concentrare il monitoraggio su zone mirate e su specifiche finestre temporali. Visto il carattere tecnico del servizio questi sono stati i motivi principali che hanno portato alla scelta di questo tipo di immagini.

Il periodo coperto va dal 17 maggio al 15 ottobre e la metodologia si basa sull'estrazione delle medie e anomalie sulle aree forestali di montagna (dati vettoriali dell'uso del suolo 2008, Regione Emilia-Romagna). Per consultare i bollettini fare riferimento al sito Arpa [XX].

Questo approccio permette di eliminare falsi allarmi sulle aree agricole ed urbane e di valutare solo una classe naturale in espansione. Ogni anno vengono fatti dei rilievi con personale forestale per valutare qualitativamente la corrispondenza dei dati. Si è verificato che nel caso di forte siccità i valori dell'indice registravano cali significativi. Il fenomeno è risultato visibile sia sulle faggete che nelle zone appenniniche più esposte a sud caratterizzate da roverelle (*Quercus pubescens*). Sulle faggete sono stati visti trasparenza della chiome e arricciamento dell'apparato fogliare dei getti degli ultimi anni (rami a frusta), mentre comune ad entrambe le formazioni è stata la precoce perdita fogliare.

Dal 2012 è iniziato uno studio di validazione locale su alcune faggete collocate a monte del bacino del Brasimone (Bologna).

Oltre ai bollettini, questi prodotti sono stati usati anche in altri campi:

- Analisi anomalie NDVI su provincia di Ferrara per l'estate 2006
- Individuazione delle aree golenali inondate durante la piena del Po nella primavera 2009
- Analisi anomalie NDVI su castagneti della Valle del Santerno per l'anno 2011 e 2012
- Sperimentazione del progetto COLT a risoluzione minima di 6 ha (Spisni et al., 2011) [XXI]
- Analisi della diffusione della zanzara tigre (Albieri *et. al.*, 2009)

Questi sono alcuni lavori eseguiti da Arpa a scala geografica regionale, essi vogliono essere uno spunto per altre future applicazione tecniche e per diffondere a livello locale questi preziosi dati.

CONCLUSIONI

Durante l'ultimo decennio l'analisi degli indici vegetazionali da satellite si è dimostrata un valido strumento di supporto allo studio dei cambiamenti climatici e delle dinamiche dell'uso del suolo a livello nazionale e globale. Ulteriori approfondimenti sull'efficacia a scala locale/regionale potranno essere sviluppati, in modo da validare i risultati e garantire un proficuo accesso a queste fonti di dati temporalmente distribuite e a bassi costi.

La scelta delle agenzie spaziali internazionali di continuare a progettare sensori a medie risoluzioni, minori di 1 km, gioca a favore degli studi locali. SUOMI NPP della NASA è un buon esempio, mentre ESA risulta in ritardo, anche a causa della perdita di ENVISAT, ed è in attesa del lancio, previsto per la fine del 2013, di Sentinel-3 a 300 m di risoluzione geometrica. Il sensore OLCI segue le orme di MERIS [XXII]. Il satellite fa parte della costellazione Sentinel prevista dal programma europeo GMES [XXIII e XXIV].

Un ultimo aspetto di notevole importanza nella scelta dei prodotti è legato anche alla facilità di accesso ai dati. Anche in questo caso, fino ad ora, gli archivi statunitensi di NASA, NOAA e USGS sono risultati i più accessibili e funzionali in riferimento alla complessità dei data set distribuiti.

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Ove non specificatoi siti sopra riportati sono stati verificati nel mese di giugno 2012.